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EVALUATION OF SOFTWARE PROJECT

A COMPARATIVE EVALUATION OF COMMERCIAL BUILDING ENERGY SIMULATION SOFTWARE

FINAL REPORT

May, 1990

Prepared for

BONNEVILLE POWER ADMINISTRATION

Gale C. Corson Engineering

Bend, Oregon

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EXECUTIVE SUMMARY

Energy conservation in commercial and institutional buildings is frequently achieved with the help of computer-based simulation models. Models are used to estimate building energy consumption and identify the best opportunities for conservation.

The Bonneville Power Administration specifies modeling for its energy conservation programs. Bonneville therefore is interested in how accurate the simulation results are; the agency would also like to identify opportunities for improving the modeling process, including selection of accurate simulation software.

The "Evaluation of Software" project addresses these goals through a review of previous work reported in the literature, comparative simulations from several software programs and modelers, further comparisons with field data measured in real buildings, sensitivity analyses of simulation models, and a benchmarking Performance Index. The study analyzes the impacts of model-users on simulation results, estimates errors in simulation results, facilitates selection of simulation software for future energy conservation programs, and encourages improved simulation standards.

The project compares the performance of certain software packages used to estimate the energy consumed in commercial buildings. Attention is focused on ADM-2, SEA, TRAKLOAD, VCACS, and DOE-2.1. Observations may be applicable more generally to other software.

Four buildings were drawn from Bonneville's ELCAP program: one small and one large retail building; one small and one large office building. "Round-robin" simulations were conducted by eleven experienced modelers, who created 26 building models under representative field conditions; results were compared. Ten of the models were then adjusted to assure common input data, and run again with 25 defined measures, yielding sensitivity comparisons. Overall, the project implemented nearly 600 simulations.

The project demonstrates that experienced modelers are able to construct representative building energy models from any competent software, but the quality of the models and the results vary appreciably. Model quality - or degradation of it - is determined from the aggregate influence of variability in input data, software capabilities, modeling iterations, modeler experience, and modeler decisions including model complexity such as zoning and control features. Modeler variability is more significant, in general, than software variability. Opportunities are evident for improving each component of the modeling system.

Building energy modeling remains a viable approach for making decisions in energy conservation programs. The project, however, demonstrates an ongoing need to improve the modeling process, including development and selection of software.

PREFACE

> Modeling is a sophisticated way to lie to yourself. If you have sufficient discipline to look at the comparison of the monthly consumption profiles and act wisely upon what the comparison implies, you may find the lies useful and, surprisingly, accurate representations of a reality.
>
> - modeler comment

Modeling uses one object or concept to represent another. The substitute is often easier to understand or manipulate than the original. Simplicity is a favored attribute.

Rarely if ever does a model duplicate all of the features and nuances of its antecedent. The extent to which the two differ, however, is a limiting factor in the model's applicability. How well the original features are replicated in the model may govern how much reliance is placed in the model or lead to improvements in the model.

Because it is useful, modeling has been adapted to many endeavors. Among others, engineers and technicians who work with the energy requirements of buildings have found building energy simulation modeling to be a useful tool.

The Evaluation of Software project is about modeling building energy and how well it is being done. At least eleven people cooperated in constructing building energy models and making simulation runs for the project. The authors thank them and the many others who contributed to our findings and conclusions.

Their combined efforts produced copious data. Including ECM and sensitivity studies, there were nearly 600 finished computer simulations. The most important results were transcribed to a family of spreadsheets with upwards of 50,000 data points. But that is more than most readers care to assimilate. We therefore have relied on extensive graphics to present the results in the body of the report, while selected spreadsheets have been reproduced in an appendix for reference.

Where appropriate, we have attempted to included critiques or comments that identify pitfalls, oversights, errors, corrective actions, and opportunities for improvement. We are concerned in some places about the slim statistical basis, and in others the extent to which results will be extrapolated (for example, to software that was not tested, or to a wider range of modeling experience). Reviewers will undoubtedly have further suggestions. As in other studies that cross new ground, we learn from experience; there would be changes if we had the opportunity to do it again. Overall, however, we think the results make sense and we are pleased to have had a hand in reaching them.

Our findings and conclusions are accompanied by recommendations pointing both to additional research and to ways to use what has already been discovered.

Studies that set out to answer one question often raise another. Indeed, our results have prompted further questions that remain to be answered some future day. We hope at least a few of the further questions will be addressed, perhaps by structuring some of Bonneville's ongoing conservation programs.

Knowledge is built from the contributions of many. We are pleased to have had a part in that process.

Gale C. Corson

Lauren A. Smith

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CHAPTER 1: INTRODUCTION

The Evaluation of Software project is one of many initiatives to support the Bonneville Power Administration's energy conservation programs in commercial buildings.

Bonneville's energy conservation programs for commercial buildings rely heavily on software that simulates the energy consumed in the buildings. The validity of the estimates depends on the quality of the simulation model. This project is an evaluation of the software and the modeling process.

The expected benefits of this study are to:

1) Determine the relative and absolute accuracy of simulation software used to simulate energy consumption of commercial buildings.

2) Determine the impacts of software users (modelers) on the relative and absolute accuracy of energy simulations.

3) Establish benchmark and/or performance index measures to facilitate recommendations and selection of simulation software packages.

4) Validate and extend the results to BPA's commercial energy conservation programs, possibly including factors to adjust previous results.

The project has in fact compared and evaluated selected computer-based simulation software used to model and analyze energy consumption in commercial buildings. Decisions about energy conservation are based on information from the models. Therefore, the quality of the models and the software is significant.

A few earlier studies have been reported in which building energy simulation software has been evaluated comparatively. Model-user factors were largely ignored in those studies. The Evaluation of Software project has sought to look at the variables introduced by the modelers as well as the software.

The project has evaluated energy modeling and simulation software in five ways:

- a literature review
- a round-robin set of comparative simulations
- simulations structured as a sensitivity study
- questioning and interviewing of informed sources
- synthesis of a software performance index

This report records the methodologies used during the project, results of the study, and comments about the results. The report presents the project's findings, evaluations, and conclusions. The report describes what happened, but explains only a few of the reasons "why". Many of the unanswered questions call for continuing analysis.

Conclusions from the project about energy simulation software, energy simulation models and how they are used should help in the design and conduct of future energy conservation programs.

1.1 The Project Team

The "Evaluation of Software" project was performed cooperatively by a team comprised of a prime contractor, six subcontractors, and two members of the Bonneville Power Administration staff. Team members were selected for their experience and capabilities in modeling energy consumption in commercial buildings.

The prime contractor was Gale C. Corson Engineering. Mr. Corson, the firm's owner and principal, was responsible for project management and for coordinating the work of other contractors. The firm and its predecessor (Center 4 Engineering) have been active with projects for building energy systems and energy conservation since 1977.

The primary subcontractor was Solarchitecture Planning, P.C.; the project was initially proposed as a joint venture, and it was carried out in that spirit. Solarchitecture's owner, Lauren A. "Larry" Smith, formed the firm in 1976 and has concentrated much of his work on building energy conservation.

Five other subcontractors were selected for the project:

- Applied Energy Management Techniques (AEMT)
- CADD Management Services
- Portland Energy Conservation, Inc. (PECI)
- Utility Systems & Applications, Inc. (US&A)
- VBB Pacific

The study compared the work of the several subcontractors, not to critique individual firms or rate the quality of their work, but rather to introduce variability into the modeling process and to understand that process better. Subcontractors were invited to express opinions and value judgments about their experiences, the modeling processes, and the software. To encourage candor and minimize the possibility of bias, modelers have been identified as a group, but except for code letters they have not been associated individually with their modeling work, simulation results, or comments.

The two Bonneville staff members who were active participants on the project team are Tom Osborn (Snake River Area office, Walla Walla) and Tim Steele (Portland main office). Both have worked on Bonneville's building energy conservation programs and are experienced building energy modelers. For this project they not only offered recommendations and guidance but also constructed building energy models and contributed to the simulation studies. Mr. Osborn was the Contracting Officer's Technical Representative (COTR) for the project.

Further information about the team members, their qualifications and contributions, may be found in Appendix B.

1.2 Bonneville Power Administration

The Bonneville Power Administration is a Federal Agency created in 1937 by the Bonneville Project Act to transmit and sell power from the Bonneville and Grand Coulee dams located on the Columbia River. The Act stated that generation of electric energy at the Bonneville project shall be for the benefit of the general public, particularly of domestic and rural customers, with preference in the disposition of electric energy to public bodies and cooperatives.

In the last 50 years, the Bonneville Power Administration's responsibilities have grown. It now transmits and markets power from 31 federal dams, two nuclear plants, and 3 coal plants via a high voltage electrical transmission network of over 14600 miles. Electricity is delivered to 385 substations, from which local utilities distribute electrical power to homes, businesses and farms. Two AC and one DC transmission lines, known as the intertie, connect the Pacific Northwest with the Southwest. Transmission of electricity generates revenue which helps keep the Pacific Northwest rates among the lowest in the nation. The BPA also delivers electricity to several aluminum smelters which provide almost 25% of the agency's annual revenue and countless jobs for the region. Today's BPA employs 3400 people, has revenues of 2.5 billion dollars and pays the US Treasury 600 million dollars per year.

In December 1980, the Pacific Northwest Electric Power Planning and Conservation Act was signed into law. This law was enacted to assist electric conservation, to encourage the development of renewable energy resources, to enhance fish and wildlife resources, and to establish a representative regional power planning council. Since then, Bonneville has been instrumental in the design and planning of various conservation activities. Through 1988, Bonneville saved an estimated 240 annual average megawatts through various conservation activities.

Current energy conservation activities include computerized energy modeling of commercial buildings. Since program decisions and incentives are based on modeled savings, and the savings provide an energy resource, accurate estimates are required. It is because of the unknown accuracy of the modeling results that this project was undertaken. Bonneville wants to be able to rely on energy savings and needs to know which software packages are the most appropriate and accurate for different programs.

CHAPTER 2: PROJECT PURPOSE AND OBJECTIVES

2.1 Background

Energy conservation was established as a priority regional policy by the Pacific Northwest Electric Power Planning and Conservation Act of 1980. Conservation is widely supported throughout the region.

The Bonneville Power Administration has sponsored a series of programs that demonstrate and support building energy conservation in commercial and institutional buildings. Starting in 1982, these include the Institutional Buildings Program (IBP), Purchase of Energy Savings Field Test (PES), Commercial Incentives Pilot Program (CIPP), Energy Edge, Commercial Retrofit and End-Use Study (CREUS), and the current Energy Smart Design.

In 1983 Bonneville launched an extensive energy conservation effort - the Commercial Audit Program, or CAP. Although CAP was a demonstration program, it was implemented broadly, through 23 energy audit contracts in Idaho, Oregon, and Washington - involving 15 energy audit contractors, some 3800 buildings, and a cost in excess of ten million dollars.

The following year Bonneville initiated ELCAP (End-Use Load and Conservation Program), to collect end-use metered energy consumption in commercial buildings; data has been accumulated on 200 buildings, including 33 in CAP.

An important goal of these programs was and still is to obtain maximum benefits from the substantial funds being invested in conservation. Many of the programs have been designed to test or demonstrate specific concepts; thus, evaluation of program results has received considerable attention. For example, Bonneville published an extensive report on CAP, "Evaluation of the Commercial Audit Program"(1), further supported by "The Commercial Audit Database" in two volumes.

Bonneville has specified the use of building energy simulation models as a common basis for estimating the benefits expected from various energy conservation programs and measures. Due to the extensive requirements for analysis and computation, these models use computers to calculate building energy consumption. Simulation results have been used in Bonneville's programs to make decisions about conservation potential, building construction, funding and installation of energy conservation measures, incentive payments, and the energy conservation programs themselves. Consequently, it is important to know how accurate the estimated savings are, and what modeling software and techniques will give the most accurate results.

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(1) Cambridge Systematics.
Full citations are given in "References", Appendix A

The computer-based simulation models estimate the energy consumed in a building, using detailed engineering calculations that account for construction, weather, and operating patterns. The models can be changed to reflect design alternatives such as insulation, lighting, heating/cooling equipment, and other features of the building that affect energy consumption. The consumption before and after a proposed change can be compared; the change in simulated energy is an estimate of the energy that will actually be conserved when an energy conservation measure (ECM) is installed in a building.

Input data for simulations can be varied easily, allowing rapid, economical evaluations and comparisons of various design alternatives. Thus, an extensive set of energy conservation measures (ECMs) can be considered, evaluated, and selected as appropriate for each project or building. This is the tool that has been used widely in Bonneville's energy conservation programs.

2.2 Discussion

Building energy modeling is a useful tool for energy conservation activities. With increasingly capable desktop computers, simulations which once were practiced only on mainframe computers now enjoy wide use and acceptance.

But what if the simulation results are not correct? What if predictions are either more optimistic or more pessimistic about energy consumption and cost savings than is warranted by the "real" performance of a building or an energy conservation measure? Then the recommendations will place either more or less emphasis on an option than is appropriate; in the worst case, a wrong go/no-go decision can be urged upon a building developer, owner, or operator.

The quality of energy simulation models for commercial buildings has been largely unknown. Software suppliers decline to disclose the contents of proprietary data files and computational algorithms; source code for the software is generally unavailable. Only a few validation studies have been published, primarily for mainframe computer software, and they are usually sketchy. Quantitative differences between simulated values and "real" results have not been tested or measured comprehensively(2).

Experience shows that every simulation software package has its own problems and limitations. Most likely, some software packages should be rated as "better" than others, while all misrepresent (or simplify) a given building's performance to a lesser or greater extent.

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(2) See Judkoff for a comparative study of mainframe energy simulation software, using a very simple building in Ottawa, Canada and two weeks of actual weather data from Ottawa, Denver, and Copenhagen. The study found wide initial discrepancies, forcing changes in the software and input data; it eventually achieved heating comparisons within about 13%, and cooling comparisons somewhat more divergent.

Similar numerical simulation models have been used to estimate energy consumption in residences. Residential models have been studied and compared more extensively than those for commercial and institutional buildings; we therefor have a fairly good idea of the magnitude of the errors which can be encountered with them. For example, Akbari et al[3] adopted DOE-2 software as a standard and then compared three residential simulation models with it, using a theoretical MCS (Model Conservation Standard) house for analysis. They found two of the simulation programs gave energy consumption results within +/- 20% of the standard, and predictions of conserved energy within +/- 10%. Results with the third modeling program were often 50% less than the standard; the authors concluded it was not a suitable analysis tool.

Computerized models used to simulate the energy consumption of commercial buildings are more sophisticated than the residential models discussed in the previous paragraph. In general they require additional data inputs and include further calculations for closer control of the model, its simulation, and its results. With these comparative improvements, it can be argued, the simulation models for commercial buildings should give results which are relatively closer to the "real" world.

On the other hand, commercial buildings are considerably more varied and complex than residences. Their air handling systems, for example, can include such capabilities as multi-zone and variable air volume; controls are often more sophisticated; more variety is found in lighting systems and their control From this perspective, then, it can be argued that simulation results for commercial buildings will be relatively less consistent.

Further investigations were indicated to resolve the two perspectives. The Evaluation of Software project was one of several efforts devised to look into these interests.

By late 1988, the CAP efforts were complete, with 3800 energy audits represented in an extensive database. The most frequently audited facility types were office complex/building and retail/dry goods, with restaurant/fast foods following.

Analysis of the audit results showed wide differences in the results achieved by the various CAP contractors. On the average, some contractors spent markedly more time on each audit than other contractors. Some projected considerably more energy savings than others. The scatter was fairly spread out, but a curious tendency was noted: less extensive work seemed to lead to more optimistic estimates of how much energy could be saved.

To this day there has not been enough analysis of the CAP building energy simulations to say just how far the estimates depart from reality, or if in fact some CAP contractors were more realistic in their estimates than others. For most CAP buildings, the energy savings projected for recommended ECMs have

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(3) Paper presented at ASHRAE Annual Meeting, June 1986, Portland, Oregon

not been compared with field reports of actual energy usage. Bonneville's ELCAP program has provided a base for comparing simulated and metered data for a small sampling of CAP buildings. But even the ELCAP program, in which Battelle-Pacific Northwest Laboratories (PNL), under contract to Bonneville, has metered the energy consumption of some 200 buildings, overlapped with the CAP program on only 33 of them.

The report "Evaluation of the Commercial Audit Program" tabulated the divergence between simulated and actual energy consumption for available CAP/ELCAP buildings(4): Ten buildings were within 10%, another seventeen were within 20%, while at least one building was off by more than 100%. Energy components (end-use components) often showed more divergence than total building energy.

The CAP evaluation report attempted to pinpoint where and why the differences arose. Some of the energy differences were traced to discrepancies in descriptive data collected by field auditors for CAP and PNL in part due to changes (occupancy, equipment, etc) that occurred in the time interval between field visits. Some differences were ascribed to PNL's inability to conform all metered data to CAP reporting categories; for example, to isolate the lighting plugged into wall receptacles. Some differences stemmed from comparing data accumulated at three different times and therefore under different weather conditions (pre-audit utility billing data, averaged historical or typical weather data in the software set, and post-audit metering). Some of the differences were due to interpretations adopted by various contractors, or to difference in report format between what had to be submitted to BPA and what was used for simulation runs. And some of the differences were due to the modeling software and how it was implemented.

In the aggregate, CAP contractors used 13 different energy simulation software packages for their work. The CAP evaluation report asserts(5), "The most striking variations were in the areas of contractor use of energy simulation programs, the selection of targets for the CAP audits, how building energy use baselines were established, the manner results were reported to Bonneville, and the treatment of demand savings." The CAP report examines factors which contributed to this variability, especially in choices made by the CAP contractors in implementing the software.

Such evaluations of available data confirm the expected variability in software packages and also in how they are implemented. However, the analyses are not quantified or comprehensive; questions raised about comparability and significance of simulation results need further analysis.

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(4) Some CAP/ELCAP buildings had to be excluded from the analysis due to incomplete or inconsistent data. As a result, many of the energy comparisons were made with a net sample size of 27, encompassing 6 building types in audits by 8 of the 15 CAP contractors.

(5) Page 6-5

At the moment, Bonneville's most extensive effort to compare simulated and actual energy savings is being pursued in the CREUS (Commercial Retrofit and End-Use Study) program, under contract to Puget Energy Services, Inc. PESI is tracking PNL's end-use metered field data against their own energy simulations for 18 commercial buildings, using ASEAM 2.1 software. Each building has been field-equipped with all ECMs recommended during the modeling process. Results of the study are expected late this year (1990).

The Evaluation of Software project is another thrust at similar questions and interests. The project enlisted a small cadre of experienced building energy modelers in efforts to identify the components, magnitude, and sources of the variables and discrepancies that affect building energy estimates. This report describes those efforts and results.

2.3 Objectives

Energy simulation models for commercial buildings provide a useful tool for conservation programs, but uncertainty about how accurate the results are limits the value of the tool.

Through the Evaluation of Software project, the Bonneville Power Administration sought to address two general goals that support and improve Bonneville's energy conservation programs for commercial buildings:

a. Provide data which will enable Bonneville to specify accurate, low-cost simulation software for its commercial building energy conservation programs.

b. Establish the accuracy of the commercial building energy simulation software that is used.

As the project developed, two other goals became evident:

c. Determine what contribution the software user (modeler) makes in the accuracy of the simulation.

d. Identify opportunities for improving the modeling process.

The first goal is future-oriented. It seeks to reduce the uncertainty associated with the results of energy simulations, so Bonneville's energy conservation program managers will be able to select and use simulation packages that give good, dependable results. A further aspect of this goal is to attain the software performance objectives at least cost.

The second goal addresses the need to interpret and draw conclusions from Bonneville's recent commercial energy conservation programs such as CAP, while looking to the future as well. It seeks to guide the use of simulation software within known application limitations and statistical measures for variability and confidence level.

The third goal recognizes the influence of the modeler and his or her ability to affect the simulation results for better or worse. Modelers are subject to human errors, they offer a spectrum of technical capacity and experience and they typically must rely on imperfect knowledge of the buildings they model.

The fourth goal seeks to increase the accuracy and repeatability of energy estimates through consistent use of the most representative data and the most effective modeling approaches.

All four goals call for accurate energy simulation software and modeling activities. Implicit in this is a comparison, and yet a close conformity between (simulated) energy estimates and what happens in the "real world".

Of course, the real world is also subject to stochastic processes, that is, irregularities. An absolute standard for energy estimates would be for them to fall within a probable range of "real" values, after reasonable allowance for the many variables. We emphasize instead a relative standard: The accuracy of the simulation software, as used, is evaluated by how closely the energy estimates approach the range of energy consumption **measured** in real buildings. The project goals therefore establish a "comparative" performance standard.

Once the performance standard has been met, consider the companion project goal: Which software packages cost the least? That is, which packages fall into an acceptable benefit/cost range for a given application?

Some software may be more appropriate than others for certain applications, due to technical limitations or economic considerations. Furthermore, some buildings have greater potential for energy savings than others, because they are less efficient to begin or because they are able to draw more extensively on conservation technologies. The cost standard is also comparative because "least cost" is open-ended, necessitating price/performance comparisons.

The remaining emphasis is on the modeler and the modeling process. Modelers select specific software to model particular buildings, based on software availability, capabilities and limitations, contract requirements, and their own experience and preferences. Some modelers have more experience than others with simulation software, building energy systems, and energy conservation. It follows that modeler qualifications and the decisions modelers make do affect the building energy simulation results.

CHAPTER 3: PROJECT DESIGN AND METHODOLOGY

Building energy simulations help us to make decisions about energy-efficient building designs and modifications, and at times about awards and incentives that encourage energy conservation measures. The utility of the decisions depends on how accurately the building energy is modeled.

This project is dedicated to an evaluation of modeling and modeling accuracy. Several approaches were considered for the project design. Five were selected.

3.1 Analysis Approaches

In one way or another, any evaluation of building energy modeling must consider three categories of variables: external, software, and modeler variables.

Quite literally there are hundreds of variables within these categories. For any given building of even modest complexity, energy modeling may depend on thousands of data points and thousands of lines of computer code, each one potentially capable of affecting the estimated building energy.

One way to analyze the contribution of a given variable is to see what happens when it changes while all other independent factors are held constant. If each variable were investigated independently - if that were even possible in a real-world building - the number of variables would quickly exceed a realistic limit. As a practical matter, simplifications and alternatives must be introduced into any analysis effort.

Only a few of the investigative approaches considered were actually selected for the Evaluation of Software project. In addition to the literature review, round robin simulations, sensitivity study, and survey described in this report, possible approaches included:

- A common, videotaped field audit to minimize modeler interpretations
- "Black box" simulations of simplified buildings with adiabatic walls
- Round robin simulations using building data for typical MCS construction
- Comparative simulations based on CAP buildings and data
- Statistical studies of the CAP database
- Interpretive, subjective evaluations of information from the CAP database

Each approach was considered, together with its potential advantages and drawbacks. The CAP database, for example, already contained a wealth of information about modeler and software impacts, if only it were possible to upgrade the quality of the data (the CAP evaluation report noted several problems, such as inconsistency in reporting certain measures) and if there were some way to relate the estimated data for each building to real-world results.

The CAP database could support a multivariate analysis linking simulated energy per square foot, by building type, by modeler, and by software type. The results would reflect the separate contributions of each, but the results would be tainted for the reasons given.

A combination of approaches seemed to offer the most for the Evaluation of Software project. An input-output (sensitivity) analysis, for example, focuses on software responses to given input perturbations; it purports to isolate and minimize the effects of modeler decisions. But application of the same stimulus to two different models (perhaps for two different buildings) constructed with the same software will yield two different responses (e.g., reducing lighting in a cooling-dominant vs. heating-dominant building). It is not feasible to explore all possible building models, so the sensitivity analysis must in part depend on an "arbitrary" selection of one or several building models, and that injects modeler choices.

On the other hand, an evaluation of how modelers impact simulation results needs to involve a goodly number of modelers: It is not enough to speculate on what they **might** do; we need to observe and record their actual decisions. It is not enough to let one modeler give it a go. The round robin approach is ideally suited to this evaluation because it involves a group of modelers under reasonably controlled conditions. However, cost is a practical consideration in limiting the number of simulations. A handful of simulations allows descriptive comparisons of modeler behavior, but the statistical confidence of the measures may be low.

Using **both** methods was chosen as the best way to evaluate modeler impacts on energy simulations, because the two can be cross checked, which therefore provides an avenue to greater confidence in the results both statistically and practically. The same combination of methods offers similar advantages for comparing overall performance of individual software packages.

There was, in fact, considerable leeway in how the goals for the current project were to be met. And when the results were in, the approaches selected did not meet all expectations of the investigative design, but they were successful in most respects, leading to useful conclusions.

The evaluative project was therefore not a detailed quality acceptance testing program or a comprehensive examination of all software features, but rather an overall process for comparison and validation, to accomplish the objectives, goals, and requirements. It sought to take results from several simulation models, using examples from real buildings with known energy consumption, and to compare those results under a limited number of conditions.

The comparisons were used to establish measures of **overall** conformity and/or divergence, both between the models themselves and/or relative to a comparative standard.

3.2 Plan of Work

The culmination of a project design effort is a plan of work. The goals, concepts, approaches, options, alternatives, and tradeoffs are distilled into a single statement of the specific work that is to be undertaken for the project. The Work Plan for the Evaluation of Software project was guided by Bonneville's original Statement of Work and adopted after careful coordination between Bonneville and the Contractor.

Significant elements from those documents are embodied in this report and discussed at appropriate places as needed. In general, what the project team accomplished followed the Plan quite closely and is documented in this report; the few changes found necessary are also described in the chapters and narrative that follow.

3.3 Study Outline

The "Evaluation of Software" project examined the interests and questions raised about the performance, reliability, and variability of computer-based energy simulation software for energy conservation decision making.

The "Evaluation of Software" project addressed these interests through a review of previous work reported in the literature, comparisons of energy consumption simulated by several software programs and modelers, further comparisons with field data measured in real buildings, sensitivity analyses of simulation models, and a benchmarking Performance Index.

1. The first approach was to take advantage of what has already been accomplished and what is already known. A literature review was therefore an early part of the project and its findings helped shape the activities that followed. With knowledge of previous efforts, the current work sought to avoid unnecessary duplication, deal with unanswered questions raised in previous investigations, and concentrate on remaining concerns. (See Chapter 10)

2. The second approach provided a "round robin" comparison of simulated building energy. Estimates of building energy were prepared from computer simulations by eleven experienced energy modelers, based on four real building from Bonneville's ELCAP program, using five representative software programs. Three "cycles" of simulations permitted evaluation of software performance, and also of how the decisions of those who use the software (the modelers) affect the results. (See Chapters 4 and 5)

3. The third approach was a sensitivity study. A series of simulations was conducted for each of two buildings selected from Bonneville's ELCAP program. Changes in input parameters caused changes in energy estimates, and these were compared for each of the five software packages. The goal was to isolate most of the modeler influence, so as to concentrate on the software differences. (See Chapter 6)

4. The fourth approach was to compile descriptive information and modeler opinions about the software used in the project. (See Chapter 7)

5. A final approach was to combine the findings into a Performance Index or benchmark process that will facilitate future comparisons of software packages. (See Chapter 8)

The five study approaches were united by a desire to view the study problem from enough perspectives that informed conclusions could be established about the contributions and significance of the several influencing factors.

Project results should have generalized significance and will probably be applied to other buildings, locations, and broader conditions. Technically, such extrapolations may be hard to justify, since most models use different features in varying circumstances. Some of the conclusions should be viewed as tentative - as hypotheses that need further scrutiny. In any event, caution should be exercised in just how far the results and conclusions are extended beyond the fairly small sample set examined in the project.

CHAPTER 4: VARIABLES AND DATA

Data used to model and interpret building energy consumption are susceptible to variations and errors. The Evaluation of Software project found numerous opportunities for adjustments and corrections: Data reported from ELCAP contained recognizable errors, with values overstated by as much as 66%. Utility billing intervals occasionally varied by 17% or more. Calendar periods were shifted by a third of a month, and potentially more. Year-to-year energy consumption ranged to +/- 43% from the mean of the extremes. Weather data varied by availability, scope, and frequency; yet some users were not able to access or even view the contents of weather files. Overall, data variables showed significant impacts on modeling choices and interpretations. The findings present opportunities for improved handling and analysis of data accompanied by improved energy estimates.

4.1 System Considerations

Building energy software programs are used to simulate energy consumption and conservation in buildings. The programs contain sets of mathematical models that seek to explain quantitatively how each component of a building behaves under given circumstances.

When the sun shines on a window, for example, part of the energy is reflected and another portion finds its way into the building. How much energy ends up in the building depends on where the sun is and how cloudy the day is; it also depends on nearby buildings and trees and on a host of window characteristics like size and orientation.

Many components affect the building energy balance: the building shell, the people who occupy the building, ventilation, lighting and other energy uses within the building. A net increase of energy entering a building is made manifest as an increase in temperature. These and other relationships are quantified in the building energy simulation through extensive calculations.

Buildings are complex. The software programs that simulate them use many mathematical relationships to represent even one zone in one building. Each equation is an approximation of one of the physical processes that govern the flow of energy in a real building. Many of the relationships are interactive with one another. Many variables are expressed in the relationships. In all, a typical building may need thousands of data elements to describe its characteristics and to perfect the software-based mathematical model.

The physical relationships are fairly well known. They are described, among other places, in ASHRAE's Fundamentals (American Society of Heating, Refrigerating and Air-Conditioning Engineers), which is the starting point for virtually all energy-modeling software.

ASHRAE's relationships, however, are neither absolute nor unique; indeed, ASHRAE itself offers more than one computational approach for certain energy systems. Relationships are only approximately understood and approximately estimated. They are often complex, requiring intricate analysis and extensive computation and offering choices for alternative approximations and computational approaches. Certain relationships are more important in some circumstances and applications than others. Some approaches surrender a little accuracy or precision in exchange for greater convenience and speed.

The parameters and relationships used to describe buildings in the software therefore represent a series of choices and compromises. A software designer faces a host of decisions and opportunities for optimizing his product for the intended application. As a result, the software that reaches the market is widely differentiated in features that range from cost, simplicity, and speed, to specific capabilities such as passive solar heating and dehumidification of natatoria. A further consequence is that the various software packages are of uneven quality, even for a given application. The potential for less than perfect results increases if there were errors in the designer's conception or coding - and there often are.

Software users are confronted with an array of possibilities from which their acquisition selections are made, often with less than complete information. Similar selections are made for each project, to match the software with the application. Some projects require more than one software package, if each will model a particular measure missing in the others; and in this instance the "base building" for each one is likely to differ from all others.

Even if software implementation and selection are optimal, however, the modeling of any particular building is still dependent on the values selected by the modeler who uses the software. If a given building is described with hundreds or thousands of parameters, then the model requires each of those hundreds or thousands of parameters to be valued, and this is where the variability of the data and the modeler's decisions come to affect the simulation model, its results, and its validity.

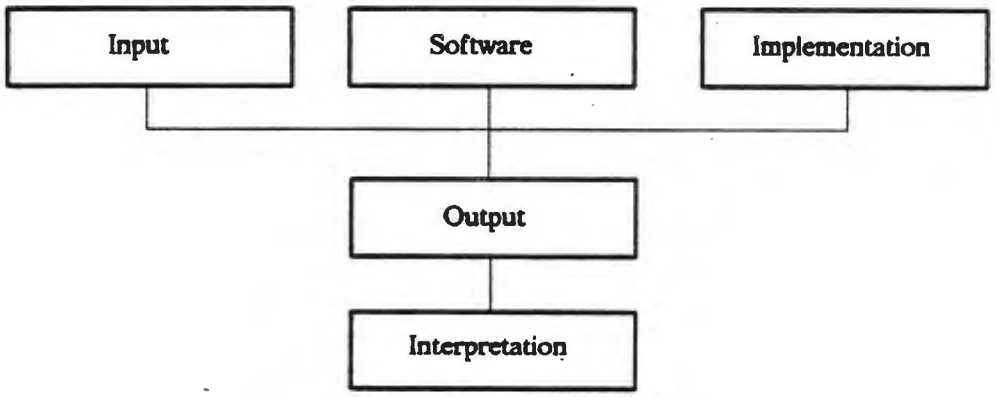
Virtually every parameter used to describe a building is subject to uncertainty or variability. The validity and quality of the modeling process and its results depend on the careful, accurate selection of input data. The extent to which the input data variables can be controlled and refined is therefore a determinant of the accuracy of the simulated energy estimates. Likewise, our ability to identify data variability and error is a first step in improving the modeling input and hence the quality of the output estimates.

Such data elements are a part of the Evaluation of Software project. They are common to the several investigative methods employed during the project. Accordingly, we seek an understanding of what the important data variables are, an examination of the data used for this project, and an analysis of the variability encountered.

4.2 Factors Contributing to Variability

Many factors can contribute to differences between the building energy consumption estimated by simulation models, and what we deem to be the actual experience in a real building.

Consider five categories of variables, described below:



Input variables occur in the data input to a simulation model. Differences may arise from data collection (field audits, utility data, weather data, drawings and specifications), modeler interpretations and choices, and data input errors.

Software variables arise from the input parameters, algorithms, look-up tables, and other relationships built into the simulation software. Most programs draw heavily on accepted ASHRAE equations, but short-cuts, compromises, options, choices of complexity, and errors coded into the software can yield results that differ from other models or reality.

Implementation variables arise when a building (or energy conservation measure) is not constructed or installed as anticipated by the model. Owners and contractors make frequent construction choices that affect a building's energy performance and may differ from the simulation model.

Output variables occur in the data obtained from the finished project. Output variables include both identified real-world variables (which usually have a counterpart in the simulation model) and unspecified random processes (which do not). Effects arise from weather differences, end-user impacts, and data monitoring. Weather differences are significant because simulation models rely on average weather conditions, and weather is never "average" over a short period of time. End-user impacts are significant when a building is used (occupancy, natural ventilation, temperature set-points, etc.) in a way not anticipated in the simulation model. Data monitoring, if practiced, may be significant depending on the scope of the data, the quality of the instrumentation (equipment, implementation, calibration), the care exercised in reading data, and any interpretations given.

Interpretation variables are encountered when people attempt to analyze and interpret differences between simulation estimates and data collected in real buildings. Such variables reflect specific samples, sample sizes, the need to fill in for missing data, and the prior experience ("bias") of the reviewers.

The variables may also be grouped into two larger categories: simulated and encountered. The first group (Input and Software variables) emphasizes differences which arise preceding and during simulations. These are due to the type and location of buildings, quality of input data, experience of the persons performing the simulations, regional differences in anticipated utility rates and construction costs, the extent and order of ECM recommendations, and the simulation software itself. Evaluations which compare simulation software packages should consider these variables.

The second group emphasizes the further variables (Implementation, Output, Interpretation) which may be encountered when comparing estimated (simulated) energy consumption with actual (metered) energy consumption. Differences may be attributed not only to the simulations, but also to discrepancies between building design and construction, use patterns that differ between building end-users/occupants, differences between actual weather encountered and what was simulated, and the quality of post-ECM energy consumption data. Evaluations which compare estimated (simulated) energy consumption with "actual" data should consider these variables as well.

All of the variables are significant because they are a key to understanding and interpreting the modeling process and the simulation software. When we are able not only to recognize the variables but also to control and manipulate them, then we have established a basis for analyzing energy simulation modeling.

In the Evaluation of Software project, attention is directed primarily to the "simulated" variables, using "encountered" variables to explain them.

A more comprehensive tabulation of the categories of variables that affect energy conservation modeling may be consulted in Appendix C.

4.3 Variability and Error; Significance

Building energy models are used to estimate and predict the energy that will be consumed in buildings, or the incremental changes in energy consumption that will occur if specific changes are made in the buildings or their occupancy and use. It is far more economical and cost effective to formulate a model and manipulate it than it is to construct a real building and/or make successive physical changes in it to see what happens.

The utility of a building energy simulation model depends on its ability to predict real outcomes within a reasonable margin of error. Acceptance of the model and the modeling process depends on a perception, that most of the time the predictions are accurate and do indeed fall within allowable ranges.

Although "reasonable", "accurate", "allowable", and "most" are subjective and qualitative, results can be measured and criteria can be assigned quantitative values.

The predicted results, the observed results, and the differences between them are direct functions of the variables discussed in the previous section. Having said that, however, it is helpful to distinguish between pure variables, real errors, and perceived errors.

"Pure" variables are those that have been integrated into the model. A change in a variable value is expected to be evidenced through a change in the output results. If a model correctly incorporates both the input value and the relationships influenced by that parameter, the changing output should reflect only the workings of the model, with no suggestion of error.

A "real" error occurs, however, when either the value of a parameter or a relationship it influences is incorrectly stated in the model. A real error may also occur in measuring or interpreting the output results. Real errors lead to real differences between the predicted and observed results.

Each variable is susceptible of error and each statement of relationships between variables is likewise susceptible of error. Therefore, when a model is constructed it may incorporate several or more errors; the more complex the model is, the greater is the likelihood of multiple errors. The overall error in the result projected by a model is a function of the component errors in "simulated" variables.

The overall error in the result determined for real-world building operations is likewise a function of the component errors in "encountered" variables. It may or may not be possible to perceive errors in the component parts of the whole.

While in practice specific errors may be compensating (offset one another), in a stricter analytical sense most errors are cumulative in character. Error analysis follows from the classical theory of errors.

A "perceived" error, in its broadest sense, is merely the difference between a predicted result and what we think the result actually turned out to be. If we have done a good job of accounting for all the variability and real errors, they will fully explain the perceived error.

Each cumulative error is significant in the sense that it contributes to the total error. But some component errors still impact the final results more forcefully than others. For example, a 10% error in the conductance of a roof is usually more significant that an equal error in the conductance of a basement floor slab, because the load through the former is usually greater than the load through the latter. As roof/attic insulation levels rise, however, floor losses become increasingly significant by comparison, and the relative significance of errors associated with them shifts accordingly.

The Evaluation of Software project was structured to track individual data components and their variability. This chapter of the report deals with input data obtained from external sources: electric utility, weather, and ELCAP data. (ELCAP data is input data in this context because modelers adapted their models to it; the same information was later used as output data to compare the final results.) Analysis is made of variability and errors in the data, and the extent to which individual modelers accounted for those differences.

Chapter 5 reports the round robin simulation effort. That effort used building descriptions designed to minimize differences in input data such as areas, power levels, and occupancy. Analysis is presented of the variability introduced by modelers as they interpret the data and apply it.

4.4 Project Data

The following paragraphs present input data used in the Evaluation of Software project, including identification of sources, description of the materials, and interpretations of their applicability and variability.

4.4.1 Weather Data

Software programs that simulate building energy use weather files. Weather files are computer data files with weather information. Their contents vary with the software design, but they typically include dry bulb temperatures, wet bulb temperatures (or other measures of air moisture), and insolation (solar energy). They may offer further information about wind direction and velocity, cloud cover, ground water temperatures, ground soil temperatures, and soil permeability and density. Each weather file contains data for an entire year, for a given site.

The most important difference in weather files arising from software design is the distinction between hourly, bin, and typical day models. Hourly models calculate building energy requirements for each of the 8760 hours in a year (some even account for February 29). Typical day models may be hourly models, but use weather data for only 12 or 52 days - typical for each month, each week, or some other fraction of the year; computer runs are faster because hourly computations are made only for typical days, and then multiplied to fill out the year. Bin models note from bin weather files how frequently various conditions occur (e.g., dry bulb outside air temperatures), compute the energy requirements for those conditions, and multiply the results by their associated frequencies; usually their computer runs are still faster.

Hourly models usually use "typical year" weather files, although they can also be run with data sets for given (actual) years. Typical year files recognize the variability of weather from year to year, using values selected to yield energy simulation results that are representative of what will be experienced on the average over the years. In this sense, a "typical year" file is directly analogous to a profiled "typical" weather day file, but offers a broader statistical base.

The software designer determines what weather information will be used, and in what format it will be stored in the computer file. Some software programs store the data in ASCII format, which is easily accessible to the program user (modeler); others use files with binary coded or encrypted data, and the modeler is asked to accept on faith that the resulting "black box" file is correct. Some software suppliers make it relatively easy for modelers to create their own weather files or modify existing ones, while others set themselves up as sole source suppliers for the additional weather files modelers must buy.

Real weather differs from one location to another. Likewise, each computer weather file is site specific, and is identified (internally or externally) with a community, latitude, longitude, and elevation.

Weather files rely on data obtained from specific observation stations Data used to build a weather file for Portland, Oregon, for example, may have been recorded at the airport. Temperatures in downtown Portland, or in other communities around Portland, differ somewhat from those at the airport.

Further differences occur in "micro-climates", even for buildings in close proximity; the differences arise from shading, wind patterns, vegetation, nearby water bodies, and relative elevations. These nuances are not reflected in the usual weather file.

Equally significant, raw weather data are available from several sources and in several formats - for example in three-hour or eight-hour time intervals. Even if a modeler is able to specify what goes into a weather file, the source of the data makes a difference; different sources and different data formats result in differing energy estimates from a building energy simulation model.

The three most commonly used weather data series are TRY (Test Reference Year), TMY (Typical Meteorological Year, and WYEC (Weather Year for Energy Calculation). TRY files were established by selecting a most representative single year from 1948-1975 weather data for each of 60 U.S. communities; files are devoid of solar data. Each TMY file, for 233 locations, is a collection of weather data for the twelve calendar months, each month selected independently as the most representative month from 23 years of solar and other weather data. WYEC files, though limited to 51 locations, are the most recent; their conception is similar to TMY, but adjusted to obtain superior statistical agreement with long-term averages of dry bulb temperatures, insolation, and wet bulb temperatures.

It should be obvious that computer weather files created from any one of the three weather data series will differ from the other two, and simulation results obtained with them will therefore differ as well. The Evaluation of Software project did not attempt to quantify these differences.

For any given location, the real weather changes with fairly consistent seasonal patterns. In the northern hemisphere the overall pattern is colder in winter, warmer in summer. Locations in higher latitudes and at higher elevations generally are cooler than those farther south or closer to sea level.

Sites near oceans and other large water bodies are often more temperate and more humid, while those on the lee side of mountains are likely to be relatively sunny and dry. Weather files characterize these differences.

Weather differences affect the energy required to comfort-condition buildings. Cold temperatures require heating; hot, humid weather calls for cooling. Overcast days are likely to need more lighting.

Computer weather files can reflect not only the diurnal and seasonal weather patterns found at the target community, but also much of the day-to-day weather variability that ultimately shows up as peak demands for heating and cooling.

However, computer weather files do not reflect changes that occur from year to year. Some years are in fact colder, or wetter, or windier, than others. As noted above, most weather files contain a single set of data to represent any and all years, that is, weather for a "typical" year. Obviously this is not an "average" year, because the extremes of temperature are important in simulating peak design conditions. But what constitutes a "typical" year is, once again, a matter of judgement, and that judgement affects the performance of the simulation model.

A well designed typical year weather file may give good results for modeling the average energy consumption or the average savings from ECMs in a given building. It is a reasonable approach to take when simulating the energy consumption of a new building under design.

On the other hand, typical year weather files may be less suitable for estimating energy consumption in existing buildings. The distinction arises because modelers try to optimize their models by approximating the historical energy consumption pattern. Utilities maintain billing records (histories of building energy consumption) and make them available for energy audits. But none of the actual consumption data is for "typical" years, since each weather year is unique. The utility history is a record of energy consumed during unique weather years. To avoid an "apples and oranges" comparison, therefore, an adjustment is needed either to the real weather data (to make it more "typical" of average conditions) or to the computer weather file (to reflect the actual weather during the years when the utility data was recorded).

In all, there are many variables affecting weather data and its use. They in turn affect energy simulations and their interpretation. How significant the differences are has not until now been investigated experimentally. Analysis of data from the Evaluation of Software project could help an understanding of these factors.

The four buildings selected for the Evaluation of Software project were in two communities - Eugene, Oregon and Richland, Washington. Eugene is at the head of a low-lying inland valley; it has a relatively even climate, frequently tempered by cloud cover, and influenced at times by the ocean about 60 miles away. Richland is on a high inland plateau; it has a dryer, less temperate climate, often marked by clear skies and cold nights.

The significance of micro-climates was noted by modelers working with the buildings in Richland. One weather data series for Richland is recorded at a station near the Columbia River, while most of the city sits farther back from the water. Modelers suggested that the "best" data was probably that obtained for Hanford, Washington. Depending on the availability of weather files for specific software, however, modelers actually used data from Richland and six surrounding locations. Weather files for the buildings in Eugene showed a similar variety.

Temperature/degree-day data for the Eugene and Richland were obtained from NOAA for the years covered in the Evaluation of Software project (1984-89 overall; but most interest was focused on 1987-88). The data reproduced in Table 4.1 were distributed to the several modelers working on simulations for the project.

The modelers were free to consult other weather reference data as well. None of them made formal use of weather data to adjust or qualify any of their simulations or results, although several commented on it.

[The modeler using DOE 2.1 software had access to a weather file (in TRY format) containing actual data for 1987 and used it for the applicable part of his work starting with Cycle 2. DOE 2.1 can accommodate weather data directly in TMY, TRY, WYEC, and several other formats, but each of the other four software packages is limited to a single proprietary format. DOE 2.1 is also the only software in the sample set capable of interpolating hourly values where weather data are supplied in tri-hourly (every third hour) increments.]

On the other hand, none of the weather data for Eugene and Richland suggests severe deviations during the several years covered in the study. This is shown in Figure 4.1, where the same tabular information is in graphic form. It is possible that modelers did in fact use the weather data to make qualitative judgments, and chose to avoid adjustments inasmuch as the data suggested that relatively little compensation would be needed.

Although the limited sample investigated in the Evaluation of Software project failed to demonstrate much significance in weather variability, the topic warrants further attention in the future. Even small differences may be cumulative. How likely a modeler is to make adjustments depends not only in their magnitude but also in how readily available the adjustment data are, how widely the adjustments (process and results) are recognized, and the ease with which the adjustments can be made (availability of adjustment tools).

TABLE 4.1 COMPARATIVE WEATHER DATA

EUGENE, OREGON
(Monthly) Heating Degree Days

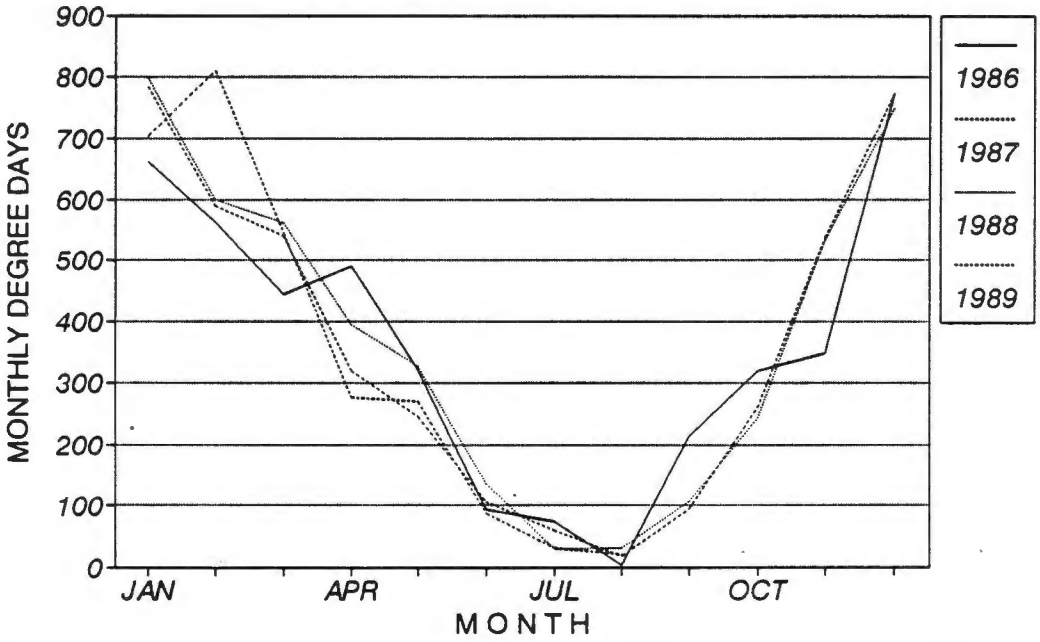
Month	Normal	1985	1986	1897	1988	1989
Jan	784		662	784	798	705
Feb	589		562	589	600	811
Mar	539		444	539	561	544
Apr	370		489	320	395	278
May	245		321	245	327	271
Jun	105		93	105	136	87
Jul	60		74	60	29	31
Aug	17		3	17	31	21
Sep	94		213	94	108	
Oct	262		319	262	244	
Nov	537		348	537	533	
Dec	774	662	773	774	749	

RICHLAND, WASHINGTON AIRPORT
Average Monthly Temperatures

Month	Normal	1985	1986	1987	1988
Jan	33.5		35.7	32.0	33.2
Feb	40.4		41.3	41.1	40.9
Mar	46.3		51.0	49.1	46.2
Apr	53.9		52.8	57.5	54.6
May	62.1		62.0	64.8	60.9
Jun	69.4		73.3	70.3	66.9
Jul	75.7		70.5	no record	73.5
Aug	74.0		77.1	72.0	71.8
Sep	66.3		62.6	67.5	63.6
Oct	54.7		54.9	53.2	57.7
Nov	42.7		44.5	44.3	45.4
Dec	36.6	23.7	33.1	32.3	32.9

HEATING DEGREE DAYS

EUGENE, OREGON



AVERAGE MONTHLY TEMPERATURES

RICHLAND, WASHINGTON

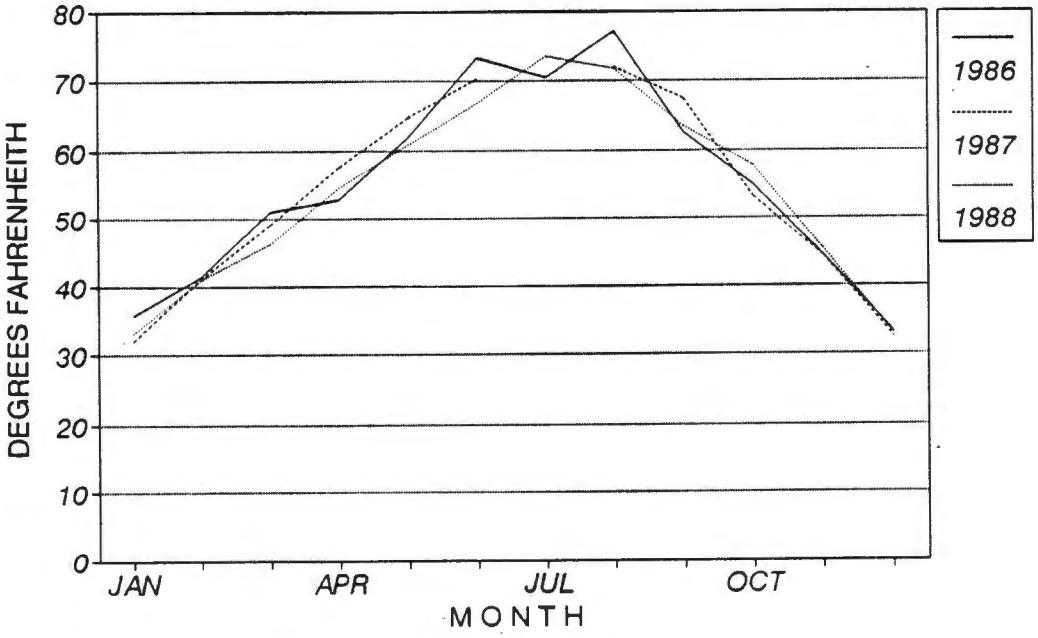


FIGURE 4.1

4.4.2 Utility Data

Energy utilities bill their customers according to how much energy the customers use. Other billing factors may include minimum, meter, demand, and power factor items, but for most customers the energy charge is the only significant one.

Energy utilities maintain billing records for each account. Electric utilities usually keep records by individual meters and make the data available for longer periods but most readily for one or two years.

The billing history is a good representation of the energy actually used in a building, although there may be a few problems in interpreting and applying it. Meters used by electric utilities, while lacking the precision and accuracy of engineering instruments, are usually accurate within several percentage points. Only infrequently are major errors noted, and when they are, the corrections are themselves recorded in the billing history.

The four buildings in the Evaluation of Software project are served by two utilities, the Eugene Water & Electric Board and the City of Richland Energy Service Department. Billing histories were obtained for the four buildings covering the years 1984 through mid-1989. For each of the buildings, data are shown graphically in Figure 4.2 (see Appendix E for tabular data).

Although nearly six years of data were secured for the project, modelers were given data only for December 1985 through March 1988, a period of 28 consecutive months. This decision was based in part on earlier observations about how much utility data modelers usually consider and an impression that it rarely exceeds two years. Instructions and reporting for the CAP program, for example, provided only for one year of billing data. The decision to limit data to that period was also made to parallel the data available from the ELCAP program; more will be said about ELCAP later. The significance of the decision to limit the distribution of data is also considered in a later paragraph.

Potential problems arise with utility billing data because reading intervals are irregular, may not be correctly recorded, or may be noted only by billing dates (billing dates themselves are irregular). Furthermore, the billing periods do not, in general, coincide with the calendar months used in building energy simulation models.

In recent years, electric utilities have reduced many of these problems areas through computer technology. Most utilities have computerized their energy consumption and billing records. They have also supplied their field meter readers with handheld data loggers. At the end of each day the data is transferred, without further transcription, directly from the data loggers to the computer, which eliminates many of the potential errors and minimizes the turn- around time. Computer processing of the data and mailing of bills frequently occurs on the next business day, further reducing both the lead time and the lag between the reading date and the billing date.

Nonetheless, billing variability is still with us. For certain fuels, such as oil, where deliveries are highly irregular, adjustments for variable intervals are essential. Although less significant, the same processes is applicable to deliveries of electricity. One day represents a 3%+ variance in a monthly period. The difference between a morning reading or one late in the day can be nearly that much. An intervening weekend, even more.

Some billings continue to show only the billing date, not the meter reading date. Single-date reports may not indicate if it is a billing date or a reading date.

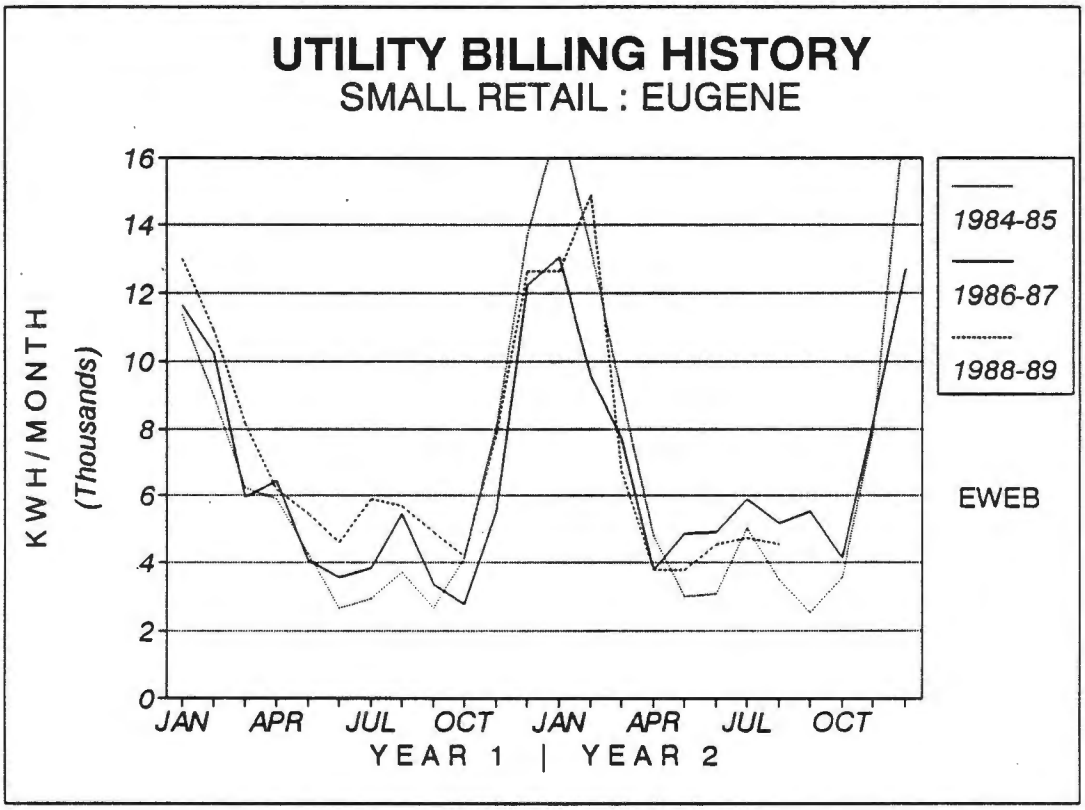
Figure 4.3 shows the interval variability found in the electric billing histories for the buildings in the Evaluation of Software project, separately for each of the two serving utilities. With one exception, all intervals were within +/- 5 days of the nominal length of the month, and most were within +/- 3 days. For a 30-day month, 5 days represents a 17% variance from the nominal value. Any building modeled to coincide with that point will depart considerably from the real consumption.

None of the modelers in the Evaluation of Software program acknowledged any attempt to adjust the billing data for interval variability before using it in the modeling process. One modeler did recognize the billing interval in comparing kWh/day consumption rates between years, but this was a side analysis that did not carry over to the modeling goal. One modeler started to adjust for billing interval variability, but did not: He said his experience with utility field readings suggests that reported dates are not reliable, so any adjustment would be unrealistic. Several modelers simply felt that other variables were more significant.

The graphs in Figure 4.4 show what happens if billing interval adjustments are made to the billing histories for the four buildings in the Evaluation of Software project, using data for calendar year 1987 for the illustration.

In the two retail stores, the effect of the interval adjustment for 1987 is relatively limited. Since many of the modelers focused on 1987 billing data in making their modeling comparisons, it may be they made a conscious choice to ignore such minimal adjustments. However, the adjustment effects are more pronounced and significant in the two office buildings, yet no adjustments were made by the modelers here either. In the most deviant instance (small office building, April 1987), the adjusted consumption is 43% higher than the unadjusted figure.

It can be conjectured that the Evaluation of Software modelers would have made adjustments for billing intervals if convenient software tools had been readily available. Such tools are not in wide use, however, and none of the utility data used or reported in the Evaluation of Software project has been adjusted for the billing interval.


UTILITY BILLING HISTORY
SMALL RETAIL : EUGENE
KWH/MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
JAN
APR
JUL
OCT
YEAR 1 | YEAR 2
1984-85
1986-87
1988-89
EWEB

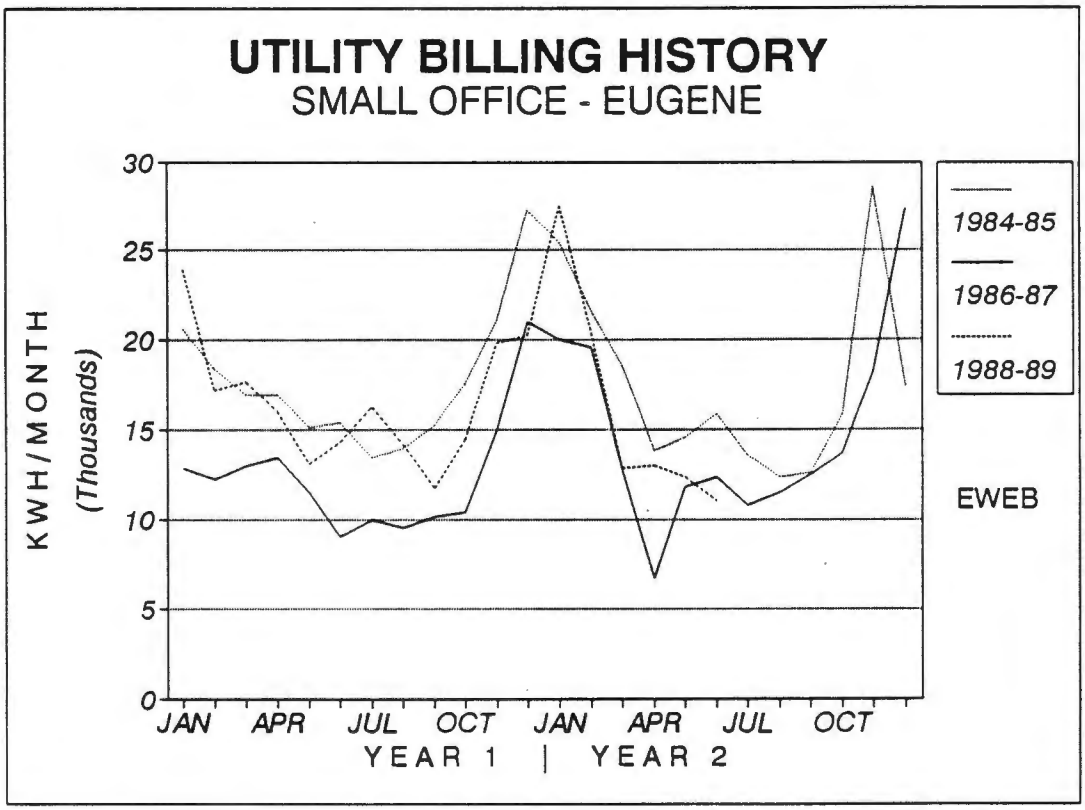
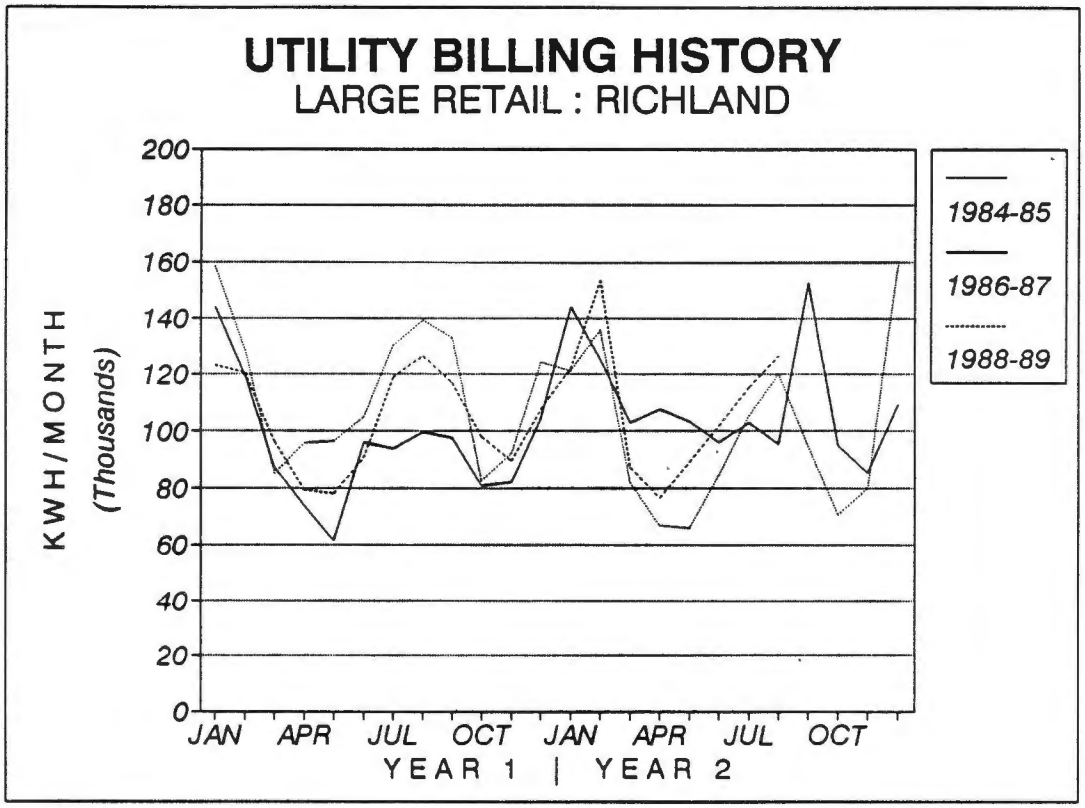

UTILITY BILLING HISTORY
SMALL OFFICE - EUGENE
KWH/MONTH
(Thousands)
30
25
20
15
10
5
0
JAN
APR
JUL
OCT
JAN
APR
JUL
OCT
YEAR 1 | YEAR 2
1984-85
1986-87
1988-89
EWEB

FIGURE 4.2



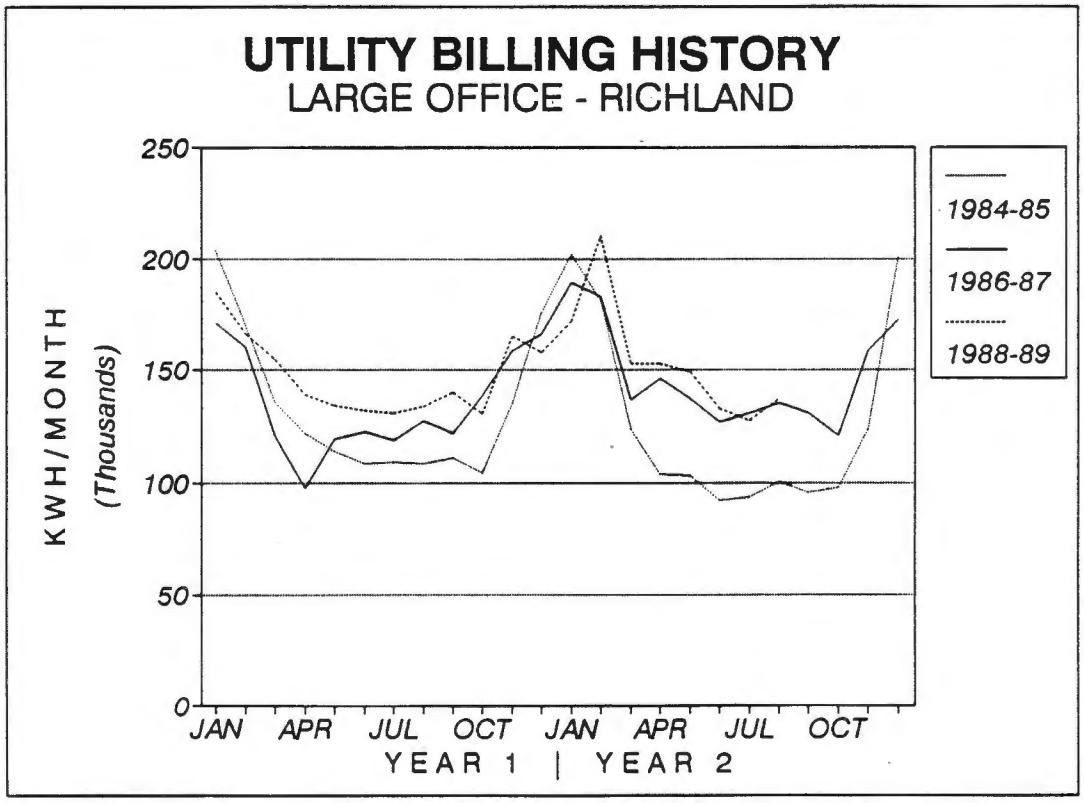
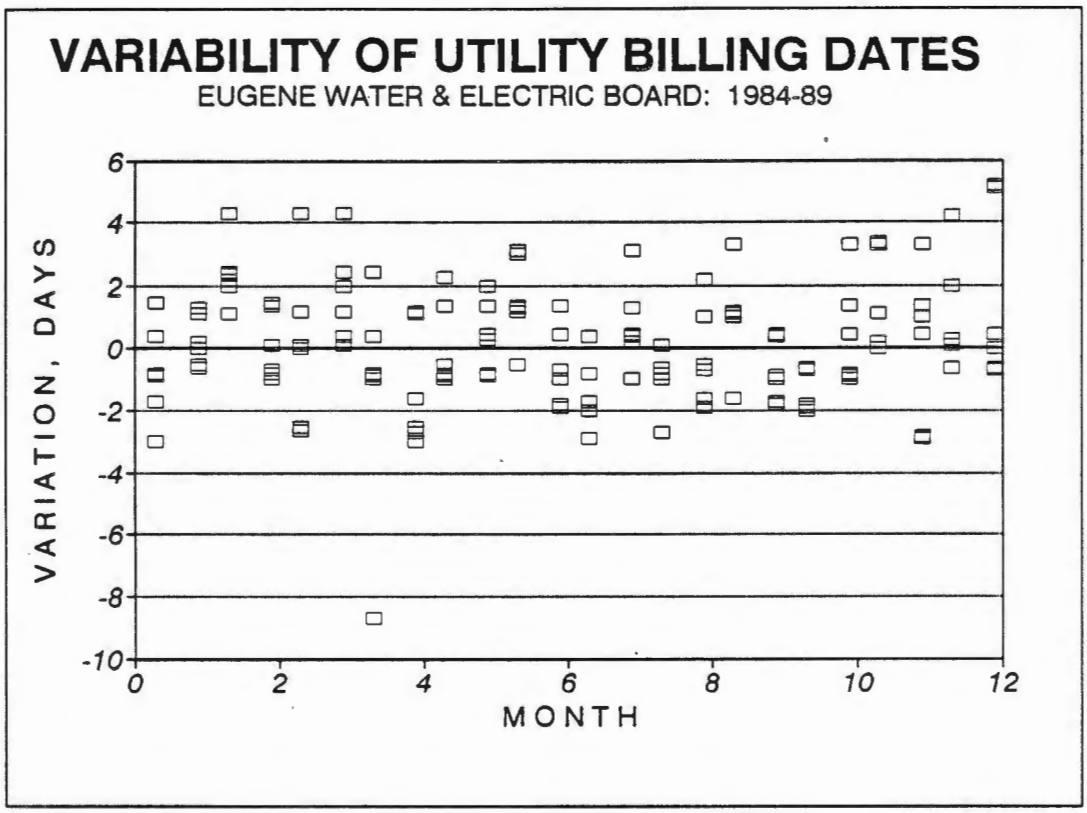
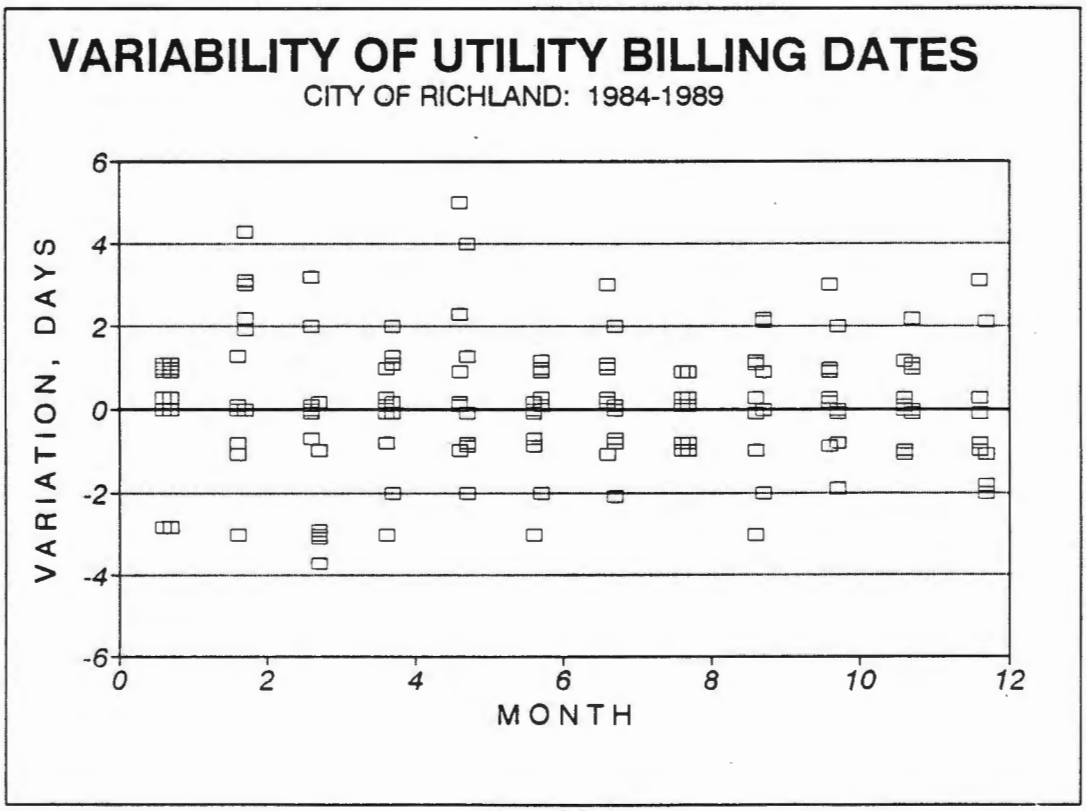


FIGURE 4.2 (continued)

FIGURE 4.3


VARIABILITY OF UTILITY BILLING DATES
EUGENE WATER & ELECTRIC BOARD: 1984-89
VARIATION, DAYS
6
4
2
0
-2
-4
-6
-8
-10
0
2
4
6
8
10
12
MONTH


VARIABILITY OF UTILITY BILLING DATES
CITY OF RICHLAND: 1984-1989
VARIATION, DAYS
6
4
2
0
-2
-4
-6
0
2
4
6
8
10
12
MONTH

Calendar adjustments, likewise, were not made by the modelers and have not been made in this report. A potential adjustment for calendar periods arises from the fact that all software simulation routines show their results by calendar months, while utility meters are usually read on some day of the month other than the first or the last. The shift can be in either direction, so it need never exceed 16 days, which means the two periods would be a half a month out of phase, or a little more than 4% of a year. However, it may also be convenient to identify a billing period by the month in which it ends; in the extreme, this practice could result in a shift that is nearly one full month out of phase.

The significance of a calendar shift is probably minimal. Annual energy consumption does not change, only the timing of the several peaks (heating and cooling). The peaks are more significant for demand modeling than for energy modeling. Modelers probably make a mental adjustment by being willing to accept a small shift, which may be evidenced as lateral displacement of the two curves (utility and simulation data) along a calendar time-line.

Nonetheless, the shift could be eliminated. Utility meter reading dates are not going to change, and statistical adjustments would require subjective inputs, but software houses could adapt their programs with relative ease: Just start the simulation by reading the weather file with an offset from the beginning, by the same number of days as the utility meter reading dates.

One subcontract modeling firm commented that it uses an Energy Information Service matrix of programs for energy management. Monthly utility billings are analyzed for the following:

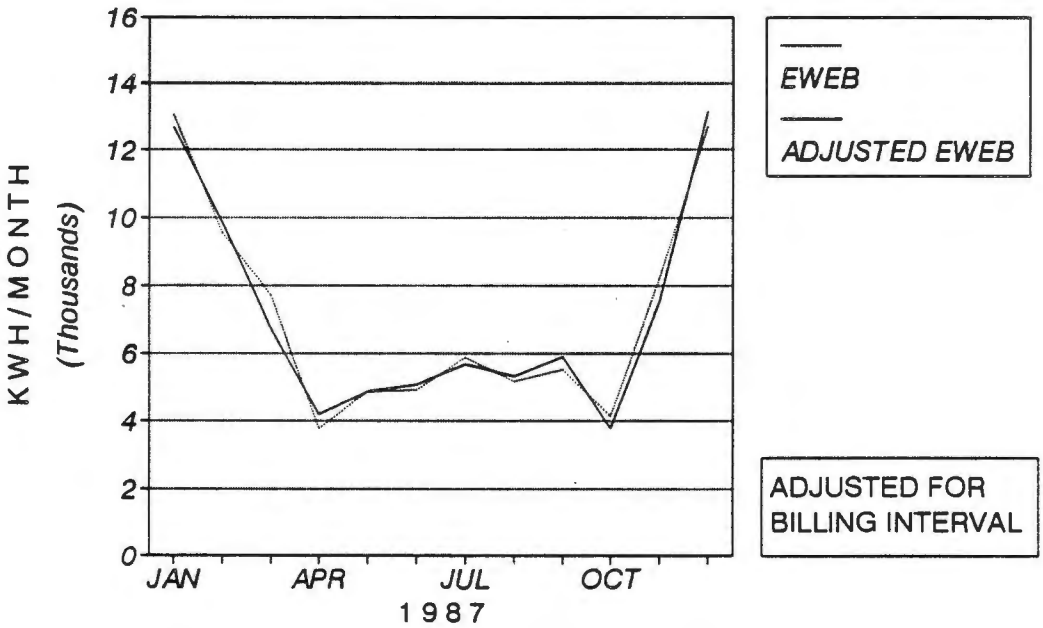
Historical Trend Analysis	Annual Energy Usage Summary
Billing Errors	Heating Degree Day Analysis
Demand Load Analysis	Cooling Degree Day Analysis
Maintenance Program Monitoring	Utility Rate Analysis
Three Year Historical Summary	Base Consumption Analysis
Service Day/Month Adjustment	Overbase Consumption Analysis
Monitoring of Effectiveness of Energy Conservation Programs	Utilization Factor Analysis
	Multiple Meter Analysis

4.4.3 Setting Modeling Goals with Utility Data

Even when a modeler has the utility billing history and has made reasonable adjustments to it, year-to-year differences in energy consumption will be evident. If the modeler is attempting to conform a model to the utility data, a decision must be made about which period and which data will be chosen as the modeling goal.

Year-to-year differences in energy consumption arise from changes in the building itself and in the way the building is used (its occupancy). If weather adjustments have not been made independently, they are an important part of the variability as well.

ADJUSTED UTILITY DATA
SMALL RETAIL : EUGENE



ADJUSTED UTILITY DATA
LARGE RETAIL : RICHLAND

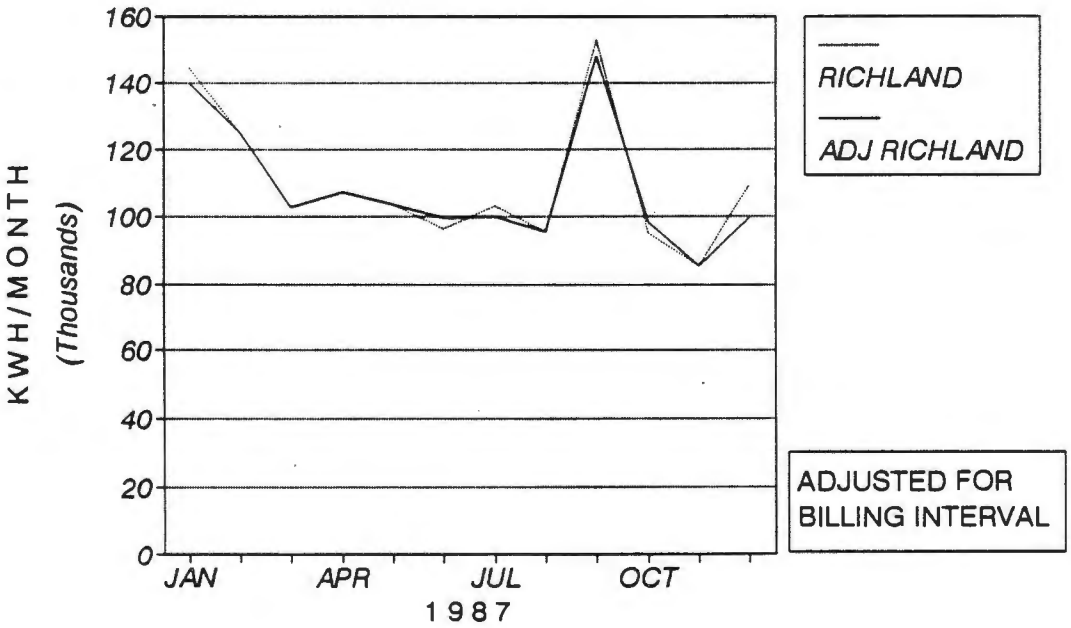
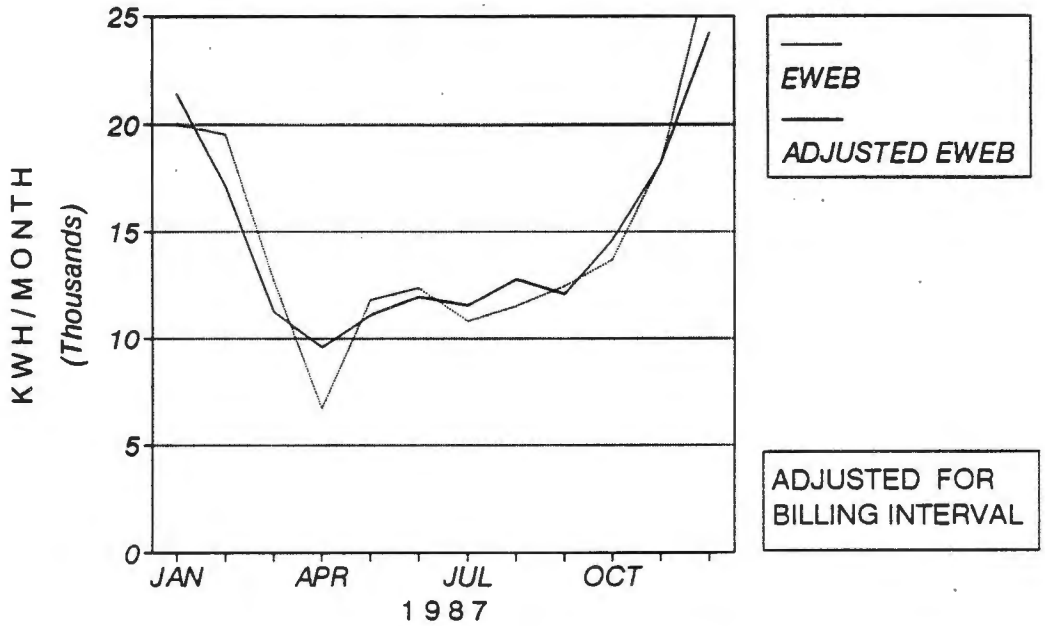


FIGURE 4.4

ADJUSTED UTILITY DATA
SMALL OFFICE - EUGENE



ADJUSTED UTILITY DATA
LARGE OFFICE - RICHLAND

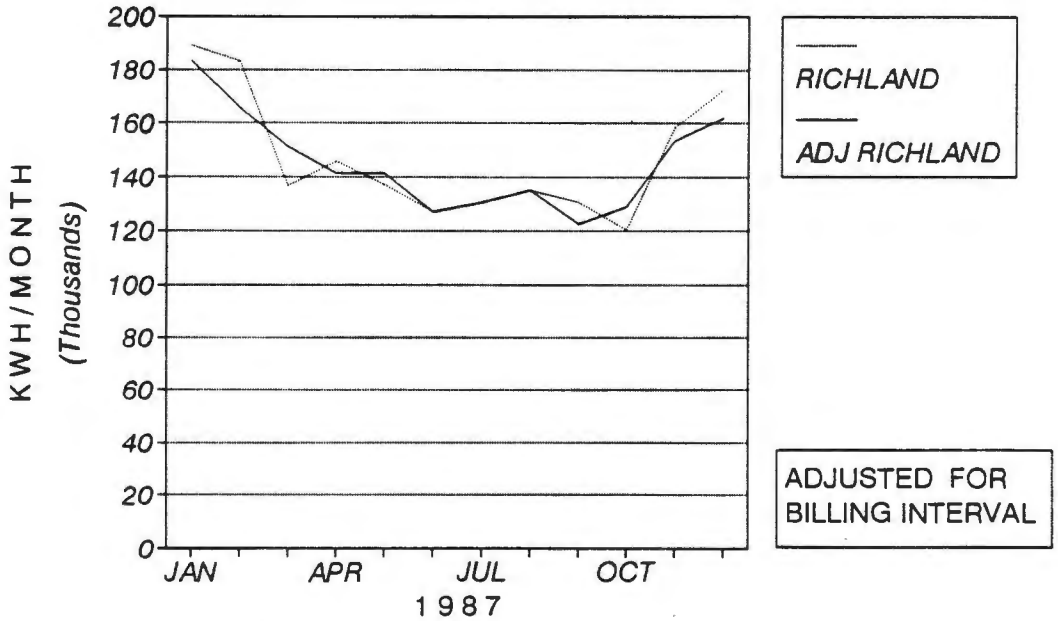


FIGURE 4.4 (continued)

Potential changes in a building cover a wide range. Structural changes, such as additions or window remodeling, are likely to be obvious. So too are major changes in equipment, such as replacements of basic HVAC plant. Less obvious are minor improvements; few will remember that a worn-out fan motor was replaced with a more efficient unit several years ago, or that window blinds were added to keep out the afternoon sun. Normal aging processes affect energy consumption, such as cracks in the wall as the building settles, and losses and embrittlement of weatherstripping. Maintenance procedures determine the neglect or replacement of filters, how quickly burned-out lamps are replaced, and how frequently timeclock settings are checked and adjusted.

Changes in the way a building is used can also be obvious or subtle. A new building tenant is a clear signal, but even the same tenant can change store or office hours, the number of employees, or the nature of the operation. A new policy on daytime or night setback temperatures, or on how much ventilation will be supplied, can have a dramatic effect on building energy consumption. Christmas decorations may be encouraged one year, but not the next.

All of these factors contribute to building energy consumption and therefore to the year-to-year range of values reported in the utility billing history. If specific readings appear to be out of line, the modeler will want to seek an explanation or alternatively may want to disregard a few isolated readings. But even with these adaptations, a range of values will remain.

Each of the four buildings used in the Evaluation of Software project show typical ranges of values. Utility data were considered for the 1984-89 period. Ranges during those years are graphed in Figure 4.5.

Each graph also shows the respective billing history for 1987. A number of the modelers chose the 1987 data for their modeling targets; 1987 was the most recent full-year of data the modelers had. The 1987 line in each graph, when compared to the range of values for 1984-89, gives a visual indication of how typical or atypical the 1987 year may have been.

Selection of an energy consumption target for a model is not always obvious or easily set by rule. The modeler's experienced, subjective decision is desired, with due consideration to factors that may have contributed to year-to-year changes. An obvious shift, explained or not, or a known change in building equipment or occupancy may be the basis for limiting the comparison to certain data and time periods.

As noted, modelers for the Evaluation of Software program were given 28 months of billing data for each building. Table 4.2 shows what they did with the data. Four modelers chose 1987 as their modeling targets. Three used the most recent 12 months (April 1987 through March 1988). Three averaged month-by- month data for calendar years 1986-87. Two averaged data for the most recent 24 or 27 months. While not conclusive, this tends to affirm the earlier observation, that modelers typically choose to use only one or two years of utility data in setting their modeling targets.

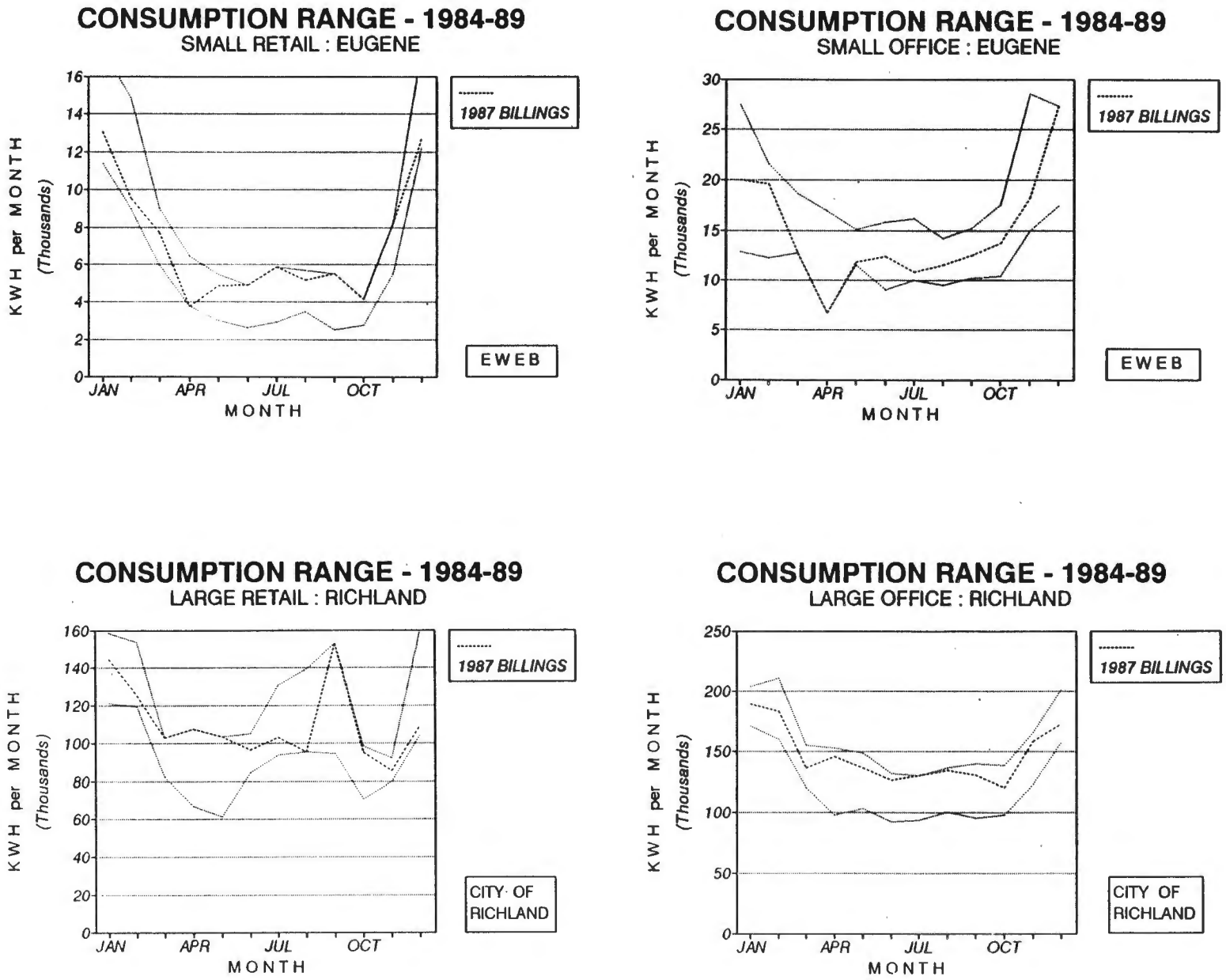

CONSUMPTION RANGE - 1984-89
SMALL RETAIL : EUGENE
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
1987 BILLINGS
EWEB
CONSUMPTION RANGE - 1984-89
SMALL OFFICE : EUGENE
KWH per MONTH
(Thousands)
30
25
20
15
10
5
0
JAN
APR
JUL
OCT
MONTH
1987 BILLINGS
EWEB
CONSUMPTION RANGE - 1984-89
LARGE RETAIL : RICHLAND
KWH per MONTH
(Thousands)
160
140
120
100
80
60
40
20
0
JAN
APR
JUL
OCT
MONTH
1987 BILLINGS
CITY OF RICHLAND
CONSUMPTION RANGE - 1984-89
LARGE OFFICE : RICHLAND
KWH per MONTH
(Thousands)
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
1987 BILLINGS
CITY OF RICHLAND

FIGURE 4.5

Table 4.2

Billing Data Targeting Techniques in Cycle 2

SOFTWARE	BUILDING Modeler	Small Retail	Large Retail	Small Office	Large Office
ADM-2	A		86-87		86-87
	H		12 mo	12 mo	
SEA	A	86-87		86-87	86-87
	B	86-87		86-87	86-87
	C		not determined		
	G			twice	
	J	86-87	1987		
TRAKLOAD	D	1987	12 mo		
	E	avg all data	avg all data		
	I	27 mo	27 mo	1987	1987
VCACS	D	1987			12 mo
	K	24 mo			24 mo
DOE-2.1	F	wtd	wtd	wtd	wtd

12 mo	most recent 12 months of data (e.g., Apr-Dec 1987 + Jan-Mar 1988)
24/27 mo	corresponding months averaged for most recent 24/27 months of data
1987	data for calendar 1987
86-87	corresponding months averaged for calendar years 1986 and 1987
twice	two separate simulations: once for 1986, once for 1987 (preferred)
wtd	subjective weightings with 1986 and 1987 data

Notes: Modelers were told the "field audit" date was January 1987. They were supplied with utility billing data for Dec '85 through Mar '88.

Modelers were given no instructions about which part or all of the data should be used to conform their models. After the models were completed, the modelers were asked what strategies they used to match the data. Answers are above.

Except as noted, modelers did not use averaging, billing period interval adjustments, weather normalization, calendar shifts, or anomaly adjustments. Little formal attention was given to multi-year comparisons or identification of anomalies, although those helped some modelers determine which data to use.

The effects of averaging are shown in Figure 4.6. Data are shown for three years, 1986 through 1988. The 1986-87 average is also shown. The average tends to smooth out anomalous "peaks" and "valleys", and therefore probably provides an improved modeling target as long as both years' data are representative and accepted.

An alternative procedure would be to model to the range of values observed during several years of experience. That is, the modeling goal would be to fit the simulated energy anywhere within the high-to-low envelope of observed values.

A more sophisticated and exacting approach, given sufficient data, would be to use statistics to determine either a single-valued "most probable" fit for each month of data, or a range of values that define an arbitrary confidence interval such as the 90% level. If a statistical approach is to be used, it probably should be incorporated into the simulation/analysis software, both as a way to encourage use of the tool and to minimize errors.

4.4.4 ELCAP Data

The Evaluation of Software project took advantage Bonneville's ELCAP program as a source of data. ELCAP stands for End-Use Load and Conservation Assessment Program.

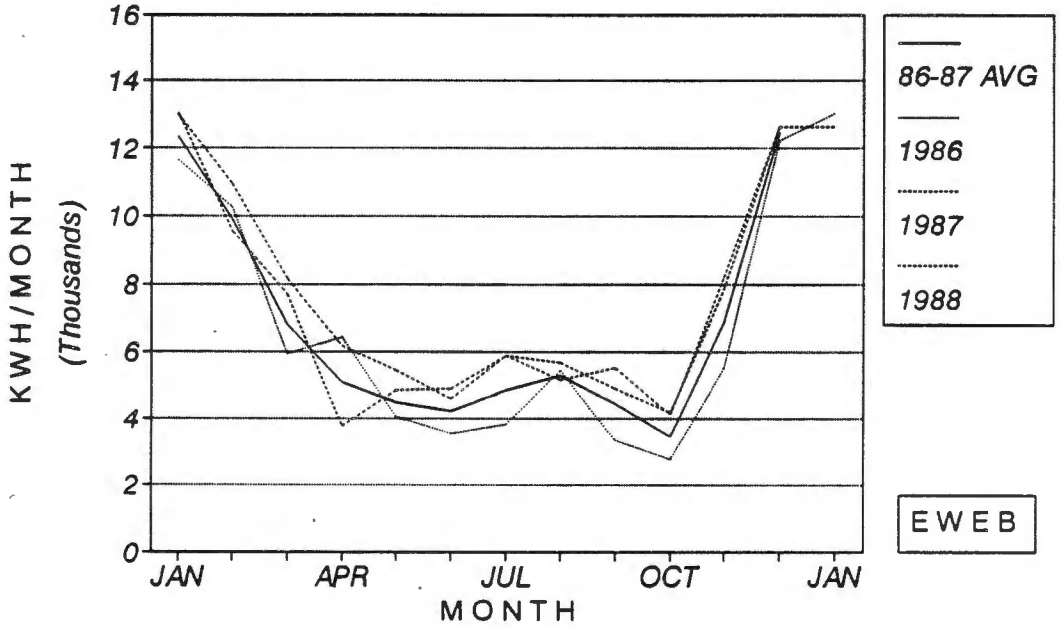
ELCAP is a study of how electricity is used by residential and commercial consumers within the Bonneville Power Administration service area. While data from utility billing records have been widely available in the past, more detailed information about actual energy end-uses, such as heating or lighting, has been minimal.

Energy meters have been installed in more than 450 residences, 50 apartments, and 140 commercial buildings of varied types.

The study, which began in 1983, is sponsored by Bonneville and managed by Battelle-Pacific Northwest Laboratories (PNL). It is designed to measure not only the amount of electricity used, but also the timing and purposes for its use.

PNL is collecting data for ELCAP through a system of energy end-use monitors connected to the electrical systems of each participating residence or business. Microprocessor-controlled data loggers measure and record electrical consumption at each site according to the various end-use electrical loads such as heating, cooling, and appliances. Data acquisition in commercial buildings may involve as many as 100 or 150 electrical energy distribution points.

BILLING DATA - AVERAGING
SMALL RETAIL : EUGENE



BILLING DATA - AVERAGING
LARGE RETAIL : RICHLAND

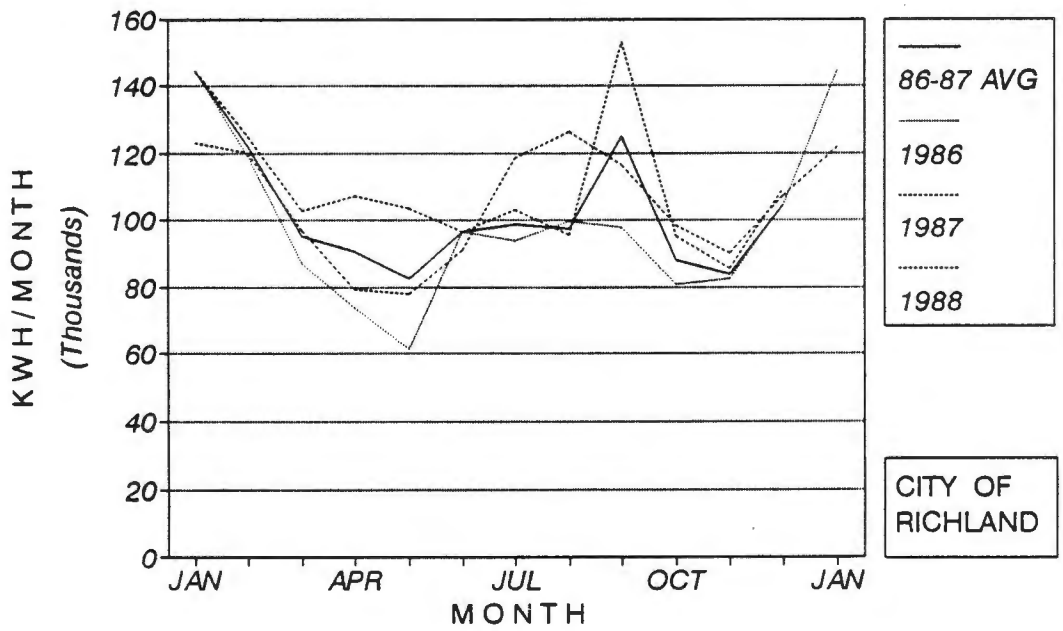
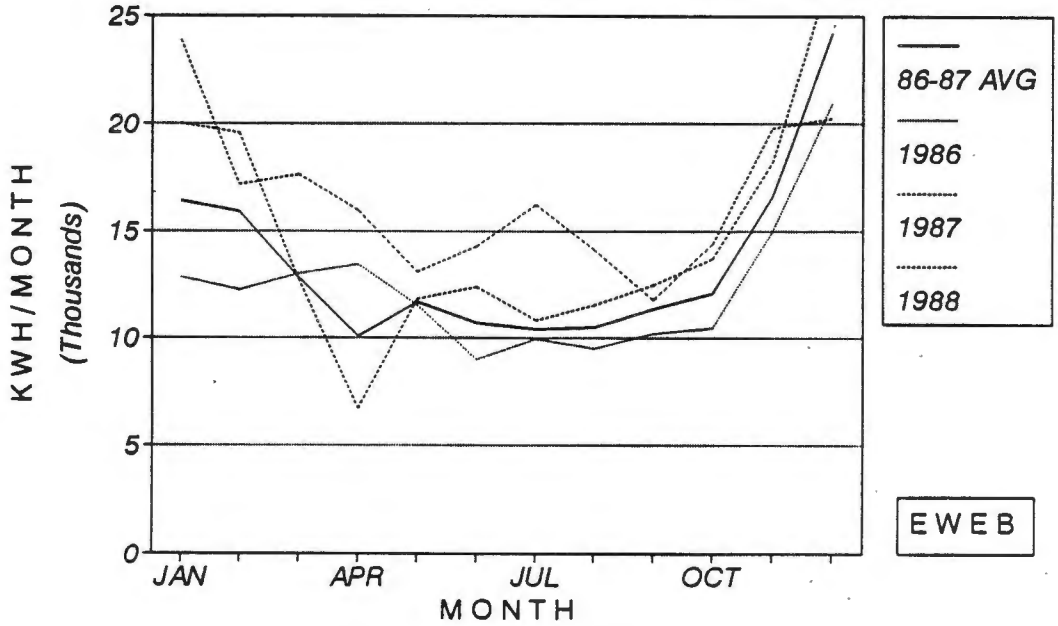


FIGURE 4.6

BILLING DATA - AVERAGING
SMALL OFFICE - EUGENE



BILLING DATA - AVERAGING
LARGE OFFICE - RICHLAND

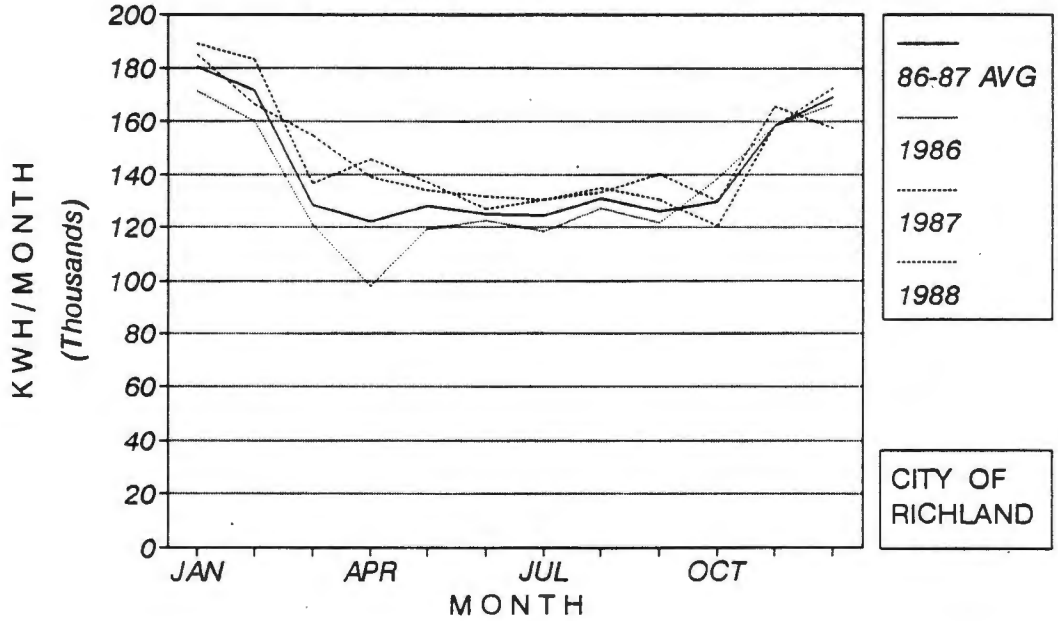


FIGURE 4.6 (continued)

The data-logging instruments not only record load measurements at regular intervals but also transmit the data periodically to a central computer at Battelle's laboratories in Richland, Washington. Generally, data transmissions occur every two weeks. Meterological information is also collected and transmitted by sensors installed at many participating sites. The sensors measure outdoor temperature, humidity, wind speed, and solar insolation.

PNL maintains a data management and analysis system to interpret, summarize, and report the data. Bonneville, regional planning agencies, and local utilities use the information to make decisions about the management of the Northwest's electrical resources.

The four buildings that served as the basis for simulations in the Evaluation of Software project were selected in part because they are ELCAP buildings and therefore metered end-use data is available for each. ELCAP data was supplied for this project, spanning the period January 1987 through March 1988. The ELCAP monthly totals are displayed in Figure 4.7 and tabulated in Appendix F.

Battelle used a data logger and recorded data on multiple channels dictated largely by metering requirements. Eventually the data elements were summed by end-use categories defined by Battelle (see Chapter 5). Only summary information (by month and end use) was provided for the Evaluation of Software project, with no opportunity to check those results against the original tapes.

Additional information from ELCAP, including meterological data, would have been constructive. Several contacts with PNL about correcting erroneous data left the impression that while ELCAP may have the data, accessing the information is difficult; efforts for this project were therefore concentrated on the data shown.

The ELCAP data have been used extensively in the Evaluation of Software project, but they have several limitations of their own. One of the limitations is that little more than one year of ELCAP data was provided. ELCAP data vary from year to year, however, for many of the same reasons that contribute to utility billing variability. The limited duration of data means there was no opportunity to explore this variability at the end-use level. The 1987 data set has been used as if it were unchanging from year to year, when in fact this obviously is not the case.

Although ELCAP data were recorded hourly, and the ELCAP computer can be instructed to make summaries for any desired time periods, data for this project were totaled by calendar month. Thus, the information supplied coincides with the calendar-month periods used in building energy simulations, but in general it did not coincide with the utility billing data.

Nonetheless, it was possible to make a reasonable cross check for 15 months of data from the two metered sources - from the utilities and from ELCAP. This comparison is included in Figure 4.7. In general the results are quite close, especially when allowance is made for the shift in calendar periods and billing interval adjustments.

Three major discrepancies were noted however, with two of them showing prominently in the graphs. All obvious discrepancies were in the two buildings in Eugene.

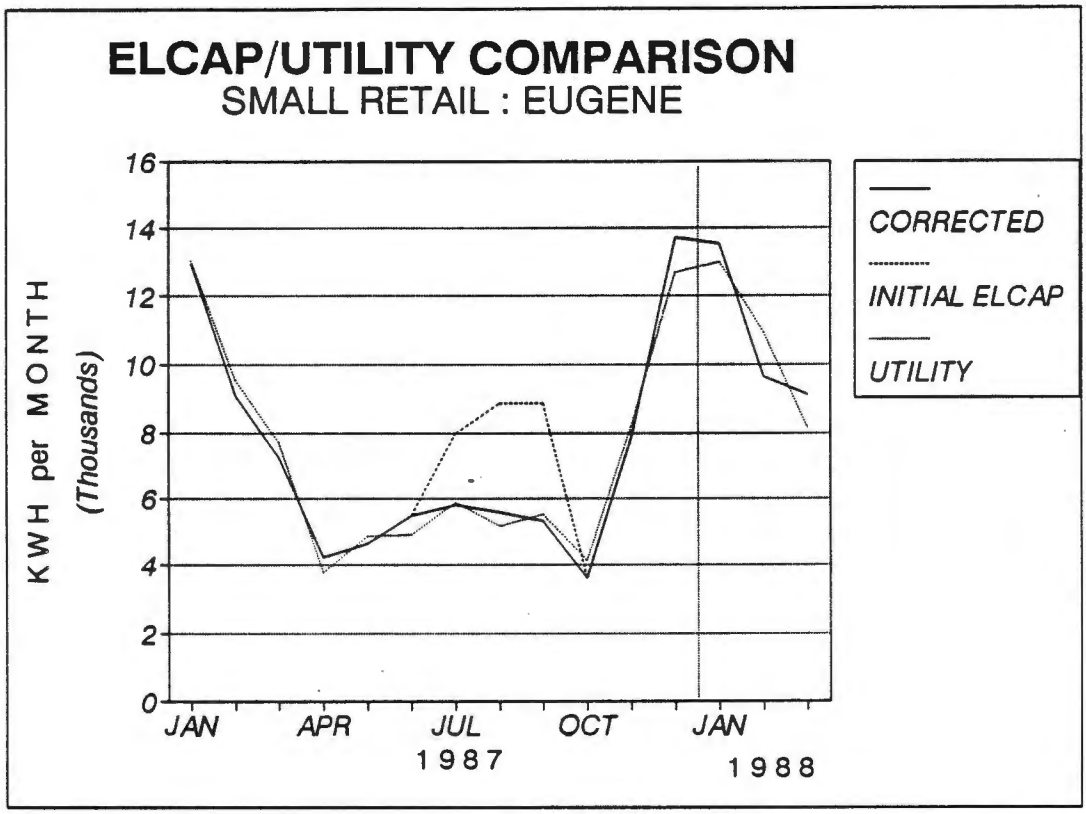
The July-August-September ELCAP data for the small retail building did not initially agree with the utility's records for the same period. The summer energy use pattern in the utility billing history was consistent from year to year, thus marking the ELCAP data as suspect. Modelers were therefore instructed to disregard the ELCAP data for those three months. After checking its records, Battelle issued corrected data for the three months, as shown in the graph.

A similar situation was found for the small office building: data from Battelle and the utility did not agree for late 1987 and early 1988. Again, modelers were told to disregard data for the affected months. Upon further checking it became clear that the reported ELCAP data for October on was not for the small office building at all, but rather data substituted from another series, for another building. Although Battelle made efforts to remedy the omission, corrected information never was provided in time to be used for the Evaluation of Software project.

The third problem was detected when one of the modelers was constructing a model for the small office building, and it became obvious to him that the ELCAP data element reported for exterior lighting during one month was not only anomalously large compared to other months, but also totally impossible. Again, after review, Battelle was able to provide corrected data.

Data collection procedures for ELCAP were designed with careful safeguards, such as crosschecking of end-use metering totals against a master meter, yet those three obvious and important errors were encountered in 15 months of data for four buildings. In the largest error for any one month, the correct value was 66% higher than what was originally stated. While two of the three errors have since been corrected, it is not unreasonable to suspect that other, undetected errors remain.

The experience with ELCAP data demonstrates that no one source of information should ever be accepted as an "absolute" standard. Quite obviously the caveat applies as much to the ELCAP program as it does to any other. In the Evaluation of Software project report, ELCAP data (with corrections) have been used extensively as a standard of comparison for the results obtained from simulation models. It is important, therefore, to remember this admonition.


ELCAP/UTILITY COMPARISON
SMALL RETAIL : EUGENE
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
JAN
1987
1988
CORRECTED
INITIAL ELCAP
UTILITY

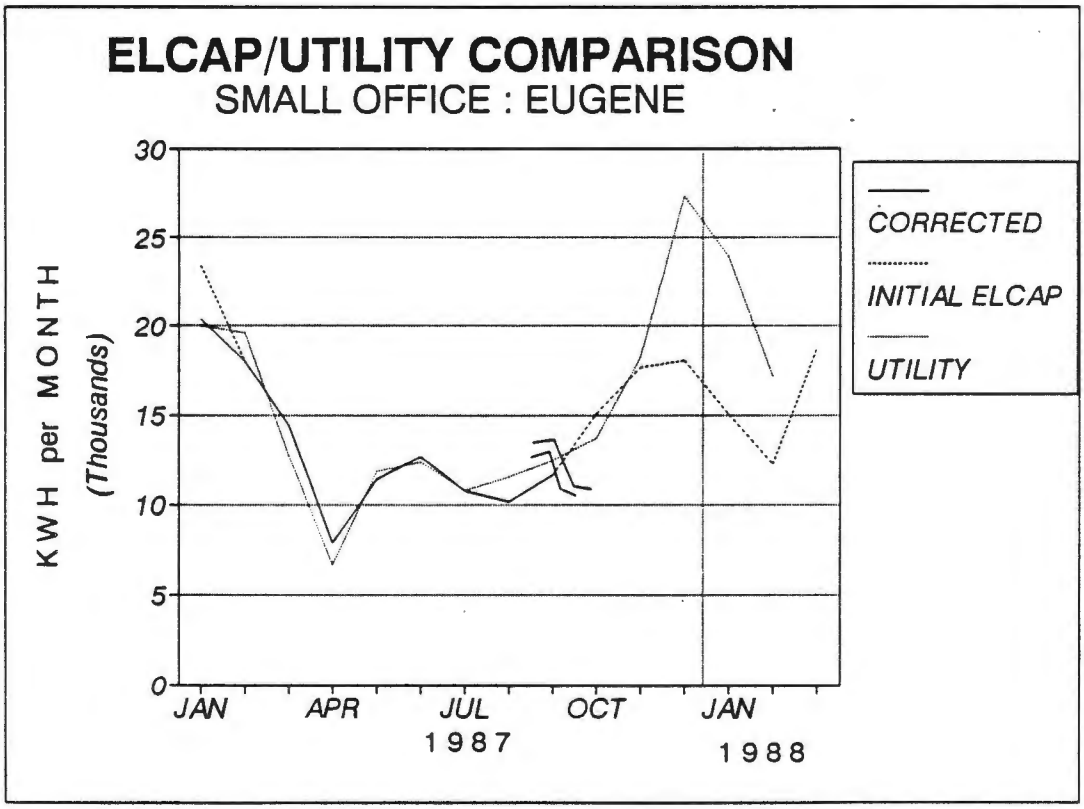
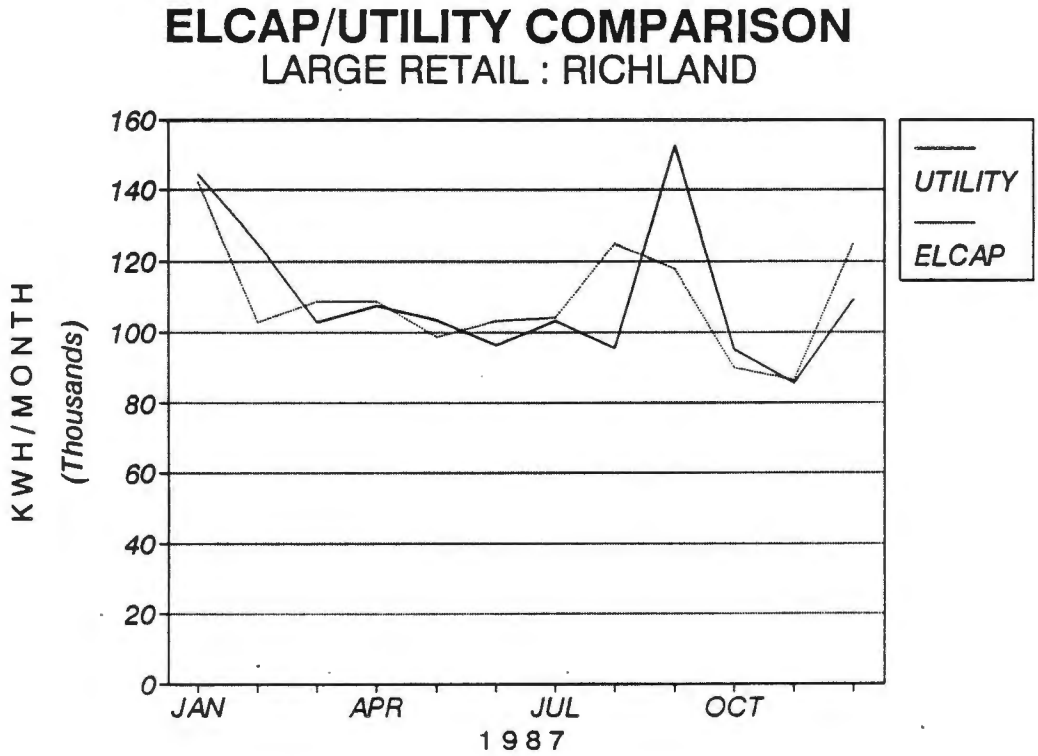

ELCAP/UTILITY COMPARISON
SMALL OFFICE : EUGENE
KWH per MONTH
(Thousands)
30
25
20
15
10
5
0
JAN
APR
JUL
OCT
JAN
1987
1988
CORRECTED
INITIAL ELCAP
UTILITY

FIGURE 4.7



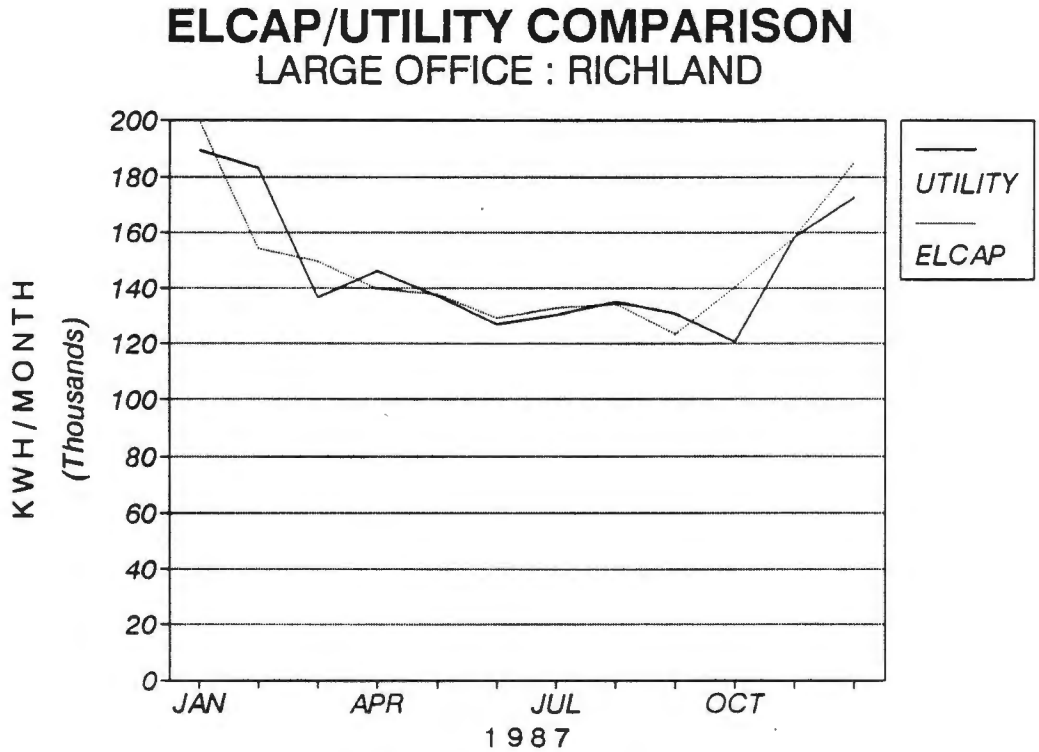


FIGURE 4.7 (continued)

4.4.5 CREUS Data

The Evaluation of Software project took advantage Bonneville's CREUS program as a further source of data. CREUS stands for Commercial Retrofit and End-Use Study.

The Bonneville Power Administration established the CREUS program to evaluate the accuracy of energy savings estimates in commercial audits, and to track energy usage effects of changes in building operation, equipment, use, structure, and maintenance procedures. Using field metering, the program documents actual reductions in commercial building energy use resulting from the installation of energy conservation measures.

The program is under contract to Puget Energy Services, Inc. (PESI), Bellevue, Washington.

Candidate buildings for the CREUS program had to be commercial facilities audited under either the Commercial Audit Program (CAP) or the Purchase of Energy Savings Field Test (PESFT) program, and participating in the end-use metering efforts of the End-Use Load and Conservation Assessment Program (ELCAP). Eighteen buildings were targeted for the CREUS program, including restaurants, banks, hotels, offices, and retail facilities.

Buildings in the program have been subjected to further audits, modeling, and simulations. ASEAM-2 was used to select recommended Energy Conservation Measures, including lighting, HVAC, and building envelope. Retrofit installations were made in the buildings to implement the ECMs. Quarterly site visits and continued field monitoring of energy consumption provide information about the savings actually realized from the ECMs. Comparisons are being made between projected and actual savings, and reasons for differences will be analyzed. A final report is due in November 1990.

The CREUS program proved to be a convenient source of information for the Evaluation of Software project because data had already been compiled from several earlier programs. CREUS project files were the primary source of descriptive information about the four buildings selected as testbeds for the current project. Descriptive building data files are discussed in the next chapter.

CHAPTER 5: ROUND ROBIN SIMULATION STUDY

A "round robin" comparison of building energy modeling and simulations was conducted in three cycles. The first two cycles focused on constructing representative building energy models (base building models). The third cycle allowed further adjustment of the model, but emphasized Energy Conservation Measures (ECMs). Wide differences were found in base building models, but the differences diminished with the number of iterations (cycles) and as the modelers received additional information. Wide differences were also found in the selection and valuing of ECMs. The differences appear to be primarily due to modeler choices, but the software is a factor as well.

5.1 Study Procedures

Overview

The Evaluation of Software project included a comparative study component for modeling and simulation of energy in four buildings from the ELCAP and CREUS programs. Eleven modelers participated in the study, using five software programs. The study was performed in three cycles, each of which provided progressively more information for the modelers.

During Cycle 1, modelers prepared simulation models and conducted energy simulations for one or more existing buildings based on the data contained in building descriptive files. The descriptive files did not include utility billings or other energy data for the buildings.

During Cycle 2, modelers received additional data in the form of actual utility billing data for the buildings, and adjusted their base building models to reflect the "best" fit with the historical energy data, consistent with the modeler's experience and judgement.

During Cycle 3, modelers received metered end-use data for the buildings from the ELCAP program, and had the option of reflecting that information in further revisions to the base building models. The resulting models were used to simulate Energy Conservation Measures. Modelers were asked to report their six best ECM results.

5.1.1 Sample Selection - Software

The Evaluation of Software project used five software packages to represent the available range of energy simulation software for commercial buildings.

The five software packages were:

software	version	modeling type	source	
ADM-2	4.1(R)	hourly	ADM Associates	Sacramento, CA
SEA	6	bin	Ferreira & Kalisinski	East Mansfield, MA
TrakLoad	3.1	bin	Morgan Systems	Berkeley, CA
VCACS	9,10	typical day	Volt Energy Management	Portland, OR
DOE	2.1 C/D	hourly	Lawrence Berkeley Lab	Berkeley, CA

The five software packages were pre-selected by the Bonneville Power Administration. Bonneville wanted to be sure the software studied would include examples of the three major modeling types - hourly, bin, and typical day. Bonneville also wanted to be sure the software would be representative of common practice in the Pacific Northwest, on present and earlier energy conservation programs. The most recent version of each software package was used in the Evaluation of Software project.

DOE 2.1 was specifically included in the project because it has undergone repeated development with U.S. Department of Energy funding, is widely known and used, and has been extensively documented including reports of validation testing. DOE 2.1 has been used more for software comparison purposes than probably any other building energy simulation software.

Selection of the software sample was again considered during the initial stage of the project. Software development is dynamic and patterns of usage change. The following were suggested as possible alternatives to one or more of the original selections:

Software	Modeling Type	Source
ASEAM	bin	ACEC Research and Management
ENERGY	hourly	Elite Software
ENTREE	typical day	Volt Energy Management
HAP	hourly	Carrier

ASEAM was excluded from further consideration because it had already been chosen for the CREUS program. CREUS included modeling of some of the same buildings selected for the Evaluation of Software project. The parallel work offered an opportunity for comparing one more software package. However, ASEAM comparisons were not added to the Evaluation of Software project.

ENTREE would have been a direct replacement for VCACS, since VCACS development has been frozen and ENTREE is in a sense its latest version.

Still other software might have been equally suitable. A larger sample would have added to the database. The final decision, however, was to proceed with the original software choices.

5.1.2 Sample Selection - Buildings

With concurrence from Bonneville, the prime contractor selected two office buildings and two non-food retail buildings from among the buildings for which Bonneville has both ELCAP and CREUS data. They were chosen for the availability of good data, to be typical of those building types, suitable for round robin simulations, and conducive of good owner-operator cooperation.

The four buildings selected for the project are listed below. All are existing buildings. In the context of the earlier CAP program, the two smaller facilities would have been classed as "level 2" bin buildings; the two larger facilities probably would have been rated as "level 3" hourly buildings.

Building	Facility Type	Approx Area	Location
1	Retail/Dry Goods	5000 ft^2	Eugene, OR
2	Retail/Dry Goods	70000 ft^2	Richland, WA
3	Office	6000 ft^2	Eugene, WA
4	Office Complex	50000 ft^2	Richland, WA

5.1.3 Descriptive Building Data Files

The contractor established a descriptive building data file for each building. Data was compiled with files from the CAP, ELCAP, and CREUS programs. The descriptive files provided partially interpreted data for the buildings. They contained tabular, narrative, pictorial, and graphic information, including some drawings. They typically avoided numerical values for building thermal components, such as wall R/U values, since these were supposed to be subject to modeler interpretation. For Cycle 1, the descriptive files did not include any utility billing, fuel data (other than type), energy consumption records, or metered energy data; this information was added during Cycles 2 and 3.

Edited copies of the descriptive files are reproduced in Appendix D. The descriptive building data files were supplied to each modeler participating in the project, in place of field audits.

The round robin comparisons therefore <u>did not</u> extend to field audits. The descriptive building data replaced the field work which a modeler normally would have conducted as part of an overall energy audit of an existing building. It is believed that variability in field audits has already been explored adequately by results from the ELCAP program and the analysis contained in the "Evaluation of the Commercial Audit Program" report.

Nonetheless, just as typical field audits are less than perfect or fully comprehensive, the same was true of the descriptive building data files.

When sufficiently critical data is missing in an engagement with a field audit, someone returns to the field to obtain it, or else the modeler uses his professional judgement to fill in the missing data with assumed values. A similar standard was established for the Evaluation of Software project: Modelers were told to ask the prime contractor for missing information, but only if it would have been critical enough to "send someone back to the field".

There were few inquiries. Supplemental descriptions were issued in response to inquiries wherever possible. The modelers did, indeed, call on their professional judgement to fill in the rest of the data.

5.1.4 Modeler Selection and Assignments

Building energy modeling and simulations were conducted by the prime contractor, five subcontractors, and two staff members of the Bonneville Power Administration. The project team was identified earlier; more extensive information appears in Appendix B. Participation of subcontractors was sought primarily to introduce a range of practices and variables in the modeling process. In all, eleven modelers are known to have participated in the program.

Among organizations specifically notified of the opportunity to participate in the project's modeling activities were a half dozen electric utilities. The subcontract group preferably would have included at least one utility. None of the utilities expressed interest in participating, however, due possibly to other work load commitments, or perhaps because they did not perceive the study efforts to have the same direct impact on their customers as their normal energy conservation efforts.

The primary factor in selecting modelers was the experience they offered in conducting commercial-sector building energy audits for the Bonneville Power Administration - such as Energy Edge and the current Energy Smart Design. These programs share a common requirement, that Bonneville and its contractors use computer software models to simulate the building energy. It was desired that typical skills of energy conservation consultants be represented in the Evaluation of Software project.

Modelers assigned to the work were required to have broad experience with respect to the variety and breadth of situations modeled, familiarity with modeling tools, and exposure to building design.

Subcontractors had to be licensed to use, offer the latest version of, and have specific experience with one or more of the software packages used in this project. Subcontractors were not assigned buildings they had modeled before, or permitted to use software which they had designed and sold.

These goals for subcontractor selections were met, including modeler experience with energy conservation activities and building energy modeling; but the range of experience with the specific modeling tools was wider than expected, since several of the modelers had only limited prior experience with the software they used on the project.

5.1.5 Base Building Models

Each modeler, working independently and without access to the buildings other than the data in the descriptive files, interpreted and applied available information to construct a simulation model and conduct an analysis of building energy for each of the assigned building/software sets. Using the specified software, the modelers simulated the building energy and reported the results.
The chosen models and modeling assignments are shown in Table 5.1.

TABLE 5.1 MODELING ASSIGNMENT MATRIX

BUILDING:	1 Small Retail	2 Large Retail	3 Small Office	4 Large Office	Total Models
SOFTWARE:					
ADM-2	[A]	A		A	2
		H	H		2
SEA	B	C	B	A	4
	J	J	G		3
TRAKLOAD	D		D		2
	E	E	I	I	4
VCACS	D			D	2
	K			K	2
DOE-2.1	F	F	F	F	4
TOTAL	7	6	6	6	25

Modelers are identified by alphabetic characters
The ADM-2/Small Office model was a supplemental assignment, for the sensitivity study

Most modelers pointed out deficiencies and inconsistencies in the data that they would have challenged during a normal energy conservation study; the questions normally would have stimulated further data collection. The modelers were asked to use their experience and professional judgement to interpret and apply information in the descriptive building data file as necessary to bridge the problems and construct the models.

5.1.6 Procedures

With few exceptions, the procedures specified for the round robin model-building and energy simulation activities were essentially what modelers do in normal energy conservation engagements for commercial buildings, for one of Bonneville's energy conservation programs such as the Commercial Audit Program (CAP). There were these differences:

- Information representing a field audit of each building was supplied in the building description files. Modelers did not visit the building sites or contact the building owners.

- Descriptive information about the building (typical of a new structure) and utility billing histories (usually provided for an existing building) were issued in separate installments; the corresponding modeling activities were accomplished in two Cycles.

- The prime contractor reserved the option to make changes in the base building models at Cycle 3, anticipating an attempt to conform the models before the ECM simulations. The option was not exercised.

- All determinations of Energy Conservation Measures were made as single measures rather than allowing for their cumulative effect. The desired number of ECMs (six) was specified in advance.

- No reports or recommendations were issued to building owners. This was a study program only.

5.1.7 Reports

Internal reporting requirements for the modeling and simulation activities were simple, but in the aggregate - considering the number of models, cycles, ECMs, and sensitivity measures simulated - extensive data was generated. Responses from individual modelers ranged from comb-bound, well documented reports to a few sheets of "bare-bones" data.

Modelers were asked to keep careful records and to submit input listings, quantified output information, and narrative comments:

<u>Input data</u> were reported both in hard copy form and on computer disk. Input listings show all input parameters and values used to construct the model (number and boundaries of zones, heating and cooling types, air handling types; specifics for each zone including infiltration rates, internal and external loads, areas, U/R values, hours of occupancy and operation, etc.).

<u>Output reports</u> show month-by-month energy consumption values for each major building end-use category (heating, cooling, lighting, etc.).

<u>Brief narrative comments</u> clarify the modeling process by recording assumptions adopted, allowances made for software limitations, and problems encountered and how they were solved.

Subcontract agreements gave the prime contractor the option to ask for additional reporting of input and output data on standard report forms used in Bonneville's Commercial Audit Program (CAP). The option was discarded when it was recognized that little or no benefit would have been obtained from the additional effort.

An important part of the Evaluation of Software study was the opportunity for the modelers to comment freeform about their experiences with building energy simulation software. The modelers were invited to submit observations and opinions, recommendations and conclusions, including anecdotal statements about the problems, situations, incidents, and solutions. Some of those comments appear at appropriate places in this report.

5.2 Input Data Files, Parameters, and Values

Construction of a base building model requires that a large number of parameters be valued and entered into one or more input data files. Many of the parameters, such as building size and material properties, are required inputs for any of the software packages.

Input data for the various software programs is not necessarily identical, however. An obvious example is the omission of extensive scheduling information from bin-type models, compared to what is required for hourly modeling.

Modelers were granted complete discretion, consistent with their experience, to use any appropriate values. But while all the modelers were working to a common set of building descriptions, some of the input values show considerable variability.

The values of input parameters used for Cycle 1, 2, and 3 models in the Evaluation of Software project are tabulated on a spreadsheet in Appendix G. Not all parameters are listed, but representative values and many of the most important details are shown. Some shortcuts were needed for practical presentation; for example, window areas were tabulated in a single total rather by direction and zone.

The relative significance of each difference in input values is not immediately apparent, although the sensitivity study reported later could be used to help make those determinations. Effects on component loads may be more obvious, such as energy for outdoor lighting that changes in proportion to the wattage entered, or the expectation that a 5% difference in wall areas will be less significant than a 50% difference in the wall thermal conductivity.

Little or no attempt has been made to relate specific parameters or values with the reasons why they were selected. In general, differences in input data arise from software limitations, software input requirements, modeler/software interfacing, modeler interpretations, and modeler choices.

Software limitations may be the most important of these factors. A bin type simulation model, as noted, is limited in its scheduling capabilities, and therefore calls for only limited input of schedule information. The ADM-2 software permits only one type of glazing and window shading in any one zone, while many allow different values for each orientation. The VCACS software used in the study is limited to 6 zones; a more detailed zonal analysis on another software package would have to be adapted for VCACS (the DOE 2.1 model of the project's large office building used 27 zones, but it required 2 hours of VAX computer time for each run.).

Software input requirements vary in format and content. Further examples may help. The VCACS software used in the project calls specifically for doors to be identified for each zone, by number, area, thermal characteristics, and infiltration leakage characteristics; many other software packages expect the modeler to lump the doors with the walls. TrakLoad uses fairly coarse precision for input variables; exterior lighting can be entered to the nearest 0.1 kW; a 50-watt distinction cannot be recognized.

Modeler/software interfacing may determine how particular values are entered. Wall areas may be either gross or net of windows; other values may be decimal or percent; outside air may be expressed in air changes, cfm, or as a percentage of supply volume; the fraction of heat from lights may go either to the plenum or the conditioned space. Some differences may be accommodated as simply as replacing an R value with its reciprocal, a U value. At other times the alternative input can affect the simulation, as may occur with the outside air options. Format differences always carry the risk of a modeler's input error, especially when the software's input and output formats are inconsistent (net and gross walls in SEA), or when the units are not even shown (ADM-2). Default values provided in most software packages tend to bias the results because there is a tendency of convenience (even among experienced modelers) to accept the defaults, although they differ from one software package to the next.

Modeler interpretations are often required. Supply air, outside air, and infiltration rates are rarely known, and must be estimated. Value estimates may likewise be needed for surface reflectance, hot water consumption, occupant levels, and other parameters. No two modelers are likely to make the same estimates, although in the Evaluation of Software program a single modeler constructing two models of the same building (with different software) was likely to use the same values in both.

Modeler choices are also of prime importance in explaining differences between simulation models. Once the problems in identifying and/or interpreting "real" values have been resolved, modelers may opt to depart from them, making further changes intended to improve the model. If, for example, a building is known to consume a certain amount of energy but a first-try model does not yield consistent results, the modeler will seek reasons and responses. The quest need not be limited to a search for better information: Modelers are not constrained to use "actual" values in the input files. The modeler may also "tweak" the model to adjust its output. Tweaking is accomplished by changing the values of the input parameters just to force the output. Changes may related to real-world conditions (e.g., rationalizing a change in the modeling setpoint

temperature because occupants can "play" with the thermostat); but at other times the changes are simply whatever is necessary to achieve a desired result.

A few comments should be made about specific input parameters and the values selected for them in the Evaluation of Software project.

Weather files, in most instances, came from the software house that supplied the software package used in the simulation. A file was typically for the nearest community already in the modeler's inventory of weather files; if another file was procured it was the nearest one the supplier had available.

Due to differing supplier approaches, some weather files are accessible to modeler input and others are not. Of the software used in the Evaluation of Software program, SEA and DOE 2.1 were the most accessible; they were also the most frequently changed.

Table 5.2 shows the weather files used in Cycle 1 of the Evaluation of Software project; only a few changes were introduced in Cycles 2 and 3. Files for the Richland buildings were identified with Richland, Moses Lake, Pendleton, Spokane, Yakima, Walla Walla, and later with Hanford. Files for the Eugene buildings were identified with Eugene, Salem, and Portland.

One model of the small office building in Eugene was run with a Richland file; when challenged, the modeler responded: a) the two communities have similar annual heating degree days, b) in his experience it wouldn't make much difference, and c) this was the closest weather file he had for that software [a closer file was available from the software supplier].

A cursory examination of degree day data for Eugene and Richland might suggest the two communities do indeed have similar climates. Eugene has 4726 base 65F heating degree days per year(1), while Richland experiences 4892(2). On the other hand, the comparative winter design temperatures (97.5%) are 22F for Eugene, 11F for Richland; the summer design dry bulb temperatures (2.5%) are 89F for Eugene, 96F for Richland(3).

Figure 5.1 compares the frequency distribution of 5-degree temperature bins for the two cities. Clearly, there are distinct differences in the summer and winter temperature regimes.

The sensitivity study (Chapter 6 of this report) later looked at the effect of transposing weather files between Richland and Eugene, and found annual energy effects ranging from 2% to 18%, with an average near 10%. However, the model cited was not off by 18% or 10%; it had simply been adapted until it met the comparative energy goals anyway - the wrong weather file notwithstanding.

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1. ASHRAE Fundamentals 1981; Chapter 53 of the State of Oregon 1990 edition of the Uniform Building Code lists 4739 degree days.
2. NOAA data, from Oregon State Extension Service.
3. ASHRAE, op cit.

TABLE 5.2 CYCLE 1 WEATHER FILES

Location: Eugene

Software	Modeler	File/Community	Source
ADM-2	H	RICHLAND	supplier (1)
SEA	A	PORTLAND	supplier
	B	PORTLAND	supplier
	G	EUGENE	modeler (2)
	J	EUGENE	modeler
TRAKLOAD	D	EUGENE	supplier
	E	EUGENE	supplier
	I	EUGENE	supplier
VCACS	D	PORTLAND	supplier
	K	EUGENE	supplier
DOE 2.1	F	SALEM	BPA

Location: Richland

ADM-2	A	RICHLAND	supplier
	H	RICHLAND	supplier
SEA	A	SPOKANE	supplier
	C	MOSES LAKE	modeler
	J	SPOKANE	supplier
TRAKLOAD	E	WALLA WALLA	Weathermaker
	I	RICHLAND	(3)
VCACS	D	PENDLETON	supplier
	K	RICHLAND	modeler (4)
DOE 2.1	F	YAKIMA	BPA

Notes:
(1) Used closest match to heating degree days of files already in hand
(2) Bin data from Air Force Manual
(3) Probably renamed Pendleton file
(4) Supplier's Yakima file (most modelers could not have made a comparable adjustment)

A COMPARISON OF WEATHER SITES

From 0100 to 2400 Hours–Yearly Total

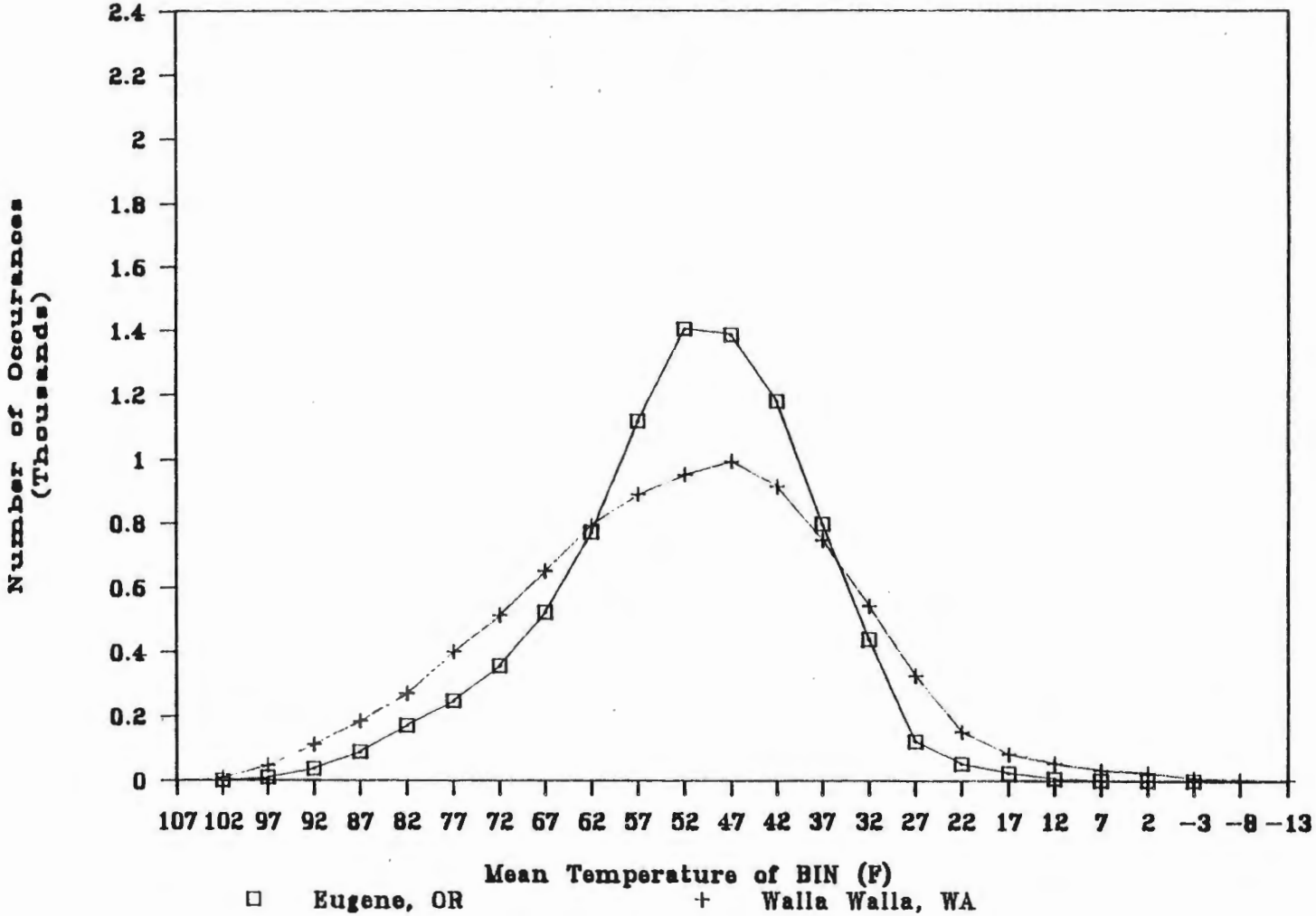


FIGURE 5.1

Zoning choices were shown in sketches by half of the modelers. Selected zoning patterns were fairly similar for all models of a given building. The exception was the DOE 2.1 model of the large office building, which used 27 zones compared to 5, 6, or 8 zones in the other models. The large number of zones in the DOE 2.1 model probably contributed to its success in achieving a good match with the ELCAP end-use data, but otherwise the number of zones seemed to make little if any impact on how well the simulated results tracked with actual overall energy consumption.

Floor UA loads, which varied over wide ranges, were estimated by several methods, none of them a direct modeling/simulation by the software. The choices seem to have been promoted by differences in the software input forms, default values, and recommendations from software manuals.

Wall R values also varied considerably, although the reasons are less obvious. The largest percentage variations occurred in estimating the value for the concrete block walls of the large retail store. Modelers agreed that these walls, apparently uninsulated, had low thermal resistance. Uncertainty about the density of the block, however, combined with the low numerical base to yield the large percentage differences despite relative small absolute changes in values.

Interior lighting differences appear to trace primarily to uncertainty in diversity factors rather than the total installed capacity.

Occupant counts were not specified for the modelers, although the nature of the occupancies was. Modelers supplied a wide range of estimates.

Other internal loads and DHW consumption also had to be assumed from the nature of each building's occupancy; again the estimates covered a wide range.

Air supply and outside air volumes varied both from modeler estimates and program "autosizing". Even when an air supply volume is entered manually, certain programs override it when necessary to meet a load, while others simply note the inadequate heating/cooling capacity. Not all software programs agree on what the autosized values should be. The range of modeled supply volumes at Cycle 2 was in the order of 2:1 for three of the buildings, but the large office building approached 6:1. Outside air settings showed even larger ranges; though not autosized, some values were computed as percentages of supply volumes that were.

Plant capacity and cooling COP were two plant parameters that showed wider ranges of estimates than expected. The COP differences may have arisen from uncertainty about how much to degrade the ratings of the used equipment, compared to the manufacturer's published ratings; then again, it is not certain that all modelers checked the published ratings. Most of the capacity differences probably can be traced to autosizing by the software, either by modeler choice or by automatic override; if so, some of the software projections were surprisingly far apart. Differences in part load curves, some of which are fixed in the programs and not accessible to the modeler, may account for part of the difference, but not all of it.

In a few instances, modelers made significant shifts in input values from one Cycle to the next. Most of these have not been traced, but it is clear that for a few, at least, the reasons lie in the detection and correction of earlier errors. The combination of iterative cycles and progressively more information apparently led the modelers to be aware of the errors and to get rid of them. In other instances the major changes may have been simply that the new information introduced at the next Cycle highlighted the inadequacy of an earlier model or estimate, demonstrating that a new approach or value was needed.

5.3 Findings and Evaluation

5.3.1 Cycle 1: Partially Informed Simulations

During Cycle 1, modelers received descriptive information about the four buildings and their use, but no information about metered energy consumption. They were asked to construct building energy models based on the descriptive information alone.

Such models are often referred to as "blind" models. Blind modeling of existing building is similar in many respects to the modeling requirements for new design buildings, where no billing history is as yet available. In other respects the designer and modeler have the advantage of being able to specify what the construction parameters for a new building shall be rather than wondering if the records and observations they have used are in fact correct.

Cycle 1 simulation results varied over a considerable range for each of the four buildings in the Evaluation of Software project, as indicated in Table 5.3. (Complete data is reported in Appendix G.) Utility data for 1987 is shown for comparison, although it was not made available to modelers until a later cycle. The use of 1987 data is explained in the previous chapter: it is a somewhat arbitrary choice; other comparisons might have been equally valid.

Table 5.3 introduces a figure of merit called "Average Monthly Divergence", determined for each simulation model. It is the average of twelve monthly computations, each the absolute percent difference between the monthly energy billed by the utility and the comparable monthly energy simulated by the model. The composite number provides an overall measure of how closely the models track with the utility data, based on the month-to-month "profile" of total energy consumption. An average monthly divergence of zero would mean that the simulated results and billing data are identical.

For comparison, the results of Cycle 2 modeling also appear in Table 5.3. By cursory examination of the results from both cycles, none of the data, including the average monthly divergence, appears to have significant correlation with the software type or with specific modelers. Similar conclusions were made following Cycle 3. That is, there was no obvious pattern whereby one software program or one modeler consistently gave appreciably better results than another, sufficient to "explain" the results.

TABLE 5.3 SUMMARY ANALYSIS OF CYCLE 1 and CYCLE 2 RESULTS

SMALL RETAIL		Annual Energy, kWh Cycle 1	Annual Energy, kWh Cycle 2	% of Utility Cy 1	% of Utility Cy 2	Average Monthly Divergence Cycle 1	Average Monthly Divergence Cycle 2
Utility (1987)		**85500**	**85500**				
Modeler A	ADM-2	89236	71999	104	84	23%	22%
Modeler B	SEA	107105	76700	125	90	55%	28%
Modeler J	SEA	71883	84591	84	99	24%	20%
Modeler D	TRAKLOAD	68179	85801	80	100	21%	17%
Modeler E	TRAKLOAD	94588	93332	111	109	23%	21%
Modeler D	VCACS	87954	85133	103	100	22%	23%
Modeler K	VCACS	98620	82408	115	96	26%	12%
Modeler F	DOE2.1	126277	90822	148	106	57%	24%
Mean		92560	82598	108	98	31%	21%

LARGE RETAIL		Annual Energy, kWh Cycle 1	Annual Energy, kWh Cycle 2	% of Utility Cy 1	% of Utility Cy 2	Monthly Divergence Cycle 1	Monthly Divergence Cycle 2
Utility (1987)		**1321200**	**1321200**				
Modeler A	ADM-2	1506401	1442555	114	109	24%	22%
Modeler H	ADM-2	1080448	1266240	82	96	21%	15%
Modeler C	SEA	1369550	1288088	104	97	21%	14%
Modeler J	SEA	2334861	1323009	177	100	81%	11%
Modeler E	TRAKLOAD	1084561	1184965	82	90	17%	13%
Modeler F	DOE 2.1	1529639	1227975	116	93	22%	14%
Mean		1484243	1288805	112	98	31%	15%

SMALL OFFICE		Annual Energy, kWh Cycle 1	Annual Energy, kWh Cycle 2	% of Utility Cy 1	% of Utility Cy 2	Monthly Divergence Cycle 1	Monthly Divergence Cycle 2
Utility (1987)		**177280**	**177280**				
Modeler H	ADM-2	174243	173456	98	98	21%	44%
Modeler B	SEA	225545	160765	127	91	48%	23%
Modeler G	SEA	128801	185767	73	105	28%	24%
Modeler D	TRAKLOAD	208672	142605	118	80	48%	25%
Modeler I	TRAKLOAD	209695	170257	118	96	45%	28%
Modeler F	DOE 2.1	116741	166277	66	94	33%	21%
Mean		177283	166519	100	94	21%	21%

LARGE OFFICE		Annual Energy, kWh Cycle 1	Annual Energy, kWh Cycle 2	% of Utility Cy 1	% of Utility Cy 2	Monthly Divergence Cycle 1	Monthly Divergence Cycle 2
Utility (1987)		**1767320**	**1767320**				
Modeler A	ADM-2	2125422	2187102	120	124	76%	23%
Modeler B	SEA	969483	766712	55	43	44%	57%
Modeler I	TRAKLOAD	1670195	1732105	95	98	16%	17%
Modeler D	VCACS	1069262	1764319	61	100	39%	2%
Modeler K	VCACS	647908	1722237	37	97	63%	5%
Modeler F	DOE 2.1	986363	1692104	56	96	45%	10%
Mean		1244772	1644097	71	93	47%	19%

5.3.2 Cycle 2: Informed Simulations with Utility Data

During Cycle 2, modelers were given information about the energy consumed in the buildings, in the form of electric utility billing records covering the period January 1987 through March 1988. The records provide data for total energy consumption, but no information about the contribution of specific end uses such as heating and lighting. Readings were reported at monthly intervals.

Modelers were asked to adapt their building energy models to reflect the energy reported in the utility billing history. This is a common procedure for any energy audit of an existing building. The modelers were not told how closely their models had to conform to the billing data, except to use their professional judgement to achieve the "best" fit with the historical data; they were to follow the same procedures and judgments they would normally apply to commercial audit engagements.

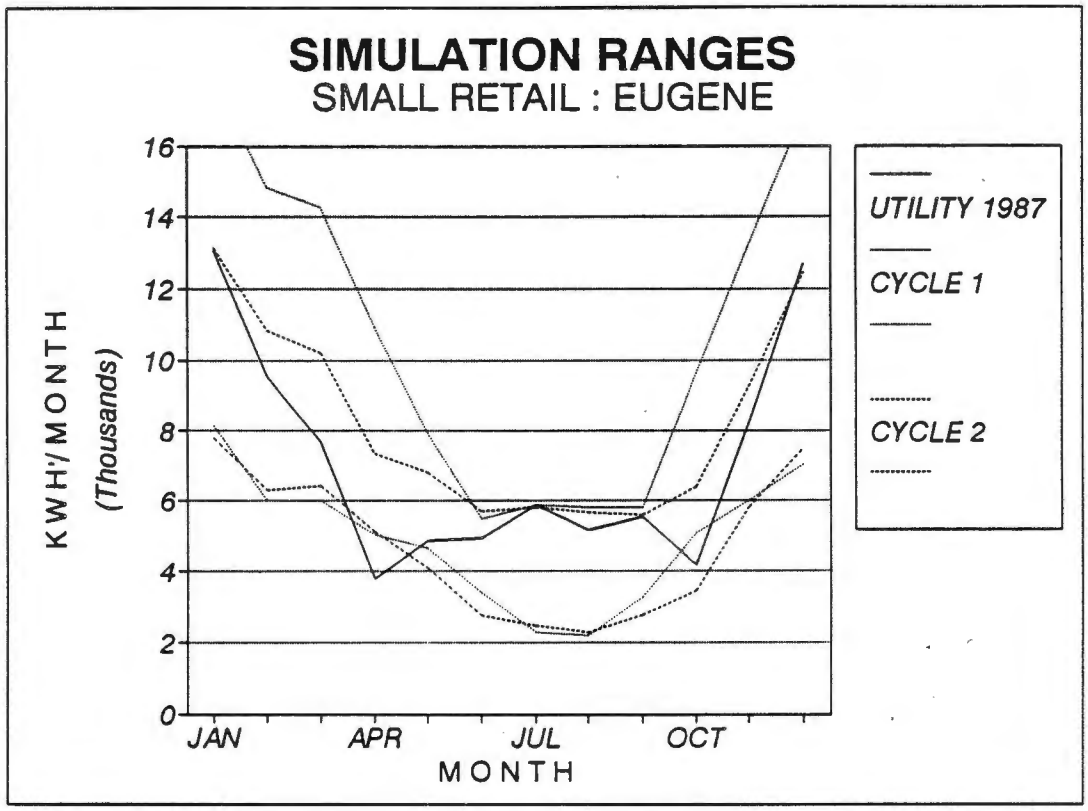
It is conceivable that modelers could have been satisfied with at least some of the Cycle 1 models, and used them without change in Cycle 2. However, all 25 of the models were in fact changed in one respect or another. Some of the changes were substantial.

The Cycle 2 simulations, predictably, resulted in energy estimates closer to the utility billing data. That is, as compared to Cycle 1, the modelers were successful in moving their models closer to the utility data targets. On the other hand, there was still a considerable range of answers for each building.

Table 5.3 compares the range of simulation results obtained during Cycle 2 with those from Cycle 1. The "average monthly divergence" figures of merit were generally lower in Cycle 2, which means the simulated monthly energy use profiles more closely match the actual energy use than before.

Cycle 1 and Cycle 2 simulation results are compared graphically in Figure 5.2, for each of the four buildings: Cycle 1 simulations are shown as one range of values, and Cycle 2 simulations as another range. In each instance the Cycle 2 range is tighter. In addition, the graphs show the billing history for the single year 1987; for the most part the 1987 lines fall within the range of Cycle 2 simulation results.

The line graphs in Figure 5.3 depict the simulation responses of individual Cycle 1 and Cycle 2 building energy models. The models shown were selected because in each instance they are paired: a given building modeled on the same software by two different modelers. Under these conditions, all the differences are due to the modelers and none to the software. During some months, Cycle 1 values (before guidance from the utility billing histories) differed by as much as 2 to 1, but the results were much closer at Cycle 2. In the aggregate including all models, these are the curves that define the ranges of values shown in the preceding (Figure 5.2) graphs.


SIMULATION RANGES
SMALL RETAIL : EUGENE
KWH/MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
UTILITY 1987
CYCLE 1
CYCLE 2

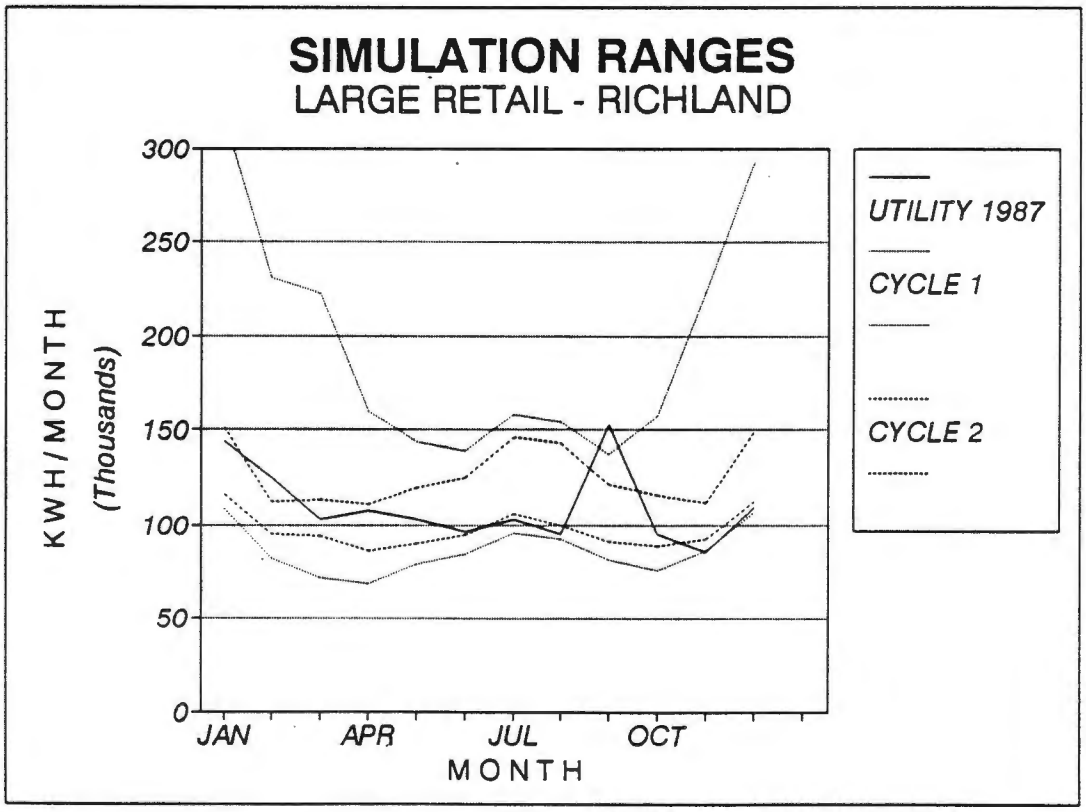
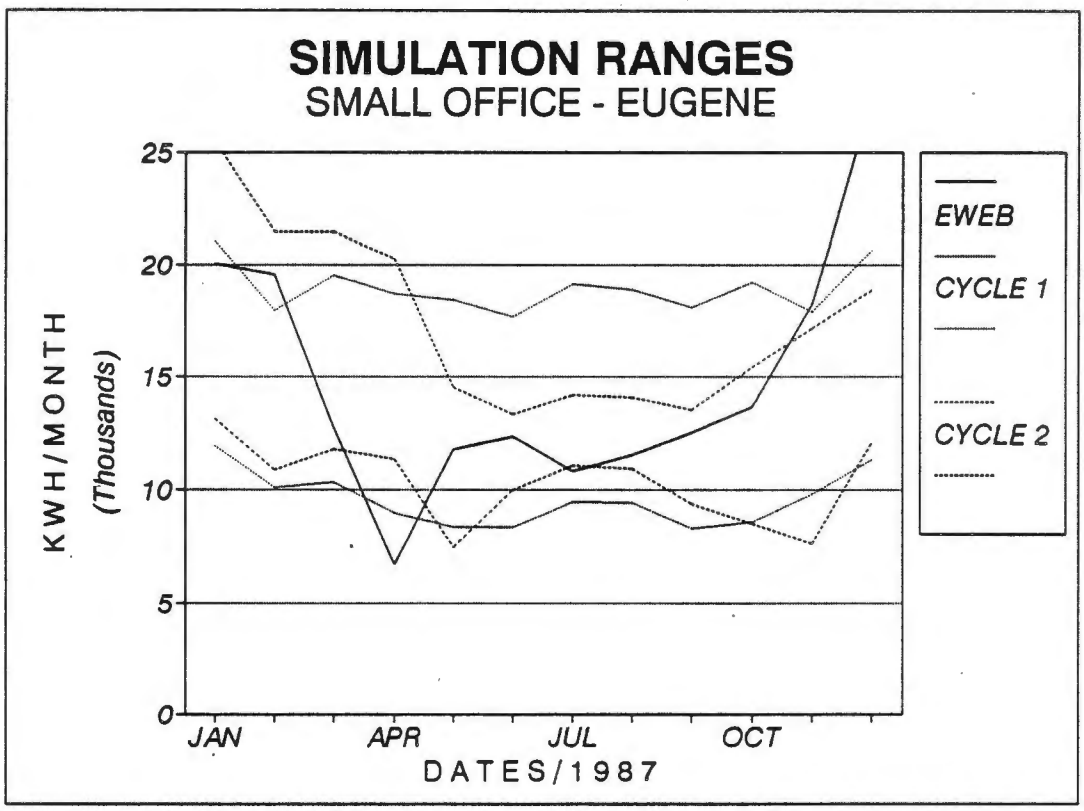

SIMULATION RANGES
LARGE RETAIL - RICHLAND
KWH/MONTH
(Thousands)
300
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
UTILITY 1987
CYCLE 1
CYCLE 2

FIGURE 5.2



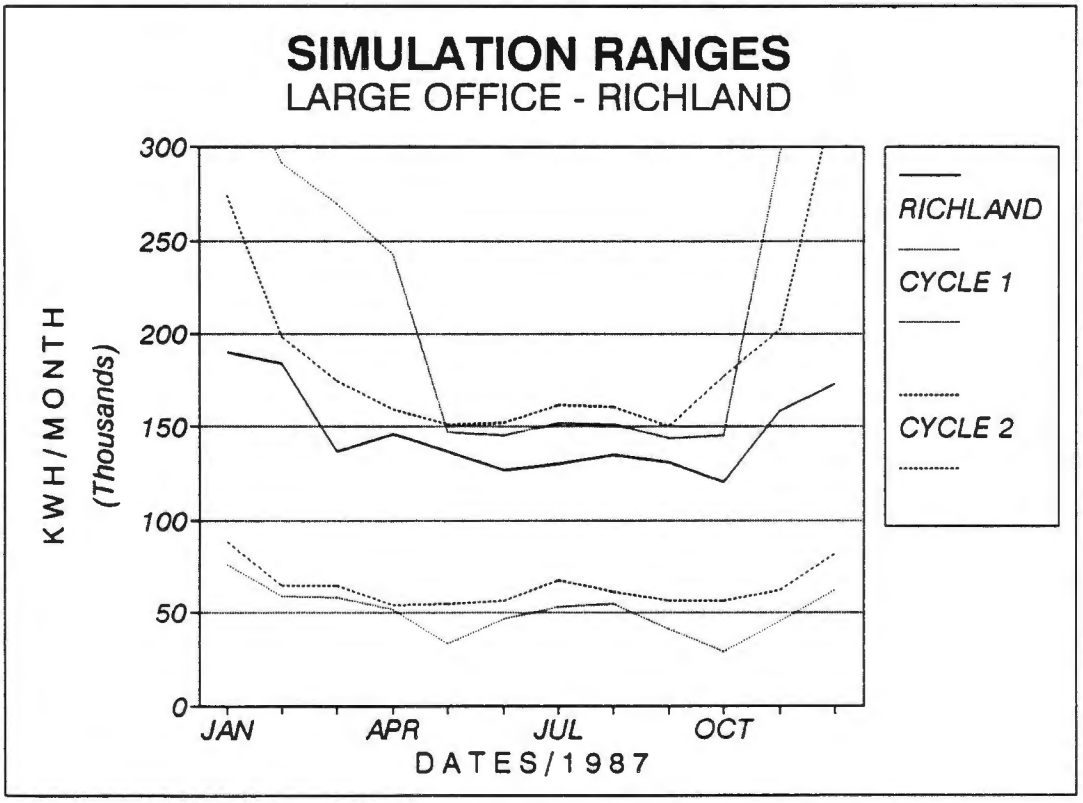
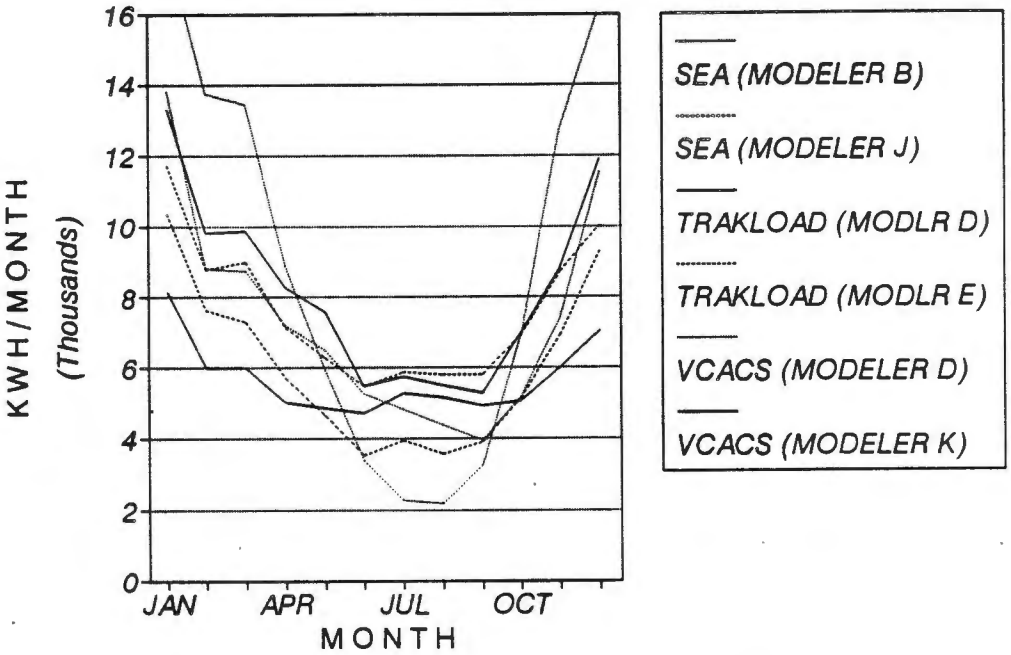


FIGURE 5.2 (continued)

CYCLE 1 COMPARISONS
SMALL RETAIL



CYCLE 2 COMPARISONS
SMALL RETAIL

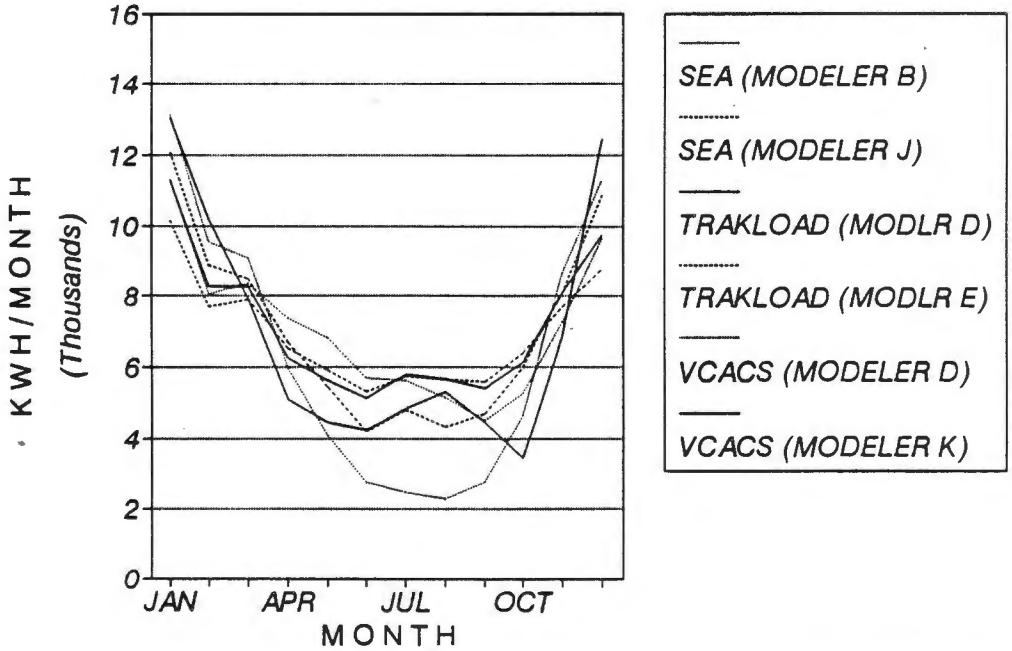
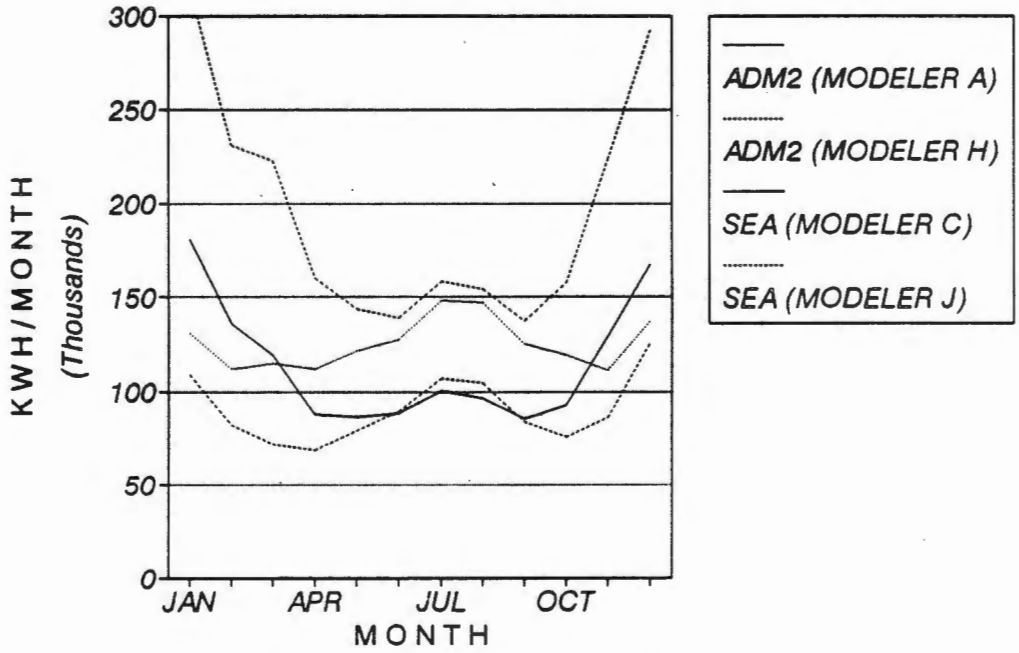


FIGURE 5.3

CYCLE 1 COMPARISONS
LARGE RETAIL



CYCLE 2 COMPARISONS
LARGE RETAIL

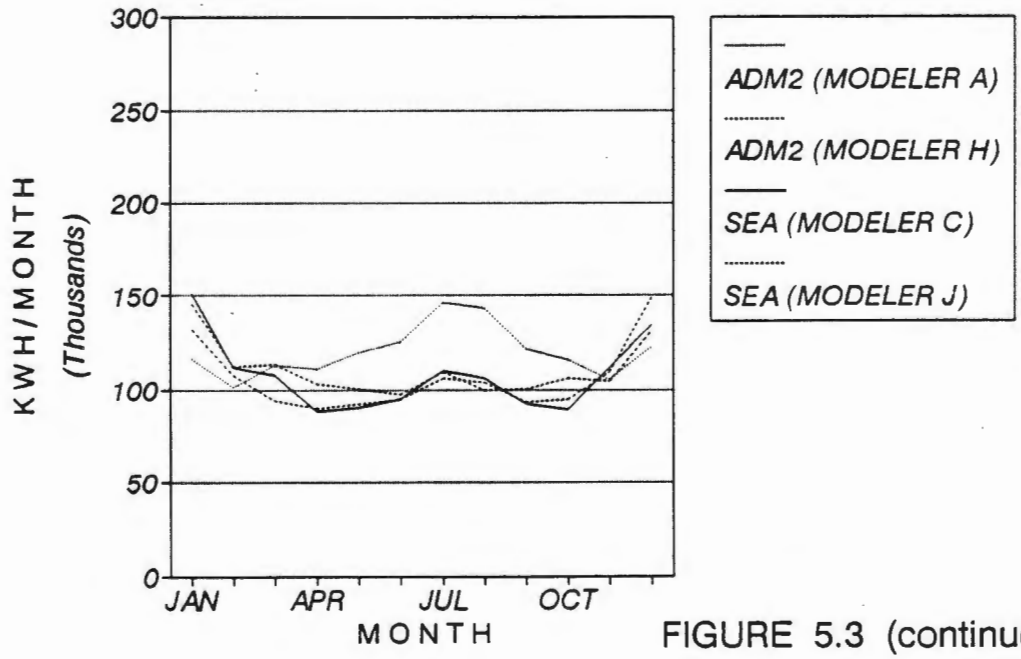


FIGURE 5.3 (continued)

Simulation results were expected to vary within reasonable ranges because the building energy models were constructed by eleven different modelers (as many as seven on one building), and the results reflect their various assumptions, approaches, and software. Isolating the work of a single modeler should be instructive because most of these differences should be minimized. Figure 5.4 compares one modeler's results for the small retail building, using two different software packages. At Cycle 1, for a few of the months, the high estimates are nearly double the low estimates. At Cycle 2 the low estimates were generally within 20% of the high estimates.

Figure 5.5 is yet another way to look at the Cycle 2 results. It graphically compares Cycle 2 simulations with electric utility data. Two ranges are shown for each of the four buildings: consumption data reported by the utilities during the period 1984-89, and Cycle 2 simulation results obtained from the various models. The ideal outcome would be for the simulation results to fall within the boundaries of the historical building energy usage. This ideal was not fully achieved in any of the four buildings, but was roughly approximated in all but the large office building. The fourth building was conformed more successfully in Cycle 3.

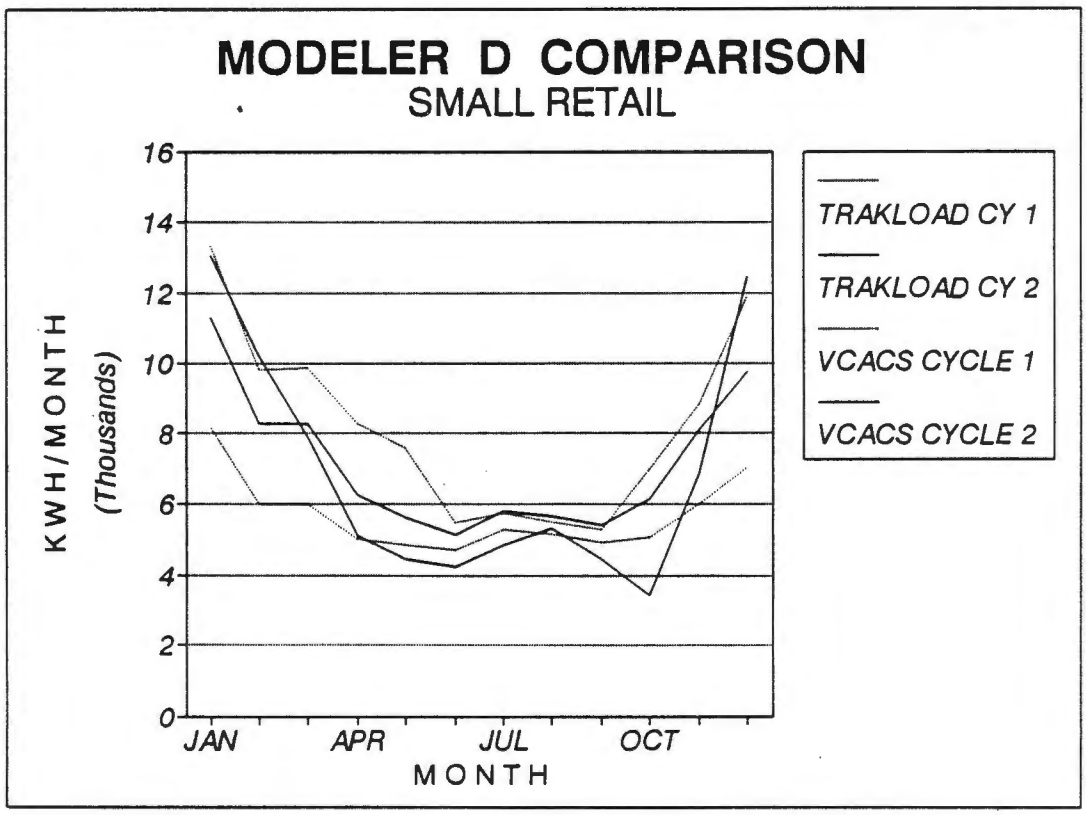


FIGURE 5.4

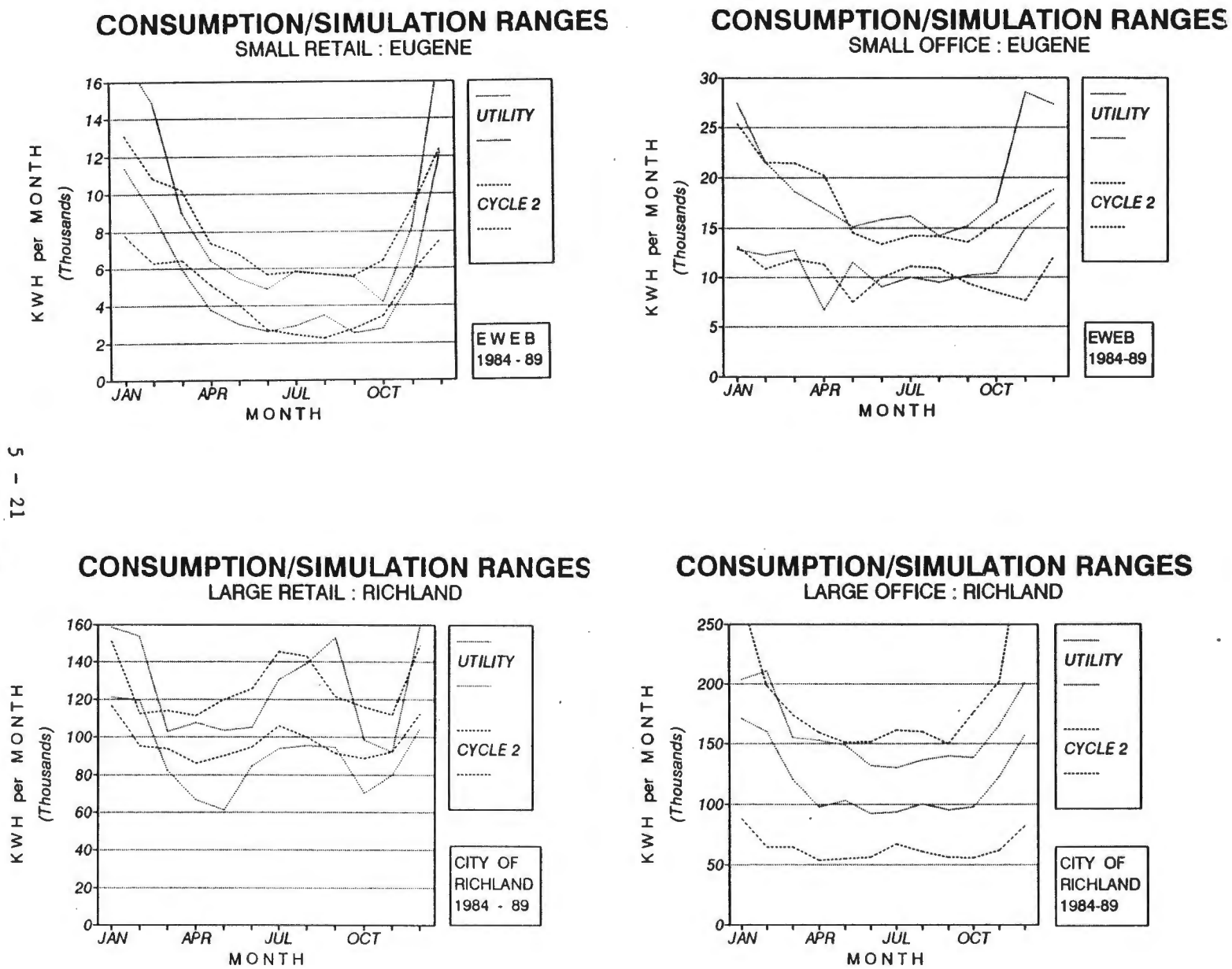

CONSUMPTION/SIMULATION RANGES
SMALL RETAIL : EUGENE
KWH per MONTH (Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 2
EWEB 1984 - 89
CONSUMPTION/SIMULATION RANGES
SMALL OFFICE : EUGENE
KWH per MONTH (Thousands)
30
25
20
15
10
5
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 2
EWEB 1984-89
CONSUMPTION/SIMULATION RANGES
LARGE RETAIL : RICHLAND
KWH per MONTH (Thousands)
160
140
120
100
80
60
40
20
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 2
CITY OF RICHLAND 1984 - 89
CONSUMPTION/SIMULATION RANGES
LARGE OFFICE : RICHLAND
KWH per MONTH (Thousands)
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 2
CITY OF RICHLAND 1984-89

FIGURE 5.5

While the "average monthly divergence" measure permits quantitative comparisons between individual models, it does nothing for explaining why the differences occur. A more sophisticated tool is needed for that purpose, and is found in the end-use energy profile graph. This type of graph allows visual comparisons of energy use by month and by end-use component - that is, by energy categories such as heating, cooling, and lighting.

A typical end-use energy profile is shown in Figure 5.6. This is a graph of 1987 ELCAP data for the small retail store. ELCAP data was metered on an end-use basis. The end-use categories shown in the figure are for heating, "mixed HVAC", interior lights, exterior lights, water heating, and other uses (receptacles).

ELCAP building energy data was obtained for each of the four buildings in the Evaluation of Software project. The ELCAP end-use energy profile for each is shown in Figure 5.7.

End-use categories reported by Battelle differ from one building to the next (see Table 5.4). Building energy simulation models, which also provide detail by energy end-use, likewise use categories that may not agree precisely. End-use energy profiles can be used to compare data from these various sources, if reasonable allowance is made for shifts between end-use categories.

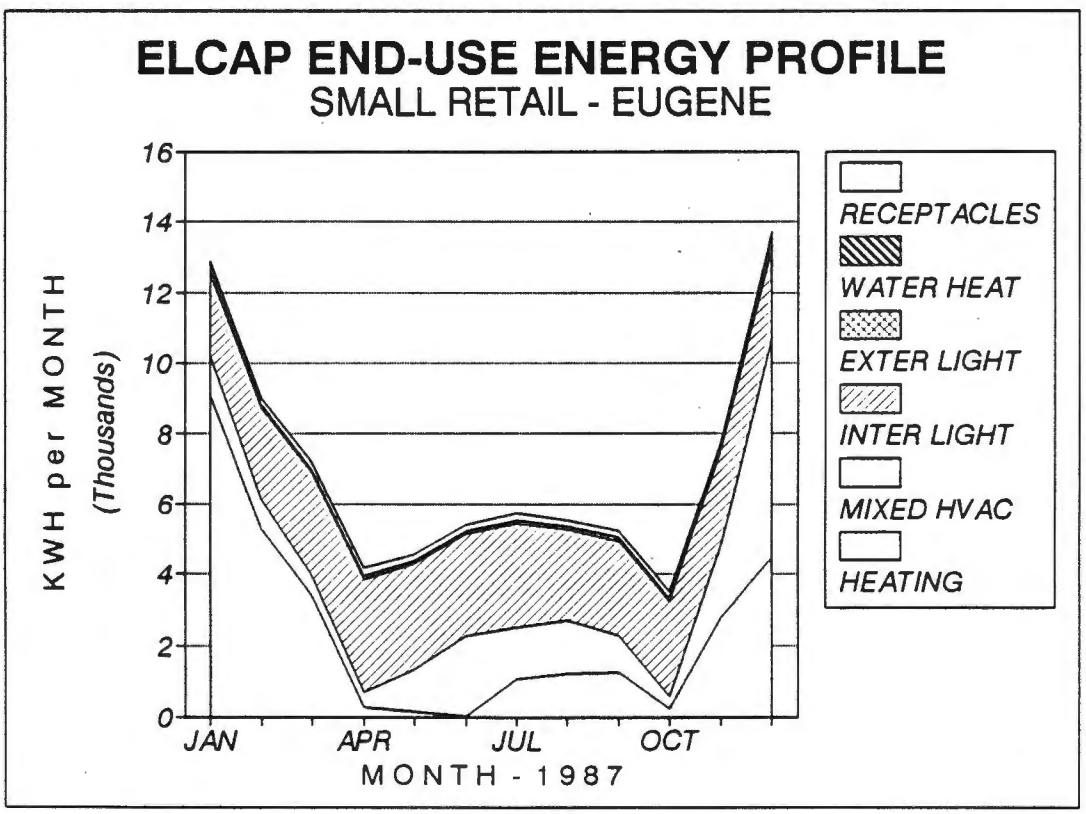


FIGURE 5.6

Table 5.4 ELCAP/CREUS End Use Categories

Small Retail Building - Site #287
- Heating - heat strips
- Mixed HVAC - heat pump (1)
- Interior Lighting
- Exterior Lighting
- Water Heating
- Receptacles

Large Retail Building - Site #556
- Interior Lighting
- General Mixed - receptacles, lighting (exterior)
- Mixed HVAC - heating/cooling units
- Sanitation - garbage compactor

Small Office Building - Site #286
- Heating - heat strips
- Mixed HVAC - heat pumps (1)
- Interior Lighting
- Ventilation - air handler
- Exterior Lighting
- Water Heating
- Other
  - Sanitation - dishwasher
  - General Mixed - lights receptacles
  - Specialty 1 - Xerox machine

Large Office Building - Site #607
- Heating - heat units, ceiling heaters, boiler
- Cooling - A/C units (DX)
- Auxiliaries - cooling tower fans, chillers (2)
- Ventilation - air handlers (2)
- Interior Lighting
- Specialty 1 - emergency battery
- Other
  - Exterior Lighting
  - Water Heating
  - Receptacles
  - Vertical Transportation - elevator
  - Data Processing - computers
  - General Mixed - receptacles, lighting

Notes: 1. DX air conditioning: building had no heat pump prior to CREUS.
2. Return circulation fans: 13 in "Auxiliaries", 2 in "Ventilation"

In general, an HVAC equipment unit or type of unit is on a single meter; HVAC categories may aggregate A/C, and/or strip heat, and fans.

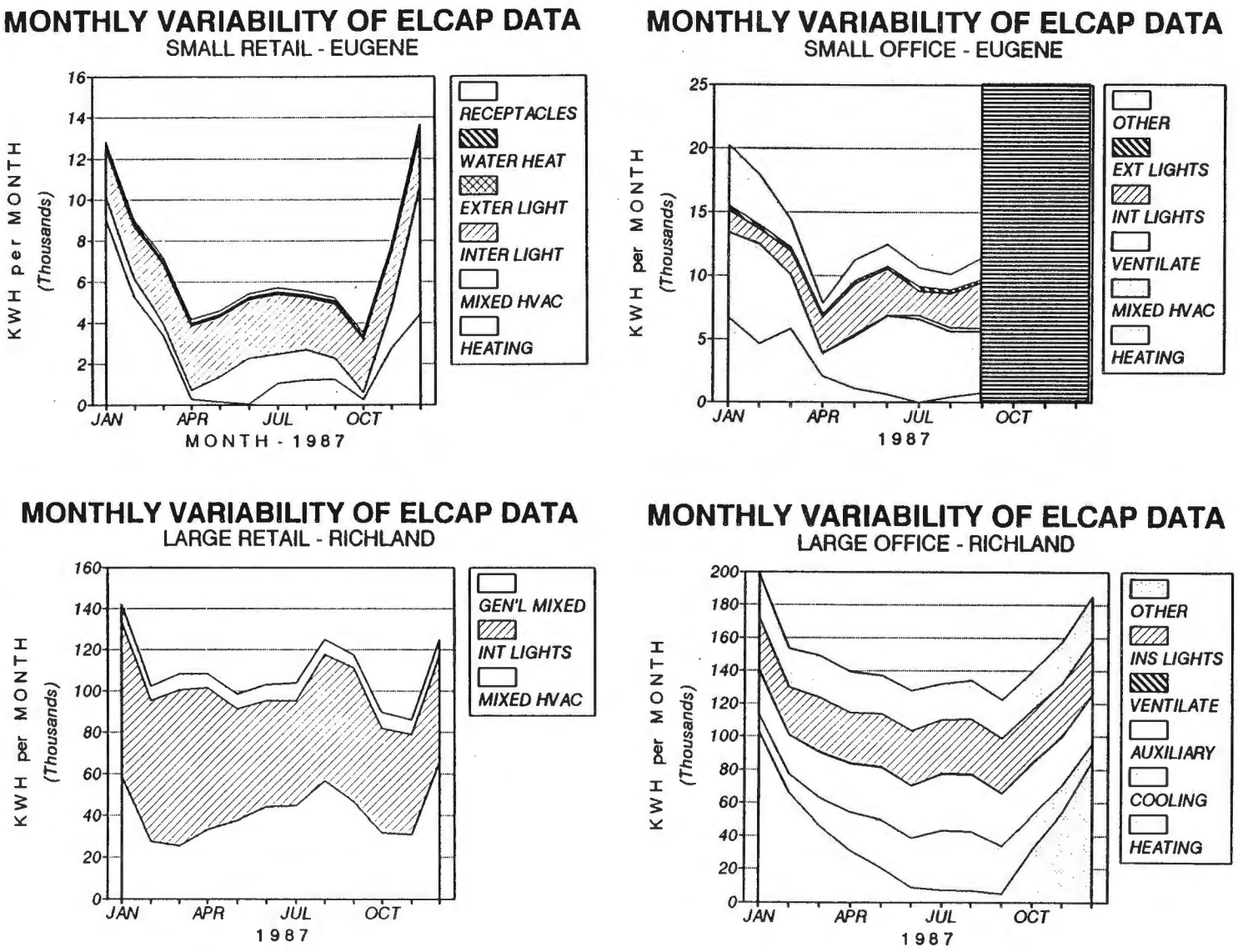

MONTHLY VARIABILITY OF ELCAP DATA
SMALL RETAIL - EUGENE
KWH per MONTH (Thousands)
MONTH - 1987
JAN
APR
JUL
OCT
RECEPTACLES
WATER HEAT
EXTER LIGHT
INTER LIGHT
MIXED HVAC
HEATING
MONTHLY VARIABILITY OF ELCAP DATA
SMALL OFFICE - EUGENE
KWH per MONTH (Thousands)
1987
OTHER
EXT LIGHTS
INT LIGHTS
VENTILATE
MIXED HVAC
HEATING
MONTHLY VARIABILITY OF ELCAP DATA
LARGE RETAIL - RICHLAND
KWH per MONTH (Thousands)
1987
GEN'L MIXED
INT LIGHTS
MIXED HVAC
MONTHLY VARIABILITY OF ELCAP DATA
LARGE OFFICE - RICHLAND
KWH per MONTH (Thousands)
1987
OTHER
INS LIGHTS
VENTILATE
AUXILIARY
COOLING
HEATING

FIGURE 5.7

Modelers in the Evaluation of Software project did not have access to the ELCAP end-use data until Cycle 3, so their Cycle 2 work was not intended to match on an end-use basis. Nonetheless, it is constructive to see how similar or different their results were in the absence of end-use data. End-use energy profiles, similar to the ELCAP examples, follow for each Cycle 2 building energy simulation model constructed for the Evaluation of Software project.

To facilitate comparisons, the shading or pattern that indicates a particular energy end-use has been used consistently in graphic renditions of profiles for the simulation models as well as the ELCAP data. Wherever possible, this convention has been observed across building types as well as within building groups. Patterns appear in the graphs in the same order as in the legend box, so an occasional re-use of the same pattern is clearly distinguishable.

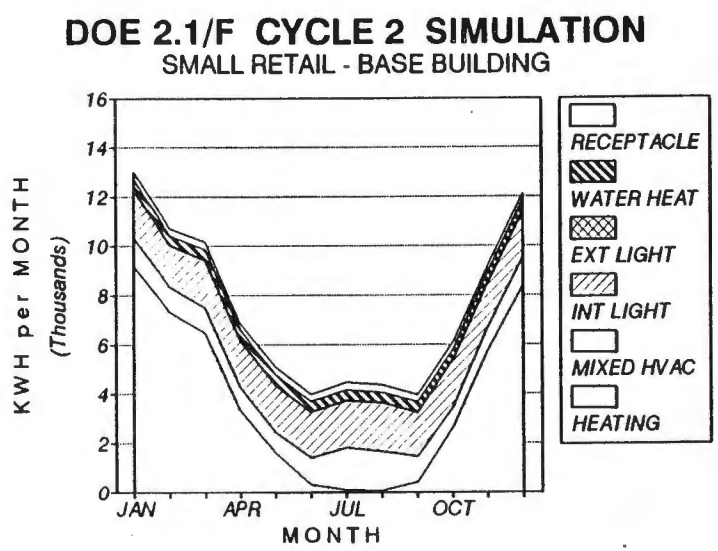
Although included in the ELCAP data series for the small retail building, the energy for exterior lights was so minimal that it does not register on the graph. Similarly, some end uses for the building energy simulation models do not register in their respective end-use energy profile graphs; but those uses have nonetheless been included in the legends for each graph.

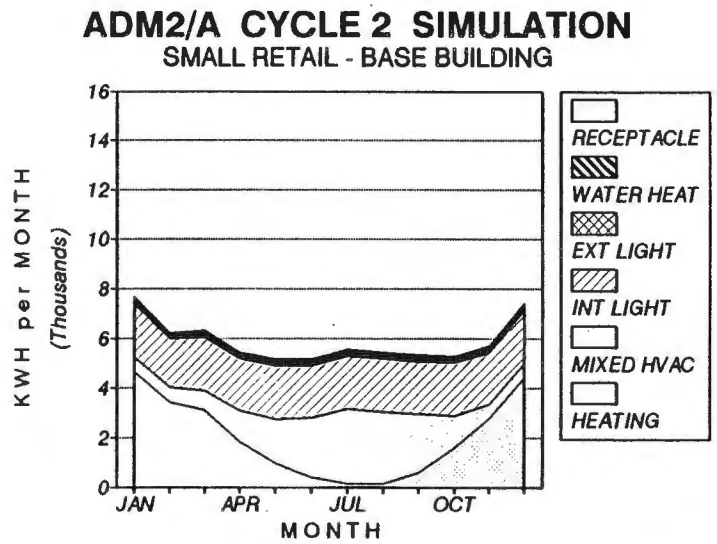
As suggested above, the ELCAP end-use series and the simulation end-use series do not always coincide, although the closest possible matches have been used. For example, some software packages lump interior and exterior lighting together; interior lighting is dominant for those buildings, so that is where the data has been reported. The spreadsheets in Appendix G describe these groupings for each building energy model. The most troublesome example of this difference is in HVAC auxiliaries such as fans and pumps. In some models the auxiliaries, or part of them, are reported in a separate "auxiliaries" category, or as "ventilation" or as "fans". In other models, heating and cooling auxiliaries may be included respectively with the heating and cooling energy. Largely for this reason, the designation "mixed HVAC" takes on a different meaning in each setting. These differences should be considered when comparisons are made.

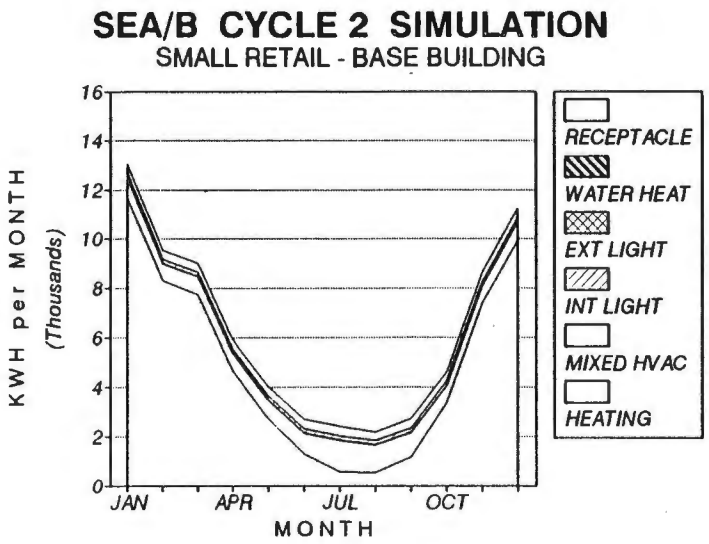
Direct visual comparisons between two profiles are most effective if both are presented at the same scale. When comparing end-use energy profiles, both the month-to-month shape and the extent or magnitude of energy consumed are significant. The closer the two profiles are, the closer the match between actual and simulated energy use, or between the simulations of two models.

To the extent the end-use components differ visually between the two profiles, some of the energy consumption estimates may be presumed to be faulty. On a visual basis, the significance of differences is a subjective evaluation; small difference are largely insignificant, but large differences with radical departures in the shape of the curves are likely to be significant.

Figure 5.8 presents end-use energy profiles for the small retail building, for each of seven simulation models constructed during Cycle 2, plus an eighth model (ADM-2) put together for the sensitivity study. Figure 5.9 provides the same type of comparison for the six Cycle 2 simulation models of the large retail building. Likewise, Figure 5.10 compares six models of the small office building. Figure 5.11 compares six models of the large office building.


DOE 2.1/F CYCLE 2 SIMULATION
SMALL RETAIL - BASE BUILDING
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
RECEPTACLE
WATER HEAT
EXT LIGHT
INT LIGHT
MIXED HVAC
HEATING


ADM2/A CYCLE 2 SIMULATION
SMALL RETAIL - BASE BUILDING
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
RECEPTACLE
WATER HEAT
EXT LIGHT
INT LIGHT
MIXED HVAC
HEATING


SEA/B CYCLE 2 SIMULATION
SMALL RETAIL - BASE BUILDING
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
RECEPTACLE
WATER HEAT
EXT LIGHT
INT LIGHT
MIXED HVAC
HEATING

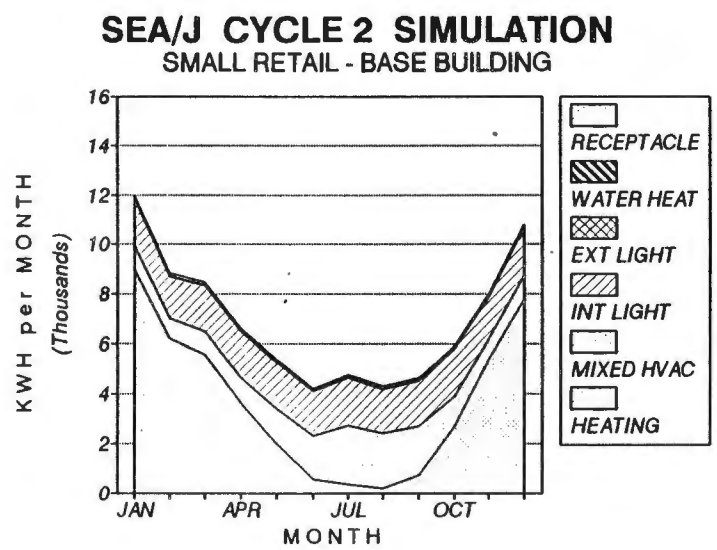

SEA/J CYCLE 2 SIMULATION
SMALL RETAIL - BASE BUILDING
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
RECEPTACLE
WATER HEAT
EXT LIGHT
INT LIGHT
MIXED HVAC
HEATING

FIGURE 5.8

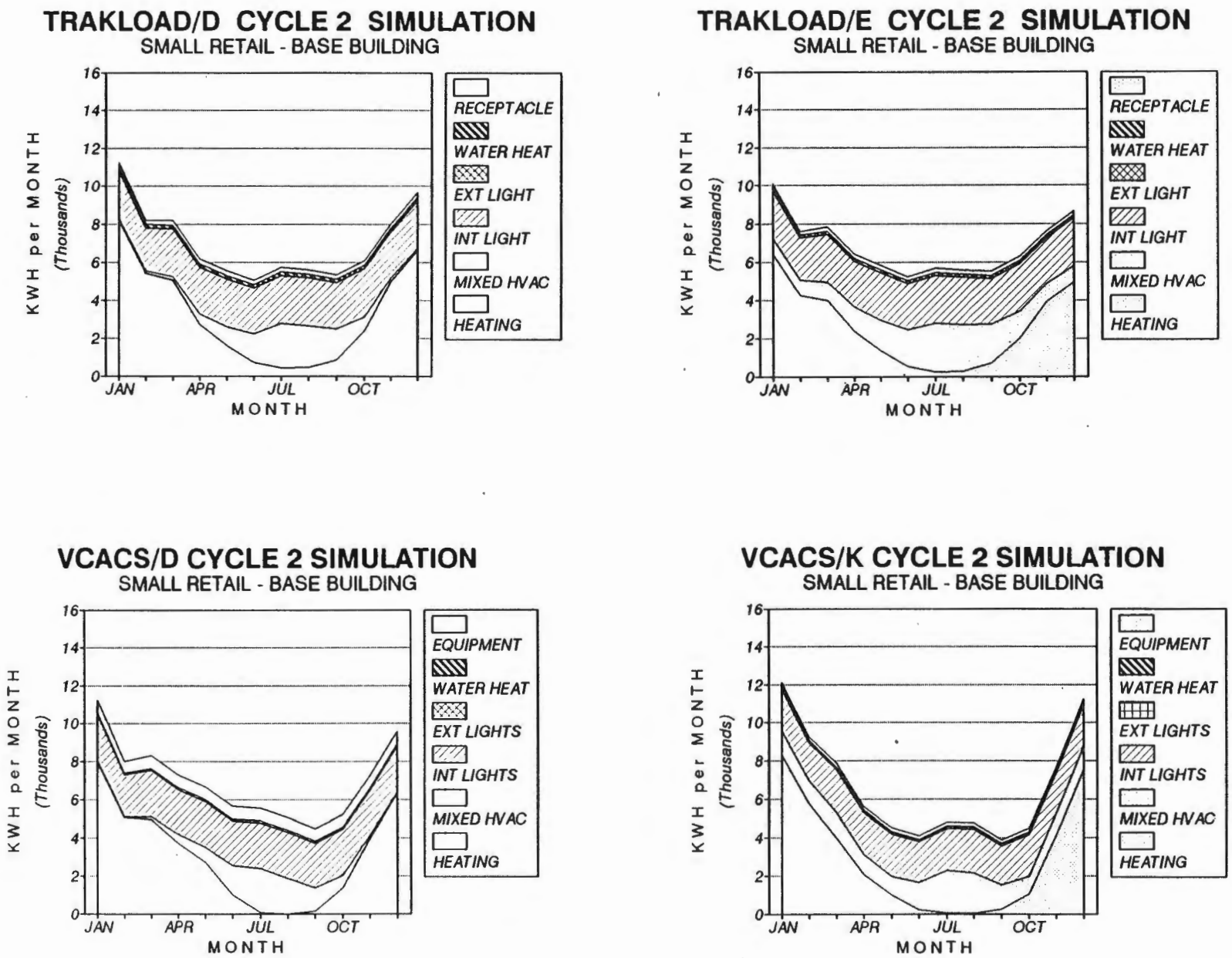


FIGURE 5.8 (continued)

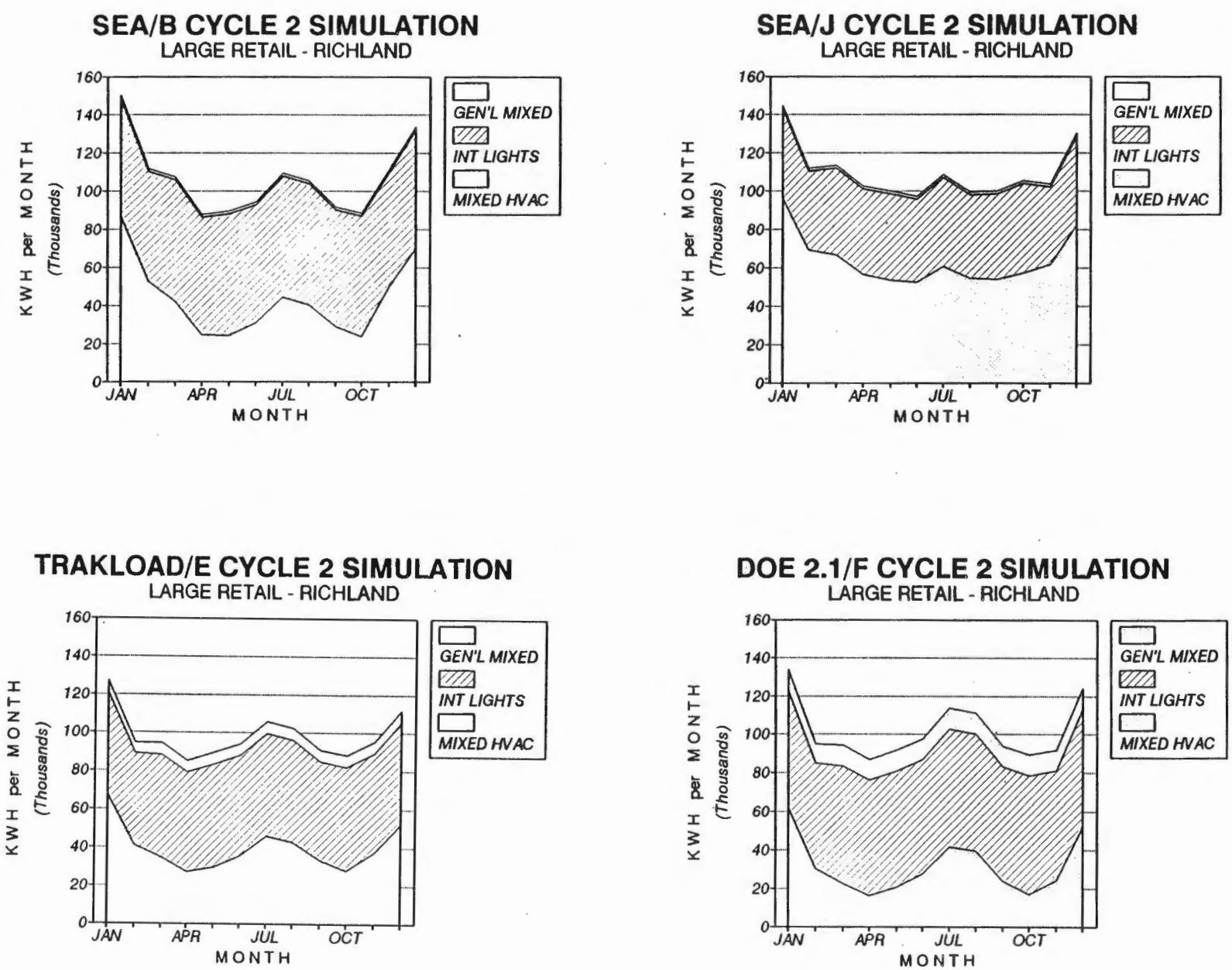
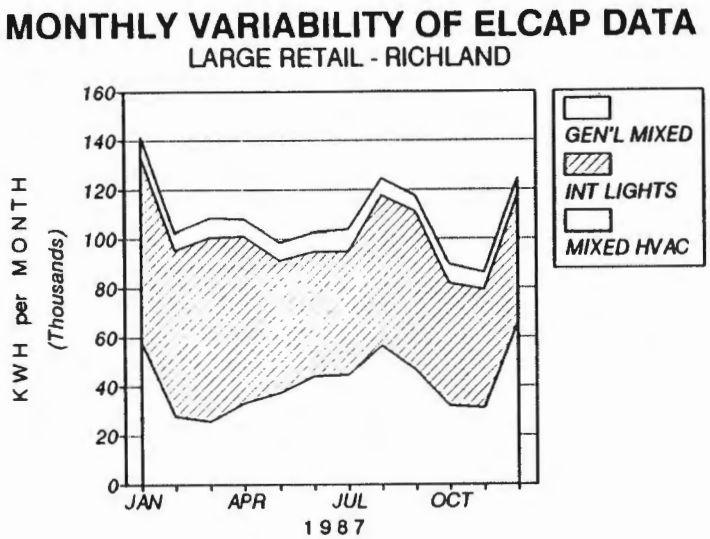
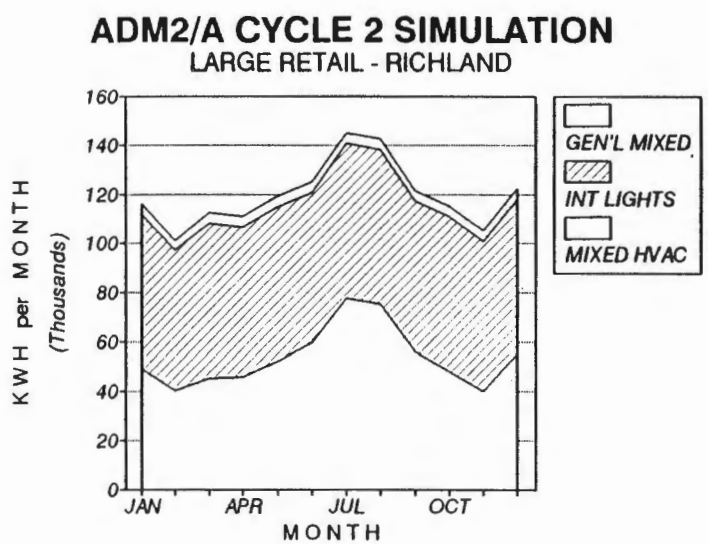

SEA/B CYCLE 2 SIMULATION
LARGE RETAIL - RICHLAND
SEA/J CYCLE 2 SIMULATION
LARGE RETAIL - RICHLAND
TRAKLOAD/E CYCLE 2 SIMULATION
LARGE RETAIL - RICHLAND
DOE 2.1/F CYCLE 2 SIMULATION
LARGE RETAIL - RICHLAND
KWH per MONTH
(Thousands)
0
20
40
60
80
100
120
140
160
JAN
APR
JUL
OCT
MONTH
GEN'L MIXED
INT LIGHTS
MIXED HVAC

FIGURE 5.9





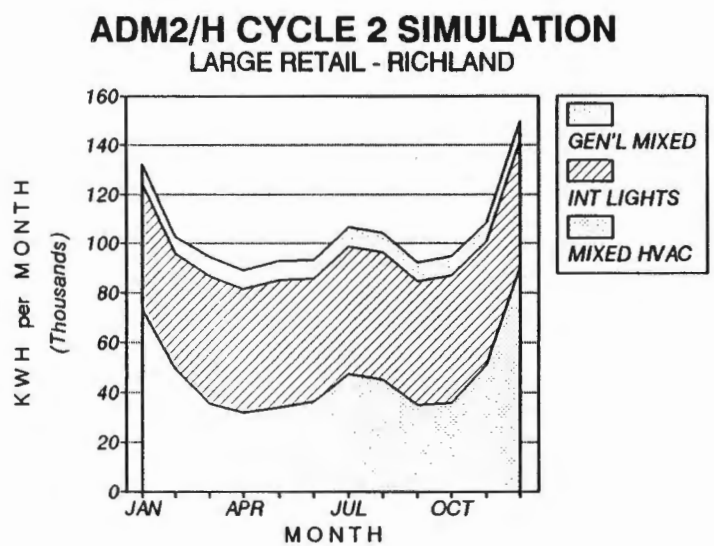


FIGURE 5.9 (continued)

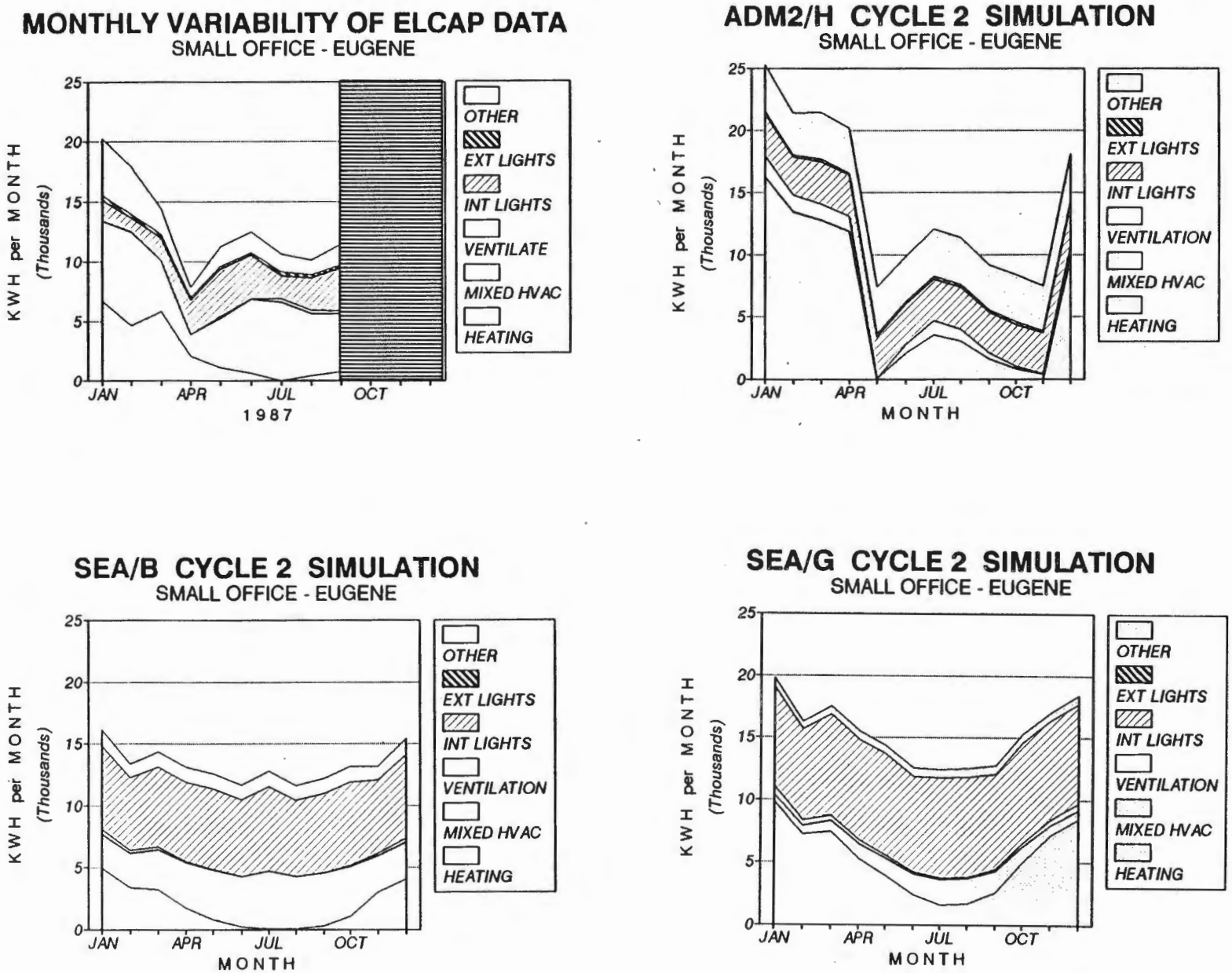
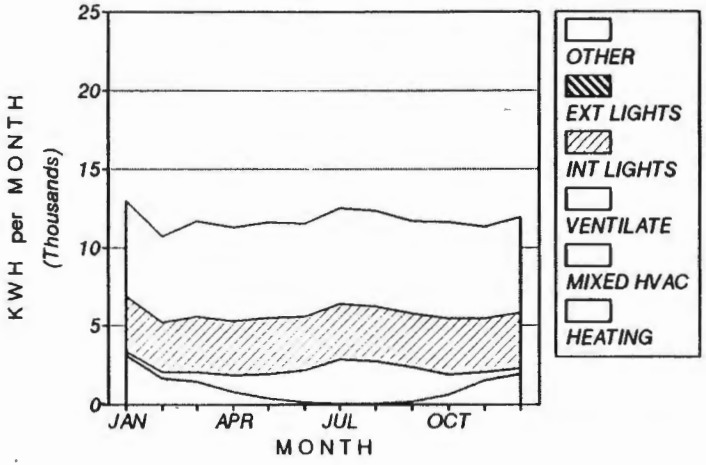
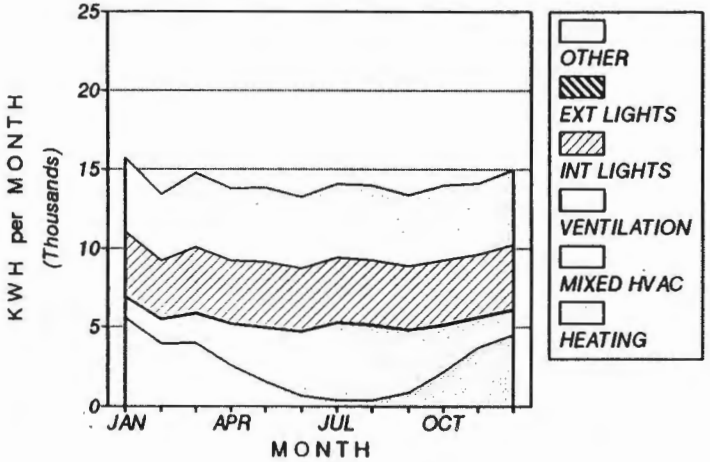

MONTHLY VARIABILITY OF ELCAP DATA
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
25
20
15
10
5
0
JAN
APR
JUL
OCT
1987
OTHER
EXT LIGHTS
INT LIGHTS
VENTILATE
MIXED HVAC
HEATING
ADM2/H CYCLE 2 SIMULATION
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
25
20
15
10
5
0
JAN
APR
JUL
OCT
MONTH
OTHER
EXT LIGHTS
INT LIGHTS
VENTILATION
MIXED HVAC
HEATING
SEA/B CYCLE 2 SIMULATION
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
25
20
15
10
5
0
JAN
APR
JUL
OCT
MONTH
OTHER
EXT LIGHTS
INT LIGHTS
VENTILATION
MIXED HVAC
HEATING
SEA/G CYCLE 2 SIMULATION
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
25
20
15
10
5
0
JAN
APR
JUL
OCT
MONTH
OTHER
EXT LIGHTS
INT LIGHTS
VENTILATION
MIXED HVAC
HEATING

FIGURE 5.10

TRAKLOAD/D CYCLE 2 SIMULATION
SMALL OFFICE - EUGENE



TRAKLOAD/I CYCLE 2 SIMULATION
SMALL OFFICE - EUGENE



DOE 2.1/F CYCLE 2 SIMULATION
SMALL OFFICE - EUGENE

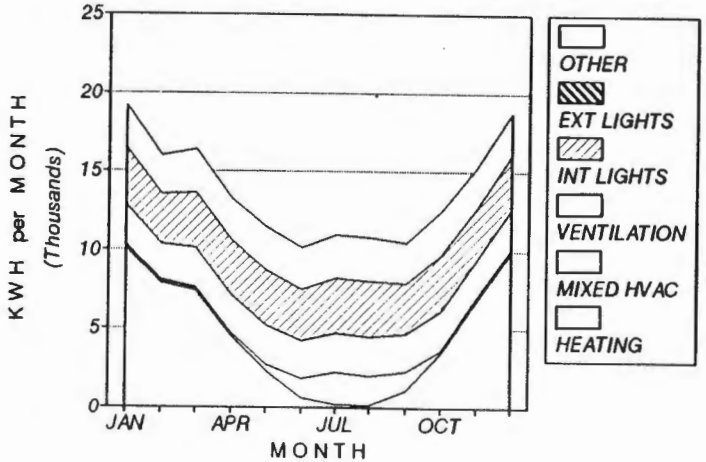
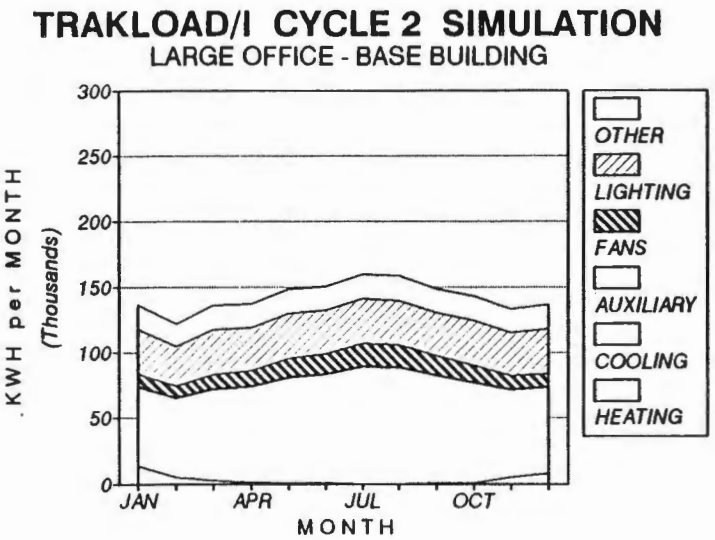
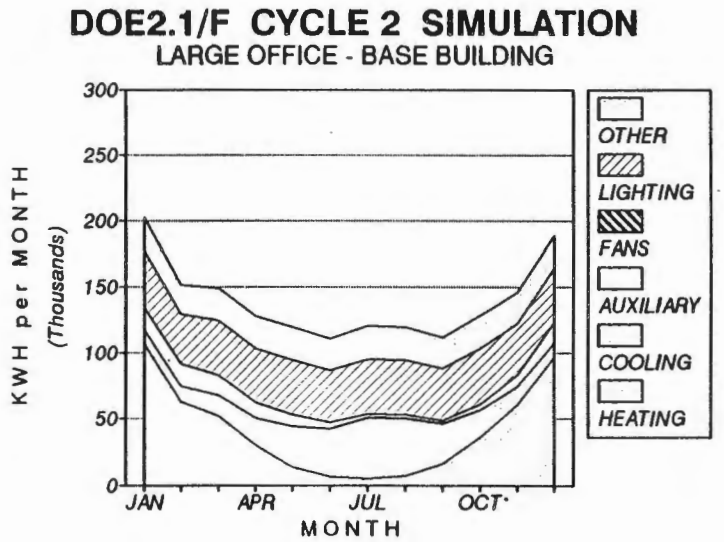
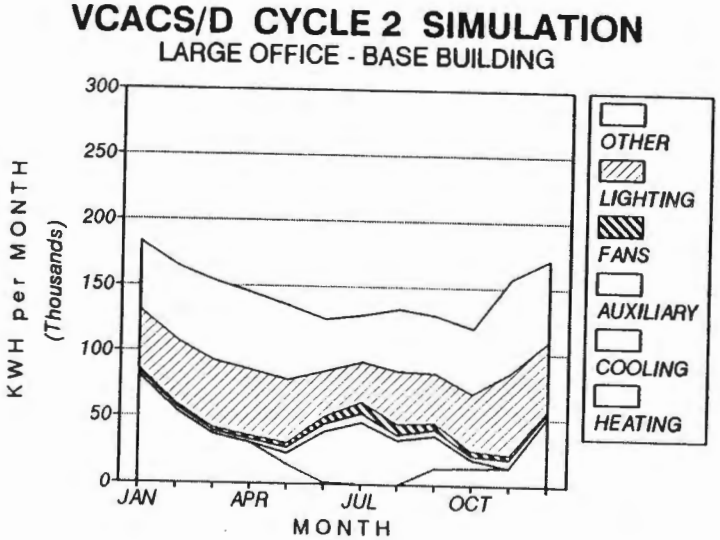


FIGURE 5.10 (continued)


TRAKLOAD/I CYCLE 2 SIMULATION
LARGE OFFICE - BASE BUILDING
KWH per MONTH
(Thousands)
300
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
OTHER
LIGHTING
FANS
AUXILIARY
COOLING
HEATING


DOE2.1/F CYCLE 2 SIMULATION
LARGE OFFICE - BASE BUILDING
KWH per MONTH
(Thousands)
300
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
OTHER
LIGHTING
FANS
AUXILIARY
COOLING
HEATING


VCACS/D CYCLE 2 SIMULATION
LARGE OFFICE - BASE BUILDING
KWH per MONTH
(Thousands)
300
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
OTHER
LIGHTING
FANS
AUXILIARY
COOLING
HEATING

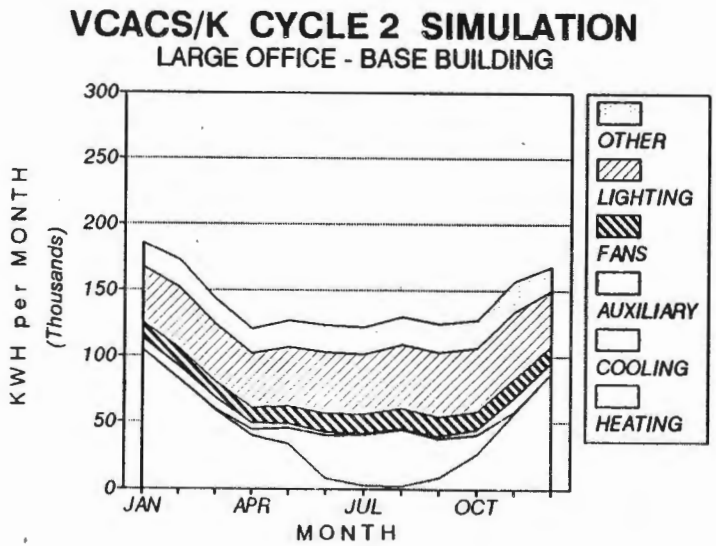
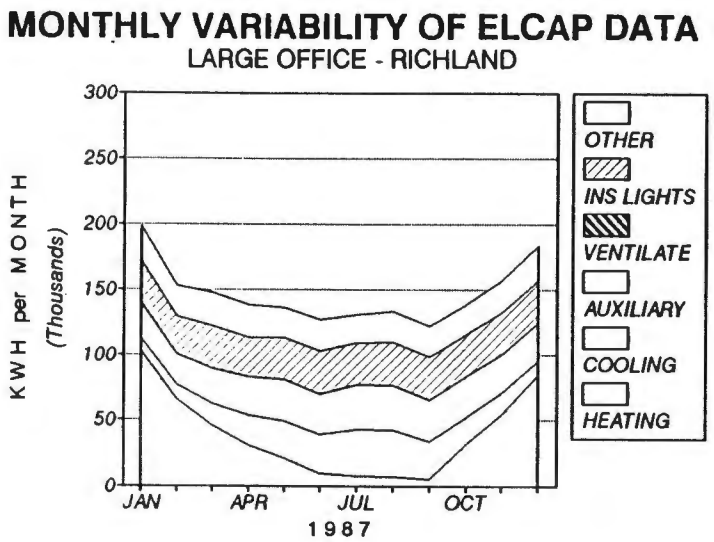
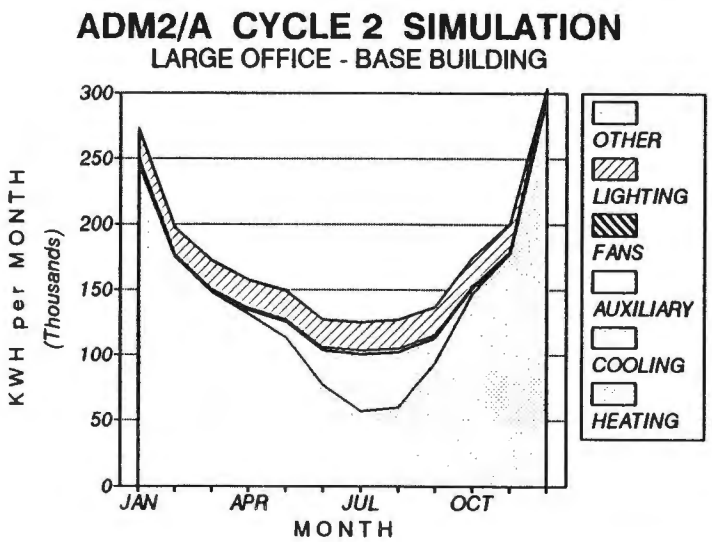

VCACS/K CYCLE 2 SIMULATION
LARGE OFFICE - BASE BUILDING
KWH per MONTH
(Thousands)
300
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
OTHER
LIGHTING
FANS
AUXILIARY
COOLING
HEATING

FIGURE 5.11





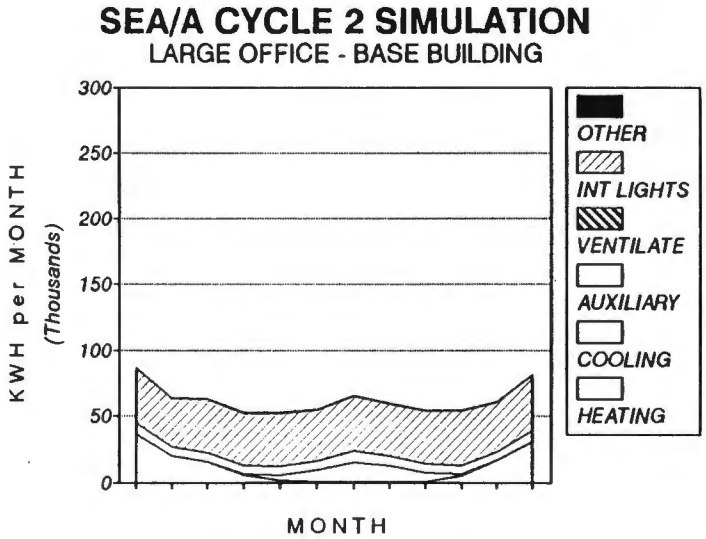


FIGURE 5.11 (continued)

(In Figure 5.10 the bold horizontal striping in the ELCAP end-use energy profile marks where data is missing from the series. Model comparisons were made with utility billing data on a total energy consumption basis.)

These graphs can be compared with the ELCAP end-use energy profile for the respective buildings in Figure 5.7. Remember, however: While simulated energy consumption that differs from the ELCAP findings may be suspect it is not necessarily wrong or deviant, for reasons already explored; major differences probably should be decided in favor of ELCAP, while modest or minor differences suggest and indeterminate preference.

Comparisons of the end-use energy profiles should make note of both the similarities and the differences. Within the "small retail" grouping of profiles (Figure 5.8), all of the models show pronounced "valleys" during warmer seasonal weather. None of the models show the sharp "W" shape and secondary summer peak of the ELCAP data, although the VCACS/K model comes closest with a rounded version of that shape including a distinct increase in summer energy use.

The designation "VCACS/K" shows that modeler K constructed this model with VCACS software.

End-use energy profiles for a given building establish a set of curves that proves to have distinct family similarities. Despite important differences between curves within a family, the family similarities of one group obviously contrast with the family similarities of each other group. Comparisons can therefore be made between building groups, in addition to those within each group. For example, The magnitude of energy use, extent of summer peak, and distribution of energy end-uses, differ greatly between the small and large retail buildings while showing much more in common within each building group.

The most pronounced differences between simulations within one building group are those for the large office building. The Cycle 2 models there range from winter peaking to summer peaking, from distinct summer peaks to nearly "flat" consumption throughout the year. The models that do show winter peaks and summer troughs similar to the ELCAP data still have distinctively different distributions between the several energy end uses. The models for this building are capable of showing greater differences because the building is more complex, with more variables; the modelers have reflected those opportunities in their models. Therefore, despite the more detailed modeling and control, the results were more divergent: the variable uncertainties overpowered the modeling sophistication.

One of the questions posed at the onset, addressed this tradeoff: Would the added sophistication of commercial-building software lead to improved modeling results, or would the added complexity of the commercial buildings outweigh this advantage? For the large office building example, at least, the complexities carry the greater weight.

5.3.3 Cycle 3: Informed Simulations with End-Use Data: Base Buildings

During Cycle 3, modelers were supplied with energy end-use data from the ELCAP program. Modelers were asked if the new information suggested changes in their building energy models. The models, with any adjustments, were used to simulate potential Energy Conservation Measures; the most promising measures were identified.

Metered ELCAP data collected during January 1987 through March 1988 were reported to the modelers in calendar-month periods. The calendar timing did not match the utility billing data the modelers had been using, although in most instances the agreement was good. Modelers were told to disregard segments of the ELCAP data known to be wrong (see Chapter 4); otherwise they were to accept it as correct. The energy allocation by end use was assumed to be correct.

Modelers were given the option to use their Cycle 2 base building files for modeling the ECMs, or to modify the files before making the ECM runs. They were free to disregard the ELCAP data or adapt to it. They were asked only to use professional judgment in their reviews and in their decisions to make changes of not. Of the original 25 building energy models, 17 were modified and 8 were used in Cycle 3 without change.

End-use energy profiles for the 25 Cycle 3 base building simulation models, including those unchanged from Cycle 2, are shown in Figures 5.12 through 5.15. The figures directly parallel the ones shown earlier for the Cycle 2 models. The Cycle 3 models, however, have added significance.

The end-use energy profiles reflect the changes made in the simulation models between Cycle 2 and Cycle 3. Note that now the simulated month-by-month total energy figures more closely match the 1987 data for actual energy consumption. Figure 5.16 shows this graphically, with simulation ranges for each building; in each instance the ranges reasonably approximate the actual energy consumption experience reported by utilities.

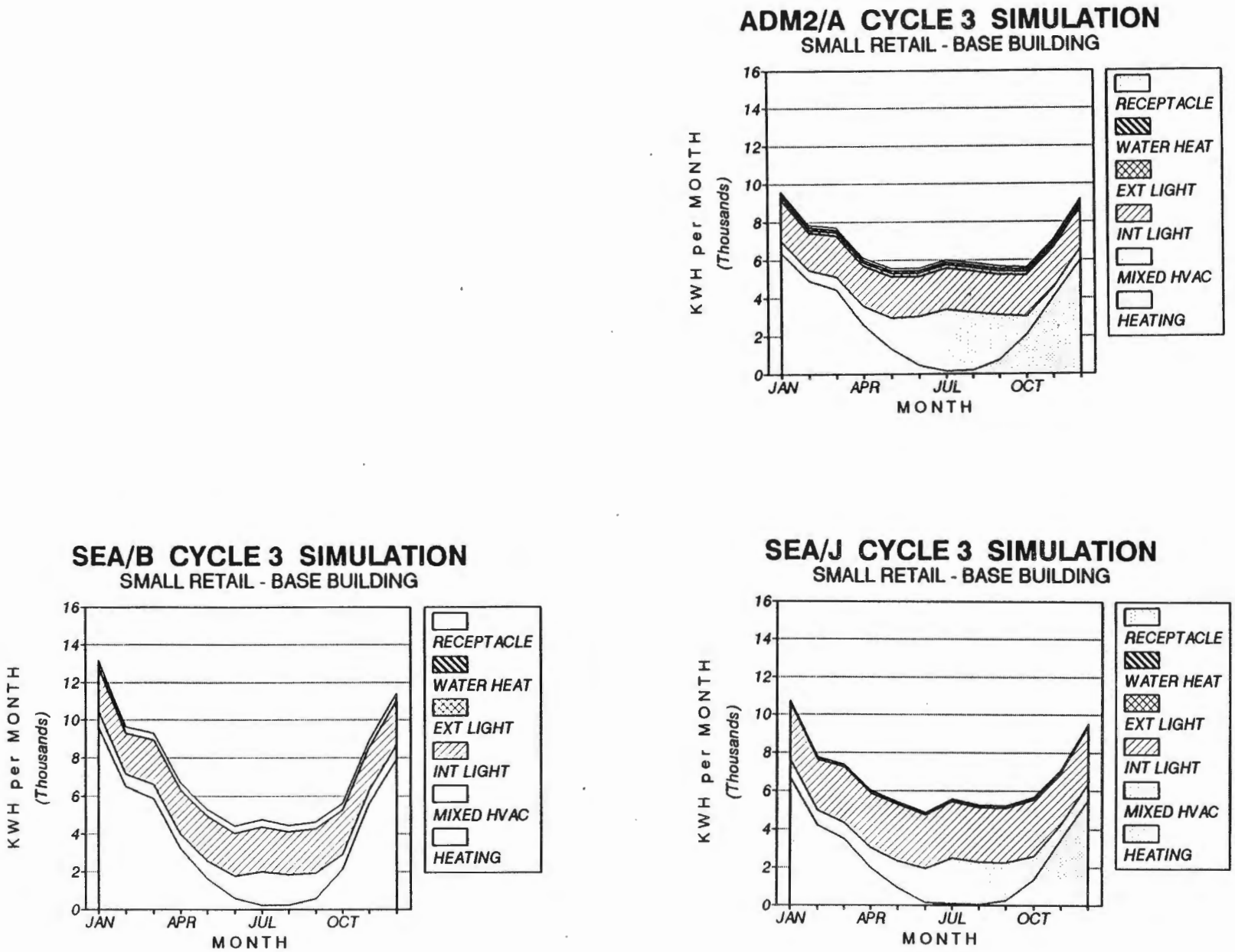
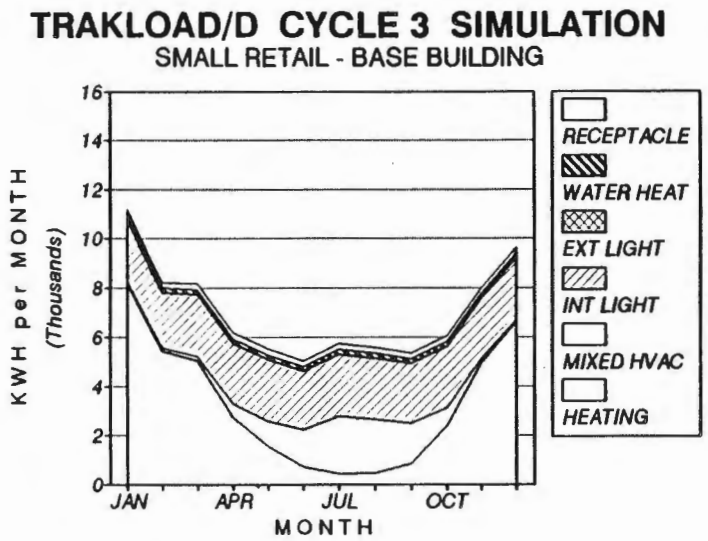
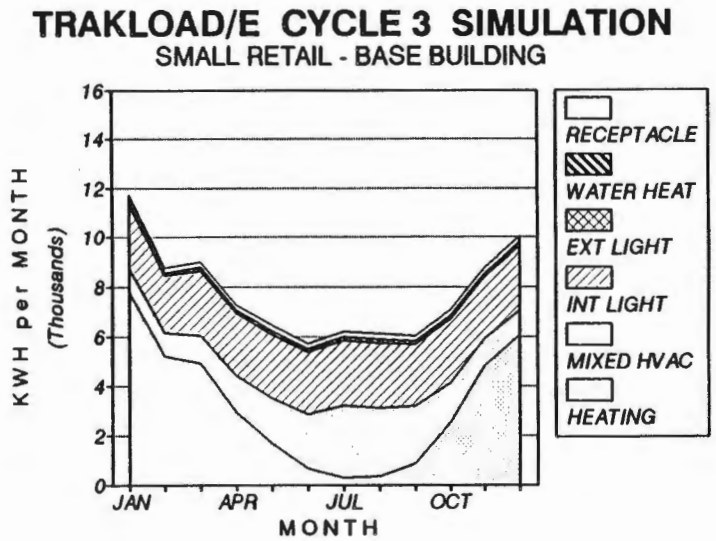
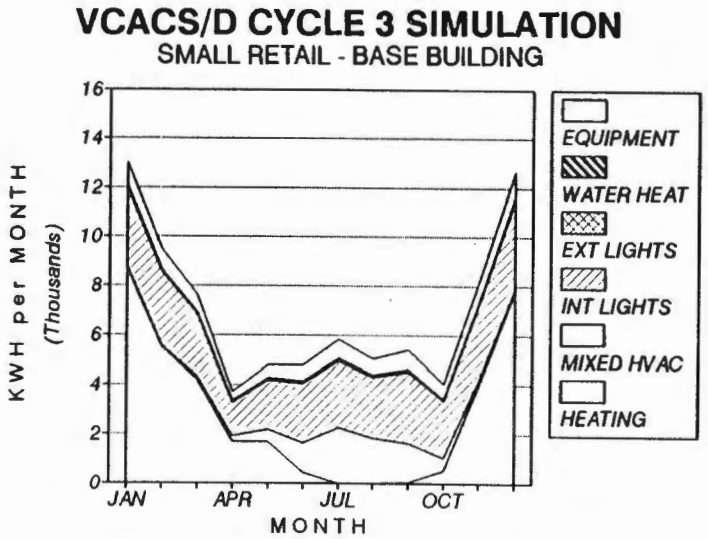

ADM2/A CYCLE 3 SIMULATION
SMALL RETAIL - BASE BUILDING
SEA/B CYCLE 3 SIMULATION
SMALL RETAIL - BASE BUILDING
SEA/J CYCLE 3 SIMULATION
SMALL RETAIL - BASE BUILDING
KWH per MONTH
(Thousands)
0
2
4
6
8
10
12
14
16
JAN
APR
JUL
OCT
MONTH
RECEPTACLE
WATER HEAT
EXT LIGHT
INT LIGHT
MIXED HVAC
HEATING

FIGURE 5.12







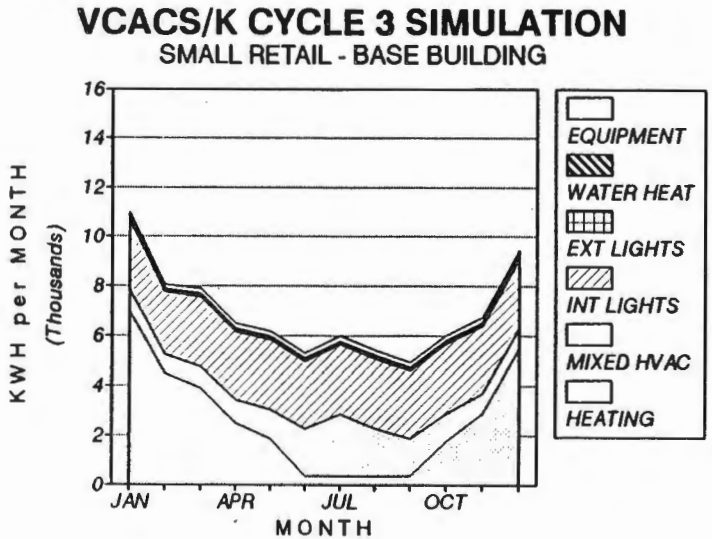
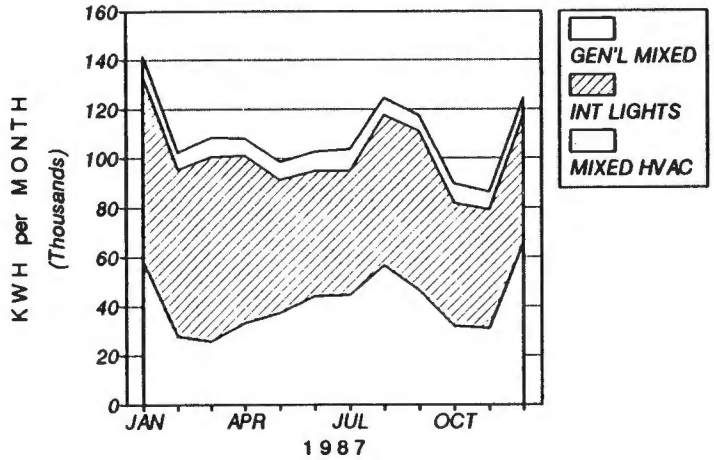


FIGURE 5.12 (continued)

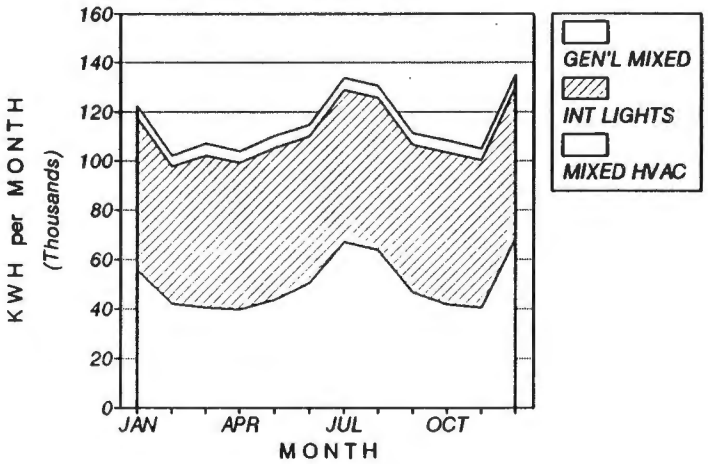
MONTHLY VARIABILITY OF ELCAP DATA

LARGE RETAIL - RICHLAND



ADM2/A CYCLE 3 SIMULATION

LARGE RETAIL - RICHLAND



ADM2/H CYCLE 3 SIMULATION

LARGE RETAIL - RICHLAND

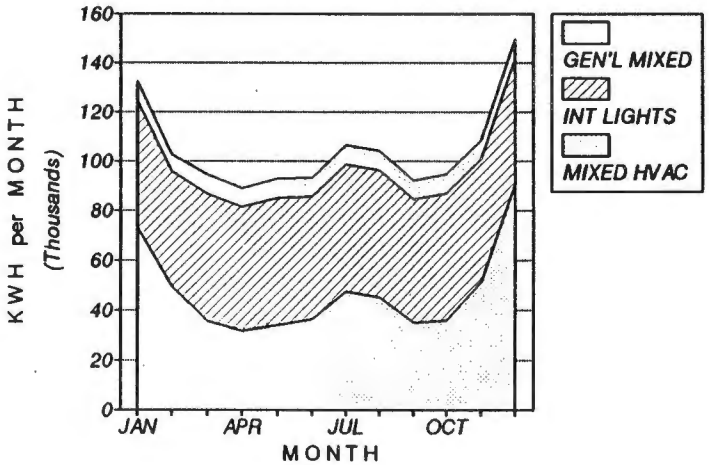


FIGURE 5.13

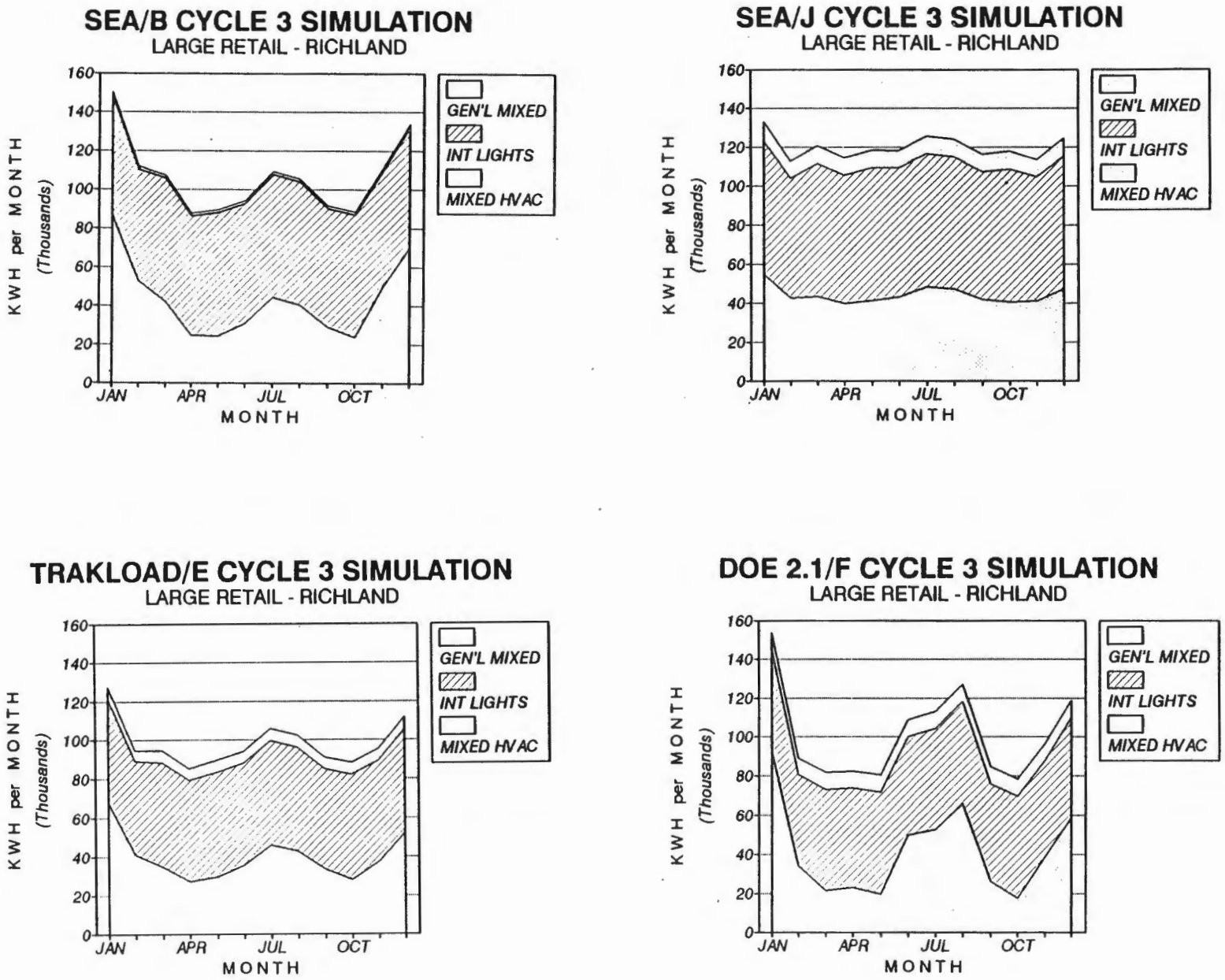


FIGURE 5.13 (continued)

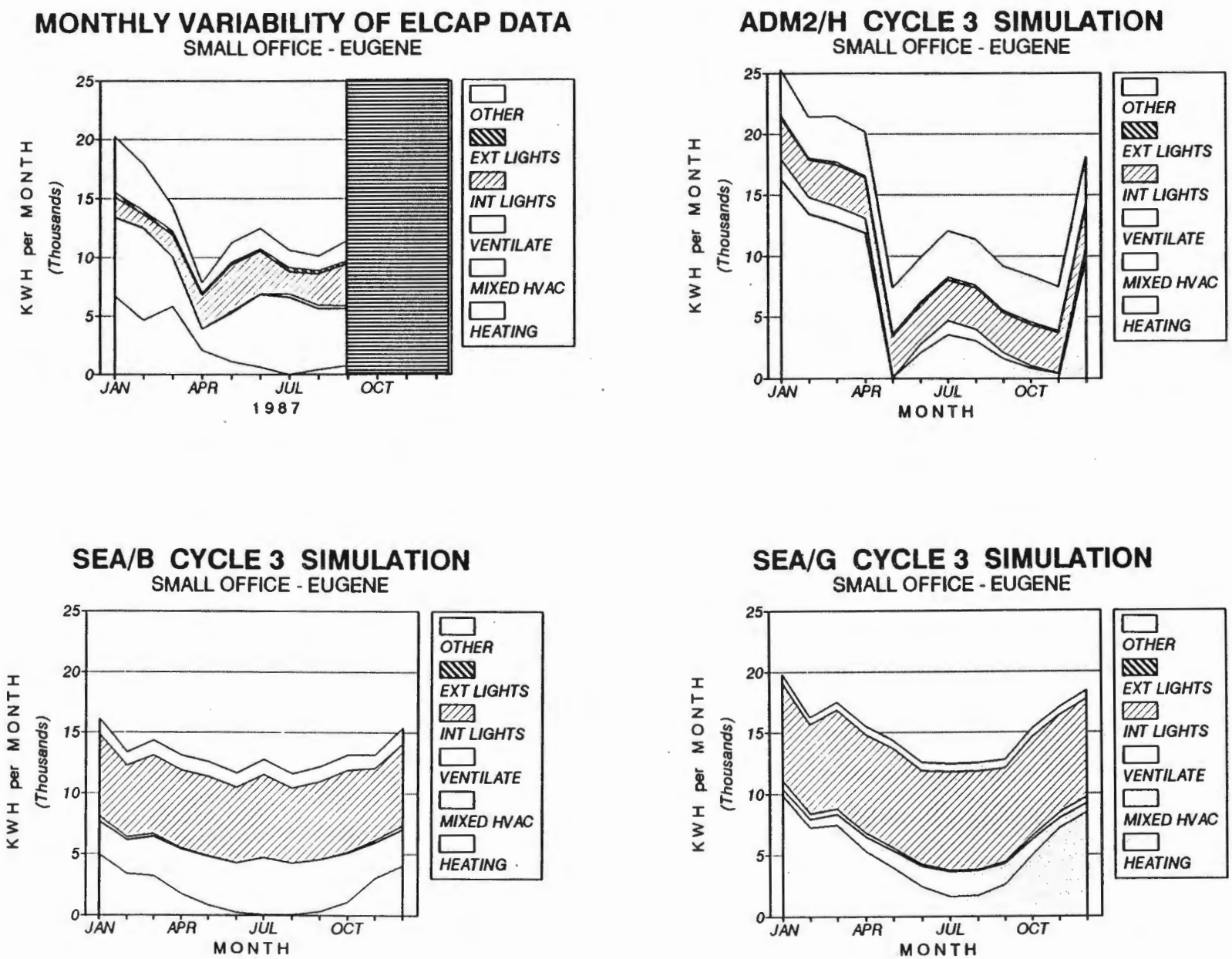
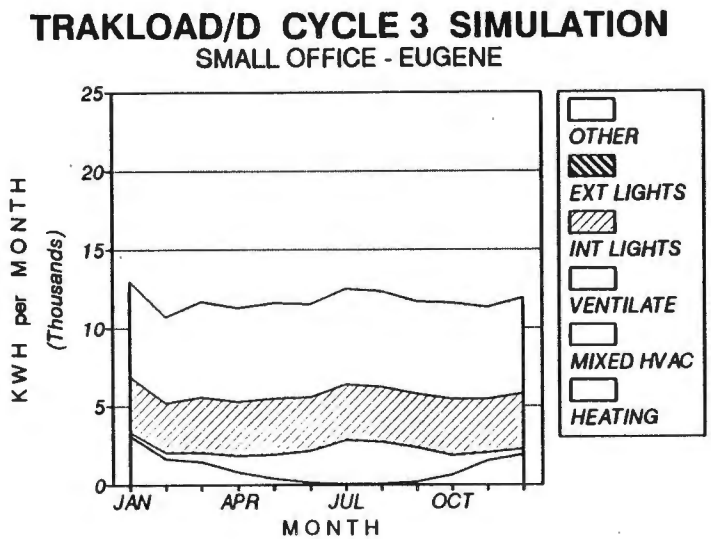
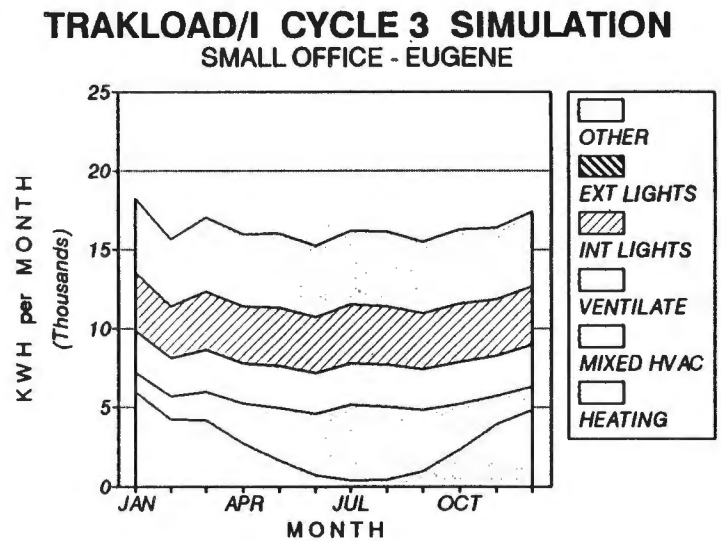

MONTHLY VARIABILITY OF ELCAP DATA
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
25
20
15
10
5
0
JAN
APR
JUL
OCT
1987
OTHER
EXT LIGHTS
INT LIGHTS
VENTILATE
MIXED HVAC
HEATING
ADM2/H CYCLE 3 SIMULATION
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
MONTH
SEA/B CYCLE 3 SIMULATION
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
MONTH
SEA/G CYCLE 3 SIMULATION
SMALL OFFICE - EUGENE
KWH per MONTH
(Thousands)
MONTH

FIGURE 5.14





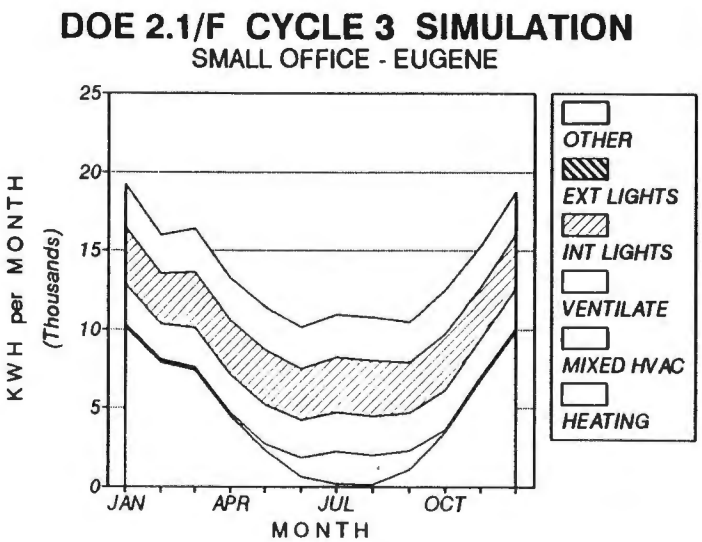
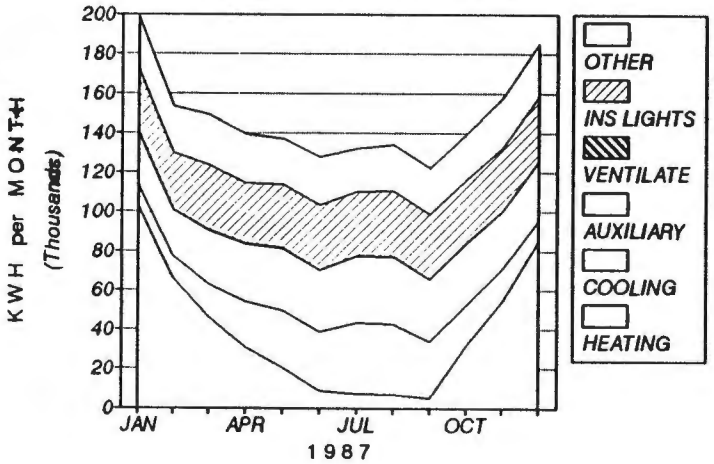


FIGURE 5.14 (continued)

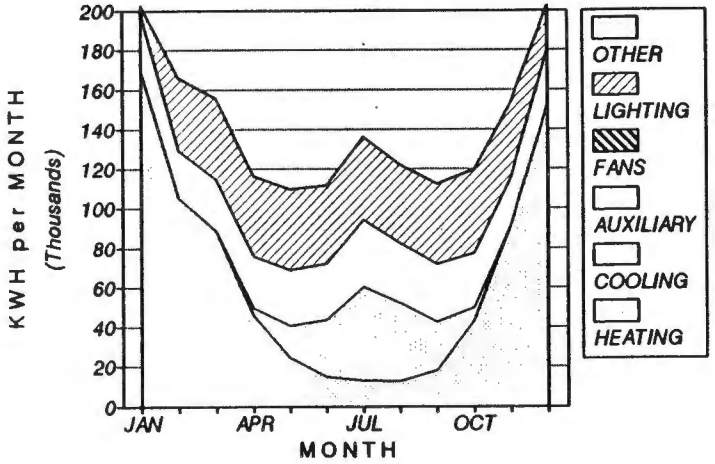
MONTHLY VARIABILITY OF ELCAP DATA

LARGE OFFICE - RICHLAND



SEA/A CYCLE 3 SIMULATION

LARGE OFFICE - BASE BUILDING



ADM2/A CYCLE 3 SIMULATION

LARGE OFFICE - BASE BUILDING

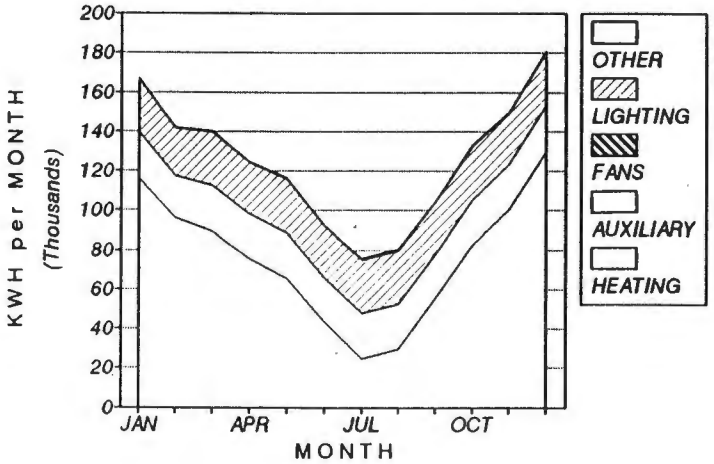


FIGURE 5.15

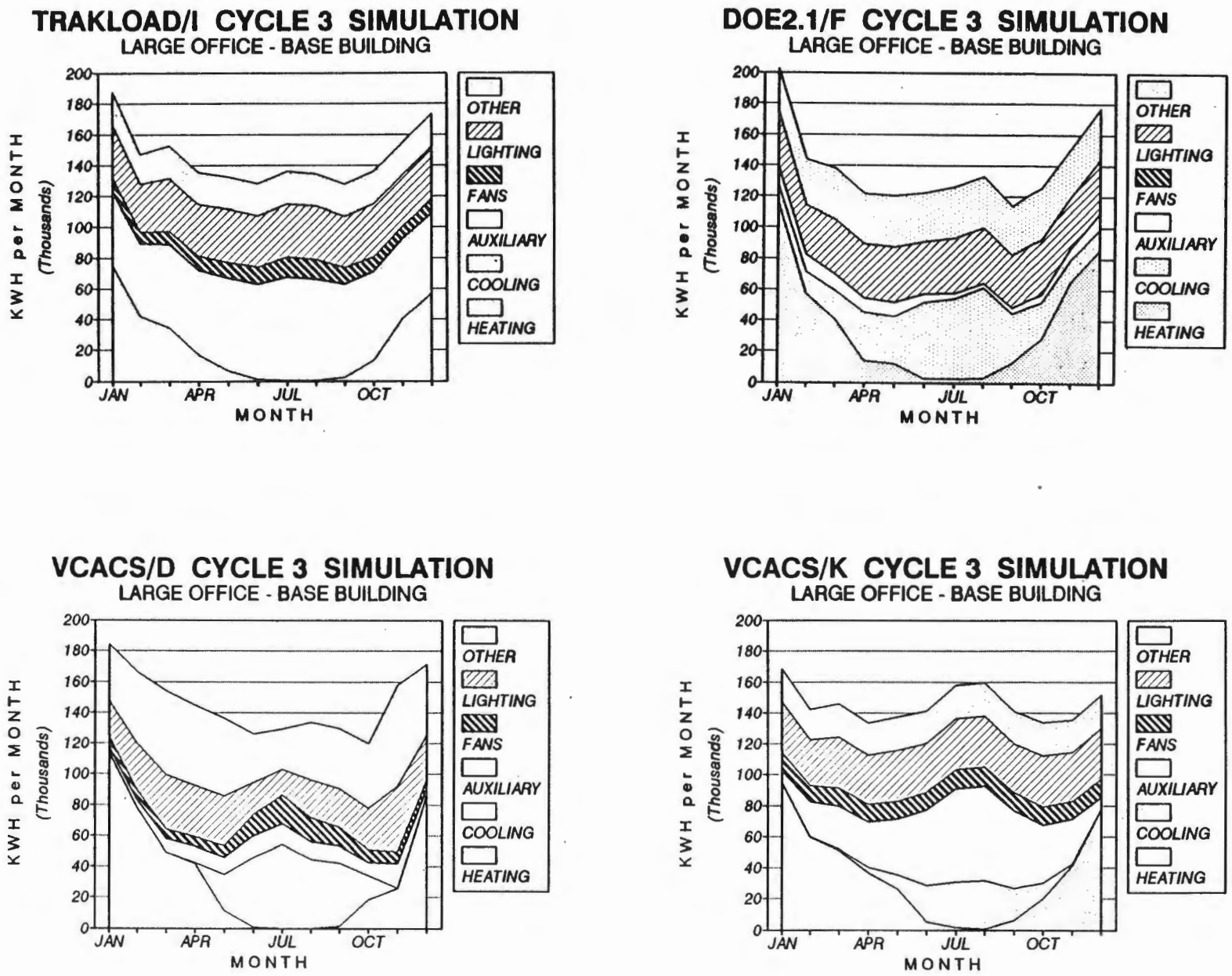


FIGURE 5.15 (continued)

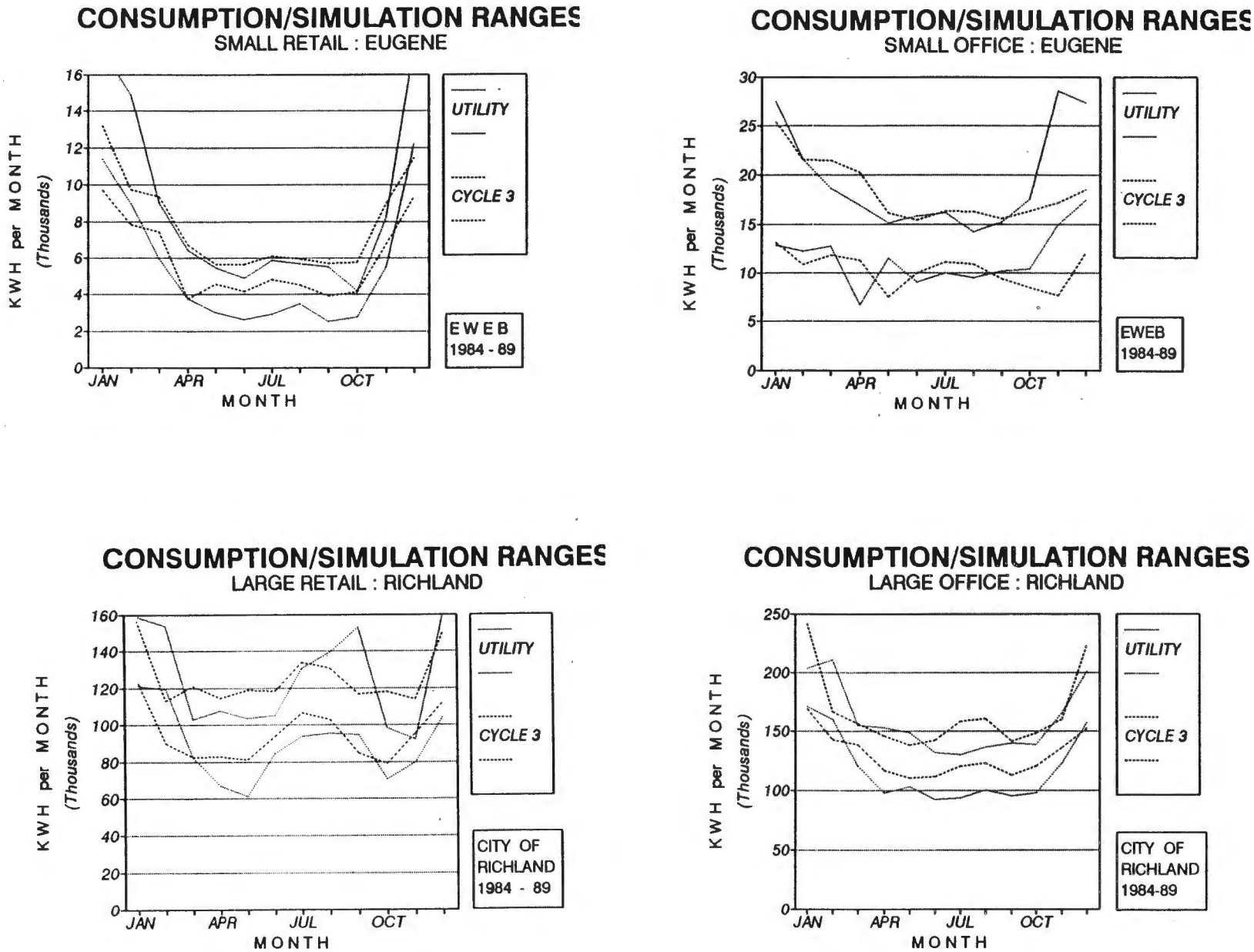

CONSUMPTION/SIMULATION RANGES
SMALL RETAIL : EUGENE
KWH per MONTH (Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 3
EWEB 1984 - 89
CONSUMPTION/SIMULATION RANGES
SMALL OFFICE : EUGENE
KWH per MONTH (Thousands)
30
25
20
15
10
5
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 3
EWEB 1984-89
CONSUMPTION/SIMULATION RANGES
LARGE RETAIL : RICHLAND
KWH per MONTH (Thousands)
160
140
120
100
80
60
40
20
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 3
CITY OF RICHLAND 1984 - 89
CONSUMPTION/SIMULATION RANGES
LARGE OFFICE : RICHLAND
KWH per MONTH (Thousands)
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTH
UTILITY
CYCLE 3
CITY OF RICHLAND 1984-89

FIGURE 5.16

The tabular results in Table 5.5 show similar improvements. Total month-by-month energy consumption from ELCAP was used to compute the average monthly divergence statistics, so the numbers differ slightly from those reported previously (utility data were used in Table 5.3).

Most of the base building model revisions made for Cycle 3 brought the simulated end-use consumption figures closer to the ELCAP breakdowns as well. The result is generally apparent from the end-use energy profiles. It can be observed as well in a second figure of merit, the "Average End-Use Divergence".

This new measure, also reported in Table 5.5, is simply an extension of the average monthly divergence concept, computed however for each energy end-use component rather than total energy. Absolute (unsigned) differences between ELCAP and the simulated energy were determined for each end use and each month, and compared with the total energy for that month; the component statistics were averaged to yield the overall figure of merit for each model. Divergence is minimized and approaches zero as the model approaches the values of the ELCAP standard; and once again, the reader is cautioned that the ELCAP data provides a relative rather than absolute standard for comparison.

The average end-use divergence statistic is an arbitrary measure, not completely comparable from one building to the next. In particular, an adaptation had to be made for the small office building because ELCAP data were not available for the last three months of the year; utility records were substituted for total consumption during those months, but end-use categories were compared with zero, overstating the real divergence.

In addition, following a subjective evaluation, energy entries for auxiliaries, fans, and ventilation categories (or two of them) were combined in some series to give more meaningful results.

Readers are reminded that energy end-use categories may be similar but not identical when ELCAP and simulated data are compared. A poor match in end-use categories between the metered data and what the software reports will show up in higher average end-use divergence. Division of the total energy into further end-use categories will tend to do the same. Subjective decisions to group certain data categories, therefore, tend to decrease the reported values.

Nonetheless, average end-use divergence provides a good tool for comparisons made in like settings. When Cycle 3 results in Table 5.5 are compared with those from Cycle 2, for example, considerable improvement (lower numbers) in the average end-use divergence is noted for most models and in the aggregate for three of the four buildings modeled.

Improvement in the models was therefore achieved progressively over the course of the three simulation cycles. The progress can be seen qualitatively in the graphs and measured quantitatively in the "average end-use divergence" figures of merit.

TABLE 5.5
SUMMARY OF CYCLE 3 RESULTS

SMALL RETAIL		Annual Energy, kWh Cycle 2	Annual Energy, kWh Cycle 3	Average Divergence Monthly Cy 2	Monthly Cy 3	End-Use Cy 2	End-Use Cy 3
Utility/ELCAP		**85500**	**85500**				
Modeler A	ADM-2	71999	82953	21%	20%	45%	46%
Modeler B	SEA	76700	88954	30%	23%	96%	46%
Modeler J	SEA	84591	81249	22%	18%	60%	36%
Modeler D	TRAKLOAD	85801	85500	18%	18%	43%	43%
Modeler E	TRAKLOAD	93332	93999	21%	27%	42%	46%
Modeler D	VCACS	85133	85500	23%	7%	53%	48%
Modeler K	VCACS	82408	84153	11%	21%	53%	34%
Modeler F	DOE2.1	90822	81097	28%	15%	63%	40%
Mean		82590	85417	29%	19%	57%	42%

LARGE RETAIL		Annual Energy, kWh Cycle 2	Annual Energy, kWh Cycle 3	Monthly Cy 2	Monthly Cy 3	End-Use Cy 2	End-Use Cy 3
Utility/ELCAP		**1321200**	**1321200**				
Modeler A	ADM-2	1442555	1388126	15%	11%	26%	20%
Modeler H	ADM-2	1266240	1266239	12%	12%	19%	19%
Modeler C	SEA	1288088	1288089	11%	11%	28%	28%
Modeler J	SEA	1323009	1442372	9%	13%	40%	20%
Modeler E	TRAKLOAD	1184965	1184966	11%	11%	18%	18%
Modeler F	DOE 2.1	1227975	1219656	9%	13%	23%	21%
Mean		1288805	1298240	11%	12%	26%	21%

SMALL OFFICE		Annual Energy, kWh Cycle 2	Annual Energy, kWh Cycle 3	Monthly Cy 2	Monthly Cy 3	End-Use Cy 2	End-Use Cy 3
Utility/ELCAP		**177280**	**177280**				
Modeler H	ADM-2	173456	173454	37%	37%	74%	74%
Modeler B	SEA	160765	160765	17%	17%	60%	60%
Modeler G	SEA	185767	185769	21%	21%	95%	95%
Modeler D	TRAKLOAD	142605	142000	22%	22%	76%	76%
Modeler I	TRAKLOAD	170257	197161	23%	33%	58%	168%
Modeler F	DOE 2.1	166277	145016	12%	12%	54%	152%
Mean		166524	171008	22%	24%	40%	104%

LARGE OFFICE		Annual Energy, kWh Cycle 2	Annual Energy, kWh Cycle 3	Monthly Cy 2	Monthly Cy 3	End-Use Cy 2	End-Use Cy 3
Utility/ELCAP		**1767320**	**1767320**				
Modeler A	ADM-2	2187102	1761791	21%	4%	120%	55%
Modeler B	SEA	766712	1776889	57%	12%	68%	47%
Modeler I	TRAKLOAD	1732105	1755029	16%	3%	93%	63%
Modeler D	VCACS	1764319	1764320	5%	5%	67%	47%
Modeler K	VCACS	1722237	1759674	6%	11%	50%	30%
Modeler F	DOE 2.1	1692104	1497993	7%	6%	27%	33%
Mean		1644092	1751544	19%	7%	74%	49%

It seems reasonable to ascribe the improvements in the models to three factors:

1. Additional information provided at each successive cycle.
2. Additional familiarity with the software and specific building models.
3. Additional iterations/trials in running the model.

Model improvements were not due to feedback about the input parameters used by other modelers or the results they achieved, since this information was not shared.

Several special outcomes during the simulation efforts are worth noting with greater emphasis. Figures 5.17 through 5.19 compare graphically some of the more interesting extremes and progressions noted in the modeling.

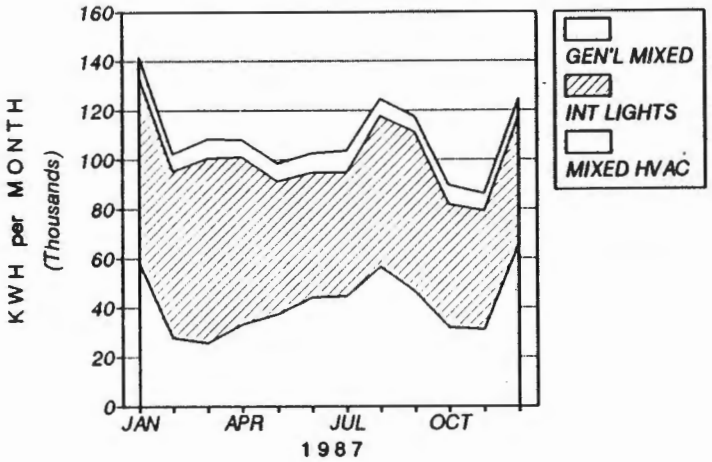
In Figure 5.17, pertaining to DOE 2.1 and the large retail building, the modeler apparently attempted, successfully, to shift the summer HVAC peak from July to August, and at the same time to increase energy consumed for cooling. In the process, however, the already understated springtime heating estimates were further reduced. The overall figure of merit (average end-use divergence) improved slightly from 23% to 21%.

In Figure 5.18 working with ADM-2 software and the large office building, the modeler encountered difficulties which reportedly centered around the correct simulation of the HVAC system. The model had to account for three different distribution systems, but a modified two-pipe system dominated the building. For a two-pipe system, ADM-2 imposes a calendar change-over from heating to cooling mode, rather than allowing dynamic decisions as some of the other models do; in the Cycle 1 model this accounts for the complete cut-off of heating during the summer, and of cooling the rest of the year. In Cycle 2 the dominant system was changed to simulate four-pipe distribution, but the estimated energy continued to be higher than the billings history. In Cycle 3, the ELCAP data showed that the model's energy end-use distribution was faulty. The modeler eventually settled on simulating a multizone system, not because the building was described that way but because it was a way to "tweak" the model to match the known data. As a result the average end-use divergence figure moved from 120% to a more satisfying 55%.

Figure 5.19 shows the same modeler's work on the same building, but with SEA software. Here the progression started in Cycle 1 with a four-pipe fan coil system, although SEA does allow dynamic changeover in a two-pipe system. When the simulated energy proved to be too low for the Cycle 2 standard, the modeler sought a solution by trying to match the input values used in the ADM-2 model, but the total energy actually went down. Here the modeler departed from the normal goal; for comparison, the low-energy model was left as the Cycle 2 result, rather than introducing further changes that might have approximated the expected total energy more closely. The problem was "solved" in Cycle 3 when the simulated distribution system was changed to add air induction to the four-pipe system, an option not offered by ADM-2. That adjustment gave an acceptable model and moved the average end-use divergence figure from 68% to a more satisfactory 47%.

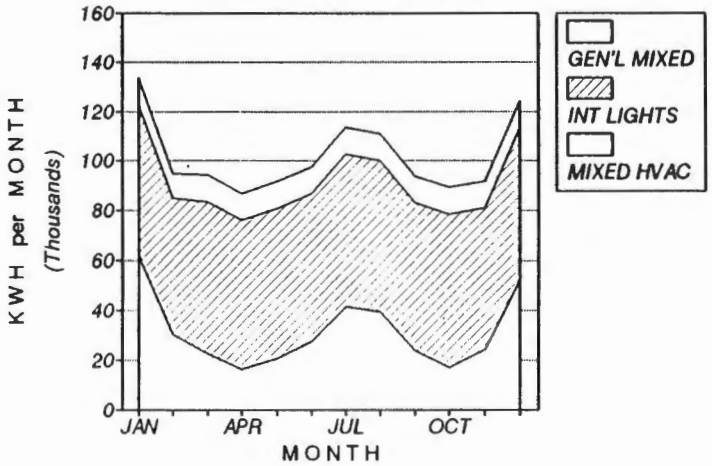
MONTHLY VARIABILITY OF ELCAP DATA

LARGE RETAIL - RICHLAND



DOE 2.1/F CYCLE 2 SIMULATION

LARGE RETAIL - RICHLAND



DOE 2.1/F CYCLE 3 SIMULATION

LARGE RETAIL - RICHLAND

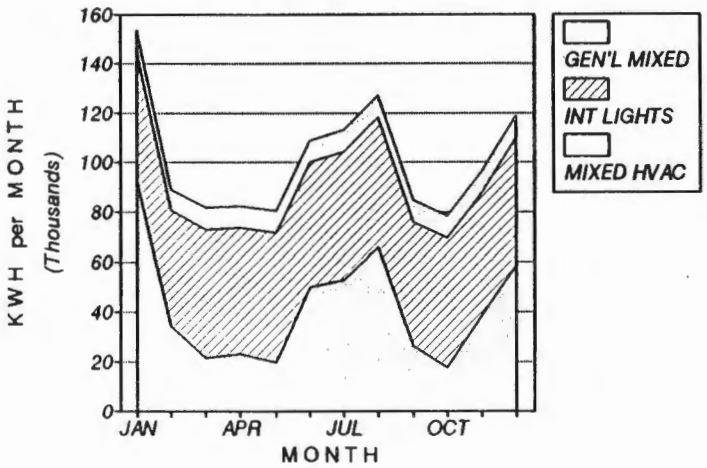
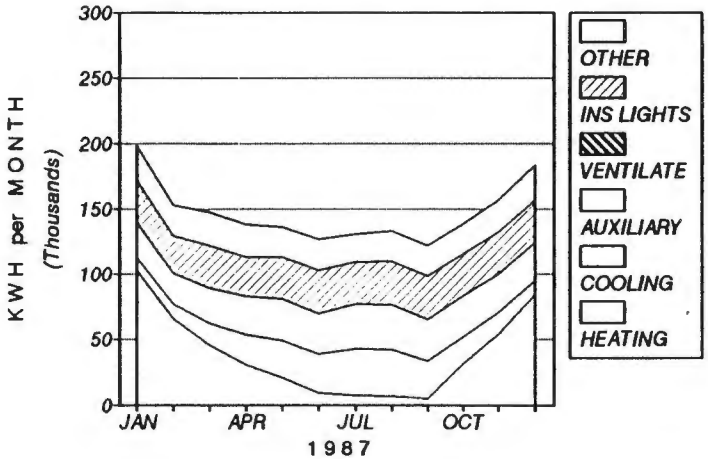


FIGURE 5.17

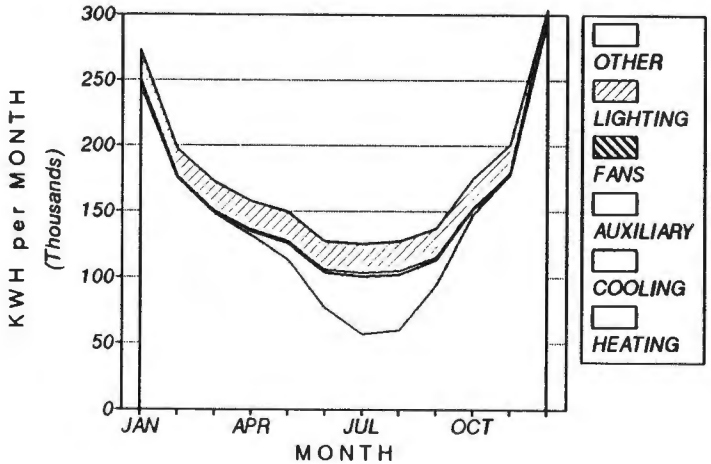
MONTHLY VARIABILITY OF ELCAP DATA

LARGE OFFICE - RICHLAND



ADM2/A CYCLE 2 SIMULATION

LARGE OFFICE - BASE BUILDING



ADM2/A CYCLE 3 SIMULATION

LARGE OFFICE - BASE BUILDING

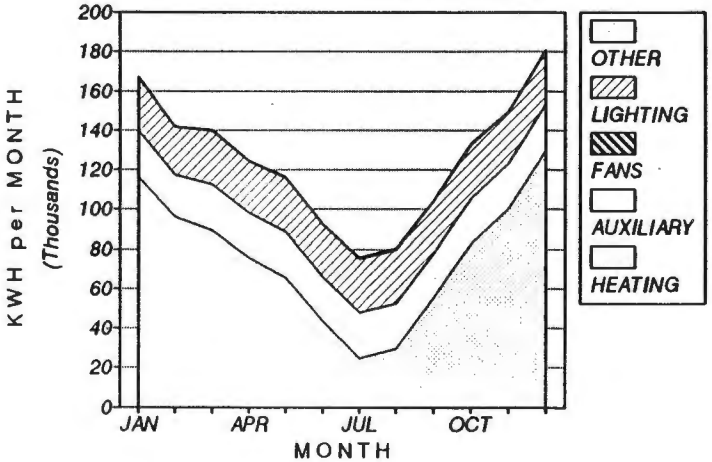
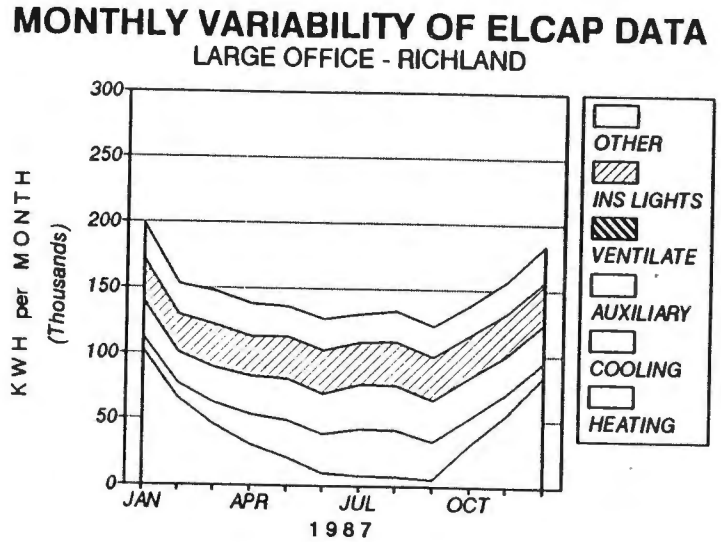
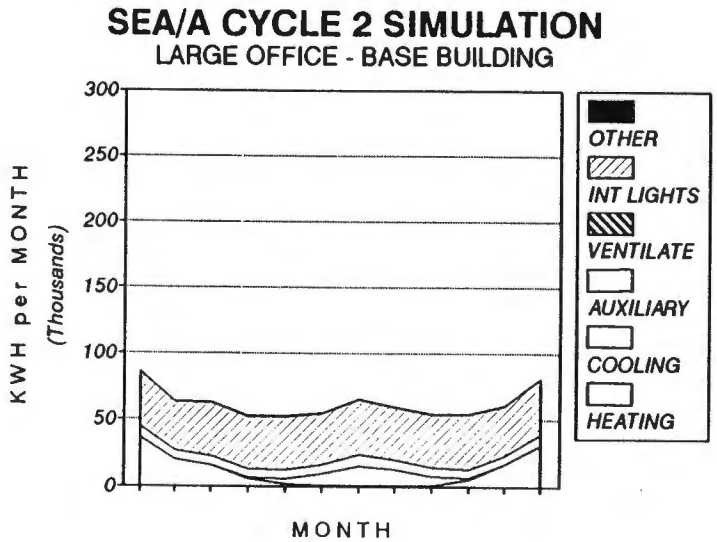


FIGURE 5.18


MONTHLY VARIABILITY OF ELCAP DATA
LARGE OFFICE - RICHLAND
KWH per MONTH
(Thousands)
300
250
200
150
100
50
0
JAN
APR
JUL
OCT
1987
OTHER
INS LIGHTS
VENTILATE
AUXILIARY
COOLING
HEATING


SEA/A CYCLE 2 SIMULATION
LARGE OFFICE - BASE BUILDING
KWH per MONTH
(Thousands)
300
250
200
150
100
50
0
MONTH
OTHER
INT LIGHTS
VENTILATE
AUXILIARY
COOLING
HEATING

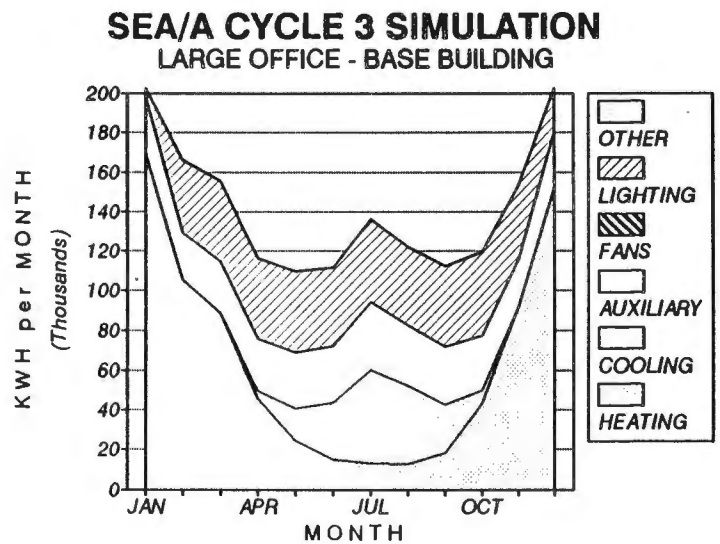

SEA/A CYCLE 3 SIMULATION
LARGE OFFICE - BASE BUILDING
KWH per MONTH
(Thousands)
200
180
160
140
120
100
80
60
40
20
0
JAN
APR
JUL
OCT
MONTH
OTHER
LIGHTING
FANS
AUXILIARY
COOLING
HEATING

FIGURE 5.19

5.3.4 Energy Conservation Measures

During the ECM phase of Cycle 3, modelers were asked to use their base building models to simulate the estimated energy savings of potential Energy Conservation Measures. The primary reason for developing the Cycle 3 models was to establish a good basis for modeling the ECMs.

Modelers were asked to investigate as many ECMs as they thought relevant and then report the six most effective measures, even if the measures might not have been recommended for field implementation. Some modelers reported more or less than six measures, depending on what they though was significant or potentially of interest. Some but not all indicated which measures they would have recommended, and which were merely included for reporting purposes.

The modelers were instructed to treat each measure independently. That is, each measure was to be evaluated without considering the effects of implementing other ECMs. Normally, many measures are interactive; the energy savings that can be achieved by a given measure may be reduced by another measure, and the second of the two may lose its economic viability. In the usual situation, perhaps a regular energy conservation engagement, the cumulative effect of ECMs must be considered. Cycle 3 ECMs were considered independently to promote greater comparability between models and to simplify the comparisons; it also meant that modelers were free to choose ECMs without the need to conform them to a common pattern.

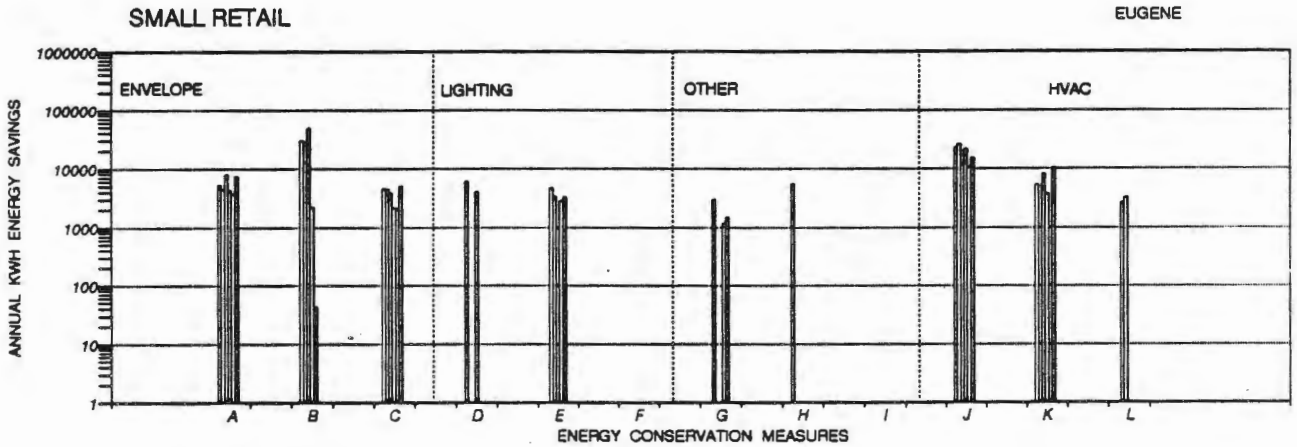
ECM recommendations reflect economic factors as well as energy savings. The modelers were in effect asked to consider not only energy savings but also cost savings from reduced energy, installed costs, the expected life of the measure, and payback. Payback criteria were not specified. The modelers were given rate schedules for the two electric utilities represented in the study. Most modelers did indeed relate their ECM recommendations to economic measures, although apparently a few looked only at the energy savings.

Modelers' estimates of ECM initial cost and expected life are known to vary, in much the way that construction proposals vary. This factor was explored in the "CAP Evaluation Report". The Evaluation of Software project chose to rely on the earlier analysis without further investigation. Modeler estimates and their resulting go/no-go recommendations were accepted without challenge.

In all, the modelers reported about 150 ECMs for the original 25 base building models; many were duplicates of course. All but four measures projected energy savings (two showed negative savings and two anticipated no change), but for some the payback period was so lengthy that the measures were not recommended or at least would not have been recommended for field implementation.

The Energy Conservation Measures proposed by the modelers are described in Table 5.6. The ECMs and their estimated energy savings are summarized in Figure 5.20 (and tabulated in Appendix H). The vertical axis of each graph is plotted to a logarithmic scale. The selection, frequency, and estimated savings of the reported ECMs varied widely from one model to another.

ENERGY CONSERVATION MEASURES - CYCLE 3



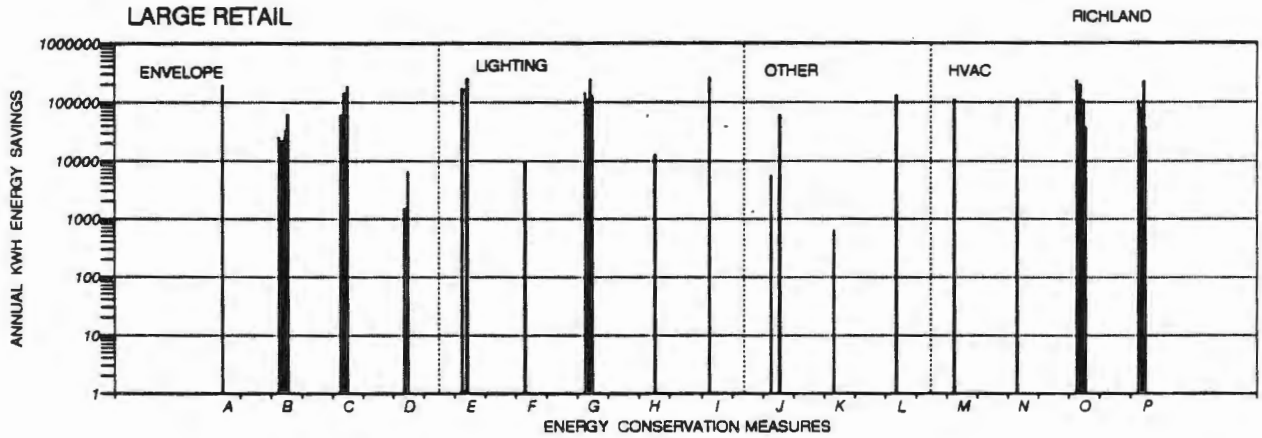
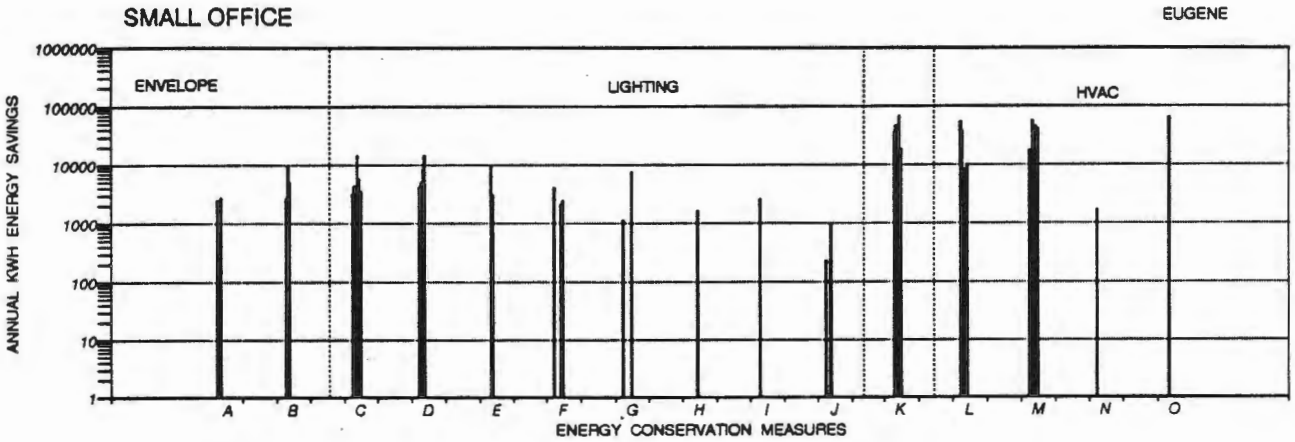


FIGURE 5.20



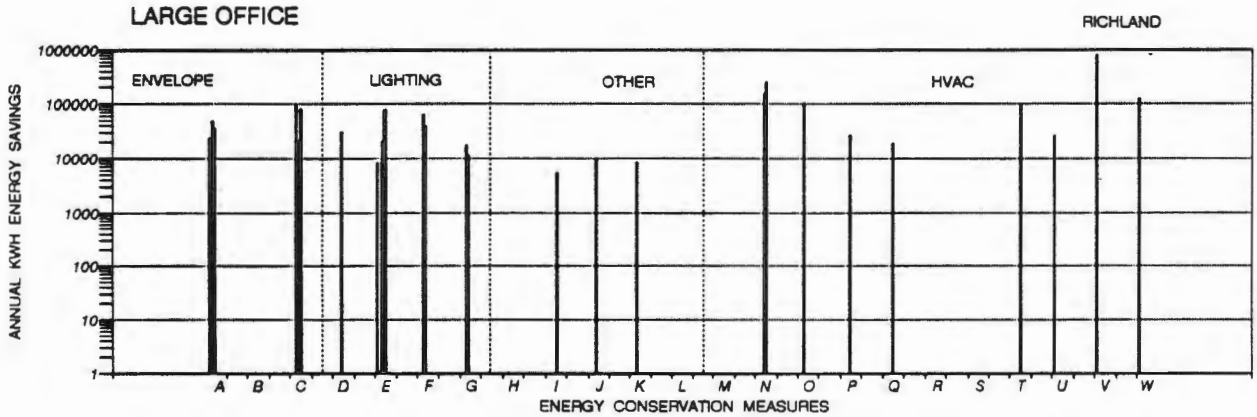


FIGURE 5.20 (continued)

Table 5.6 Energy Conservation Measures (Cycle 3)

SMALL RETAIL:

A Insulate ceiling/roof: add R10 ... R19
B Insulate walls: add R10 ... R11
C Install double pane/storm windows
D Reduce excess lighting: delamp
E Reduce average watts/sqft lighting; install EE fluor lamps
F Replace ballasts with efficient electromagnetic
G Calk and weatherstrip/door insulation
H Reduce ventilation and infiltration
I Wrap water heater, 2" insulation
J Install air source heat pump; COP 2.4 ... 3.0
K Install programmable thermostat/setpoints; nite setback
L Install add-on economizer

LARGE RETAIL:

A Lower ceiling: reduce wall & lighting
B Insulate ceiling: add about R11, making R27 to R30
C Insulate walls to R13 /with R8.7
D Replace single pane windows with double pane
E Reduce lighting with existing controls or delamping
F Relamp incandescent with fluorescent
G Replace lights with energy efficient lamps and ballasts
H Replace standard ballasts with electromagnetic
I Install replacement metal halide fixtures
J Install door between grocery, retail; weatherize warehouse
K Install R-11 wrap on hot water tank
L Reduce lighting & warm-up by one hour each before/after hours
M Replace units: air source heat pumps COP 2.6 ... 3.2; capacity chng
N Repair abandoned economizers/dampers on RTUs
O a) Inactivate or cycle off 1/3 of HVAC equipment and air supply
b) Supply programmable thermostats for RTUs/ setpoints

SMALL OFFICE:

A Insulate roof, add ~ R19 ... 21
B Install thermal pane windows or storm windows
C Replace lights with energy efficient fluorescent lamps
D Remove excess lamps/install reflectors/ use task lighting
E Reduce lighting, unoccupied periods; install motion detectors
F Replace incandescent lights with fluorescent
G Replace fluorescent ballasts with high efficiency units
H Reduce exterior lighting levels or hours
I Increase ventilation rate
J Install 2" or R11 wrap on water heater
K Install air source heat pumps
L Install [enthalpy] economizers on HVAC (RTU) equipment
M Install programmable thermostat/control: setpoint temperatures
N Install timer for entryway heaters
O Install energy management and control system

LARGE OFFICE:

A Insulate roof, from add-R7..to reach-R38
B Install window blinds and/or shades
C Install thermal pane/storm windos, reflective glass
D Delamp; reduce hours of lighting
E Improve lighting efficiency/energy efficient low watt lamps
F Replace lighting fixtures and install more efficient lighting
G Install lighting controls/daylighting
H Replace weatherstripping, 8 doors
I Install CO_2 vent controls to 20 cfm/person
J1 Install heat recovery from A/C or heat pump
J2 Install solar water heater
J3 Install timeclock control for DHW circulating pump
K1 Install 85% efficient motors in fan coil units
K2 Install temperature controls; deadband thermostats
K3 Modify for perimteter heating
L1 Retrofit lesser chiller capacity 50% to improve partial loading
L2 Retrofit higher efficiency chiller, COP 4.0
M1 Retrofit higher efficiency pump motors for cooling tower
M2 As above + free cooling/strainer cycle in tower
N Install water loop heat pump COP 2.8 for main system:
air/air heat pump COP 2.8 for basement and drive-in
O1 Repair energy management and control system
O2 Install selective control switching

In Figure 5.20, the Energy Conservation Measures have been grouped in major categories for each building. While the measures are similar from one building to the next, note that there are differences between them: Measure "A" for one building is not necessarily the same for the next building.

In each graph and for each measure, the number of vertical bars indicates the number of modelers who reported that ECM for that building. The height of the bars indicates the estimated ECM savings. ECMs with zero or negative savings were omitted.

For any given measure the modelers proposed options that ranged from no analysis, to a negative recommendation, to a positive recommendation. That is, for certain measures, some modelers were recommending the ECM at that same time others were discarding it. Several observations have been offered to explain why greater consensus was lacking in the ECM recommendations:

- The base building models may be the most important reason for the differences: Different models will project different savings. If for example a building has significant summer cooling but its model fails to recognize it, the results will tend to ignore viable ECMs for cooling system performance and control. Review of the Cycle 3 graphics presented earlier in this section show sufficient differences between the building energy models to affect the ECM simulation results. This is not surprising given the range of values used for input parameters - for example various thermal R or U values assigned to a given wall, which obviously can bias a conclusion about recommending further insulation.

- Modelers used different input value <u>changes</u> to effect a given ECM. When considering insulation for a roof/attic, for example, the R value added in one instance ranged from a low of 10 to a high of 19.

- Modelers' estimates of initial ECM costs also differ, affecting the payback period. Thus some measures may have been (or might have been) recommended by one modeler but not by another, even with identical energy savings. In a real-world instance, lower or higher rates charged by utilities can produce a similar go/no-go inconsistency, even with identical energy savings (and equal potential for regional benefits).

- Software differences, including weather file differences, may have been a factor. An example has already been cited of how one modeler got sharply different responses from ADM-2 and SEA, despite similar input values. Another example can be noted by comparing the Cycle 2 or Cycle 3 end-use energy profiles for the large retail building: All the models show winter peaks that are higher in January than December - except for the ADM-2 models, which reverse the relationship, strongly implicating differences in the ADM-2 weather files.

- Additional reasons suggested for the varied results and recommendations are subjective differences in modelers' go/no-go criteria, and modeler experience or "mind-bent" leading them to explore one potential ECM but not another.

Early in this report reference was made to a study which compared energy simulation modeling for residences. The study report found rather poor agreement between simulated and actual energy consumption, but much better agreement on the energy saved by specific Energy Conservation Measures. This may be the origin of a belief that has been widely shared among those who work with modeling of commercial buildings, that in the commercial field as well, the building energy estimate may be off but the ECM estimate will usually be closer.

Findings from the Evaluation of Software project dispute this premise. In fact, for many ECMs, the ranges of simulated savings encountered show considerably more variance than found in the total building energy consumption figures.

The rule of thumb probably should be restated: A building energy estimate is likely to have a few problems, but an ECM estimate will usually be worse. Indeed, this is the more rational expectation. Recognizing that projected savings represent computed differences, it follows from the mathematics that the savings are likely to demonstrate larger relative and absolute errors than the bases from which they were computed.

Of equal importance to the finding of variability, and largely as a consequence of it, some models/modelers recommended particular ECMs while other model/ modelers made contrary recommendations on the same measures. Some ECMs endorsed by one modeler were apparently deemed not important enough even to be tested (simulated) by another.

For any given real-world energy audit, it raises the question of how many valid ECMs may have been omitted, and how many uneconomical ECMs may have been recommended inappropriately.

These findings therefore have implications for the design and performance of energy conservation programs.

5.4 Supplemental Comments

Weather Files

A weather file adjustment was originally planned as a component requirement for building energy modeling in the Evaluation of Software project. Each modeler would have examined the weather data and determined the occurrences and significance of differences between the average or typical weather data used in the energy simulations and the weather recorded during the period being simulated. To the extent appropriate, each modeler would have adjusted the weather files used in the software simulations to reflect the weather conditions which actually occurred.

This exercise was planned as an unbiased way to reconcile the differences between energy data collected during a real weather year, and the energy estimates obtained from a model that relied on a typical weather year. By this procedure the typical weather file would have been replaced with a file that reflected the real data for the specific year of interest.

The extent of the work required and the inaccessibility of weather files for some software programs meant the procedure would have been uniquely limited to this analysis, rather than having extended usefulness for routine modeling purposes.

The plan was abandoned when those limitations became more evident. Three of the five software programs evaluated during the project have weather files with unpublished proprietary formats. Weather file creation or modification either requires access to proprietary "Weathermaker" software (which was available for one of the three packages) or else tedious decrypting, translation, and recoding of the file. One of the files was in fact decoded sufficiently to interpret its major components, but it appeared that further effort would have been misplaced.

The weather files used in building energy simulations remains an important factor in the quality of the building energy estimates and ECM recommendations derived from the simulations. Their significance was also explored in one of the sensitivity measures reported in Chapter 6 of this report; further recommendations are included in Chapter 9.

Model Conformance

Some building energy software packages allow a modeler to manipulate the simulated energy consumption, forcing it to conform to the energy consumption figures reported by the utility. Depending on the software, the conforming value may be annual energy consumption, energy consumption by monthly total, or one or more other factors.

In the Evaluation of Software project, both TrakLoad and VCACS offered the conformance for "forcing" feature. When monthly utility billing data is entered, VCACS will cause the simulated results to agree with the monthly totals; the program does this by using the necessary monthly ratio on each energy end-use component (everything is larger or smaller in the same ratio). TrakLoad uses a more sophisticated algorithm that looks at energy and demand during summer and winter periods. During the Evaluation of Software project the feature was tried with both TrakLoad and VCACS, and then abandoned.

While the ability to conform the results is an interesting capability, it also provides a powerful temptation to sidestep the careful work required to develop a meaningful model. In the hands of a novice modeler it has the potential for encouraging meaningless models and useless simulations. Assuming that a simulation model has been constructed carefully, however, and its output already approximates the utility data, the "forcing" feature may be as valid a way to reconcile the unknown remaining differences as any other arbitrary procedure would be.

The conformance feature should be avoided in any series involving ECM modeling. Experience with VCACS demonstrates one reason for this. Once billing data has been loaded into the VCACS file, the program will continue to simulate perfectly conformed results, with unchanging energy totals, no matter what Energy Conservation Measures are added; the savings are always zero and the results are obviously meaningless.

When the forcing feature is cancelled, ECMs can be simulated meaningfully, but savings are (and must be) made by comparing what is simulated against the unconformed base building model. The conforming feature, therefore, has utility only as a cosmetic feature; it cannot be used to construct a base building model that is valid for subsequent ECM evaluations.

5.5 Modeler Comments and Suggestions

Modelers were invited to comment on their modeling experience with this project and other engagements, recognizing that the purpose of the study is to gain further insights into the modeling process, the quality of the software used, and opportunities for improvements.

Modelers were encouraged to discuss one or more of the following: Problems encountered in modeling, insights gained, problems solved, software preferences and reasons for them, software limitations and manipulations, improvements needed in software and modeling techniques, and other aspects of software and modeling that others might gain by knowing. A few abbreviated thoughts were received in direct response, but no one elected to address the topics at length. However, comments received at other times during the project touched on a few of these points as well as others.

Selected comments follow here and in other appropriate places in this report. They have been edited for brevity, while attempting to convey the modelers' original thoughts. Modelers' opinions do not necessarily agree with those of the principal investigator.

General comments about the modeling process

- We have found that modeling in general is more often an art rather than an exact science. Good assumptions by the modeler are required to prepare an accurate building simulation. For example, modeling software often lags behind advances in HVAC equipment and control technology. In this situation, the modeler must manipulate data input to account for the software's limitation.

- We have several pre and post processing programs that supplement our capabilities with these programs. Two programs, for example, have simplified estimating loads and inputing rates schedules. In addition, we have written our own modeling programs to help with lighting analyses and degree day calculations.

Modelers' Comments - Cycle 1

- Modeling is useful to me as a diagnostic tool. At this stage in the audit, I would be making another trip to the facility to discover what the exact nature of the problems with the heating system are. The modeling has helped focus my time on what appear to be significant problems, which imply significant opportunity for effective Operations and Maintenance Measures or Energy Conservation Measures.

- I usually rely on comparisons with the historical energy consumption to use the model to identify how the building is performing. Field data often is incomplete, and does not supply the actual efficiencies and operating parameters of some of the key systems. As an initial model I am satisfied with the results transmitted here, however I would not represent it as "what is out there".

- Important questions came to light during the development of the model which I could not answer to my satisfaction from the building abstract. In the normal course of events I would try to confirm all of these questions. Instead, I made the following interpretations of the building data.

- In the event of unexplained performance I normally go to the site and discover the specific causes. If on-site inspection demonstrates that my suspicions are correct, then suitable action is taken.

- In addition to software limitations, certain building characteristics present modeling challenges. For example, air infiltration, which is difficult to measure, varies widely and has a major effect on energy use. Without expensive field tests to obtain accurate input data, the modeler must make good assumptions. This is even more true in design assistance projects where the building does not yet exist and the quality control procedures of the construction contractor will have a major impact on infiltration.

[Modelers commented further about their modeling assumptions, why they were made, and what they would do with additional field investigation.]

Modelers' Comments - Cycle 2

Several modelers presented graphical and/or tabular comparisons between their modeled results and the utility data reported for the building.

One modeler likes to have about 5 years of billing data; will not average it for end comparison but does analyze variation. Believes buildings tend to "deteriorate" 5% to 7% a year: Therefore, use most recent data, but don't worry about matching abnormalities.

- A linear regression of the monthly KWH consumption against the heating degree days showed a good correlation (r squared = 0.79). This shows internal loads relatively fixed and consistent from month to month. It also shows that the assumption of a 65 degree balance point for this building works fairly well in predicting heating loads. The simulation of this simple envelope-influenced building should be relatively accurate. [Note: The degree day data for the analysis was obtained independently; it did not fully agree with the data previously submitted to the modelers.]

- In a normal audit would talk to building owner/operator to understand changing usage patterns. More recently have also installed data logging equipment for 24 hours or more, to see what was running and when.

- The Cycle 2 changes made to the Cycle 1 building model are noted. These changes are in conflict with the information provided on building operation, but the building model now provides a close approximation to utility billing data.

Large Retail:

- Modeling revealed that the HVAC energy consumption is significantly higher than expected. A likely source of the problem is that the energy management system is not working correctly. In my experience, energy management systems are not an effective way to control this type of building. They are too complicated to be maintained and operated correctly

Small Office:

- Because of the disparity of billed demand loads and energy consumption in the utility billing information, a simulation correlation has been provided for the first and the last twelve months of utility data. Although the total consumption can be aligned, the actual and simulated monthly KWH consumption do not correspond, especially during the winter months. It appears that the simulation program cannot accurately reflect the energy usage operation of the building over a year period.

- Historical consumption makes it clear that there are significant problems with the heating system. Normally these problems are solved with some type of Operations and Maintenance Measure recommendations (OMMs). The base case model for evaluating ECM performance usually includes the effects of OMM recommendations, to make sure the ECMs do not receive credit for items that were part of the original design but which are now broken or not adjusted properly. Without on-site inspection to determine the exact nature of the problem with the HVAC system I am forced to make best guesses at what is wrong and cannot make suitable OMM recommendations or adjustments.

Large Office:

- TrakLoad will not let you enter a larger window percentage than wall. Increased the wall area to allow correct window area with 50%-50% window/wall.

Modelers' Comments - Cycle 3

- I appreciated receiving the end use metering data, but since such data is not normally available, I have chosen not to let it influence my Cycle 3 work in any way.

- Interaction of ECMs results in combined savings which often are much less than the sum of the savings of the individual parts. Use the analysis of individual measures as a decision tool in defining which measures belong in the recommended package of ECMs. Usually I run a model of the combined effect of all of the recommended ECMs and then reduce the savings attributed to each ECM so that the sum of the savings attributed to each recommended ECM equals the total savings predicted for the combined effect. The savings are reduced proportional to the sum of the individual measures.

- The most reliable method of producing modeling results that will be achievable, and more importantly verifiable, is to define a package of ECMs which will reduce the energy consumption of the building by at least 15%. Then model the package. If all of the measures are implemented, the weather- corrected building performance will usually be within less than 5% of the modeled performance.

- Since no OMMs were identified and the base case model was not adjusted for OMMs, savings for the ECMs affecting the HVAC system are out of line with what the same measures would achieve if the system was functioning correctly. This may result in a serious problem in comparing the predicted savings of the various ECMs evaluated by different modelers. The ECMs are going to pick up the saving due to the problems in the current system. since the nature of the problems are not clear, the attribution of the savings can quite justifiably differ. I assumed that the economizer additions picked up most of the current problems.

Large Retail:

- Available building description data does not indicate significant problems. There were not six measures that I would recommend based on the available data. If any of the evaluated measures are implemented singly, they will have such a small impact that the effect will not be distinguishable by the building occupant from the "noise" due to normal variations in operating conditions and weather.

CHAPTER 6: SENSITIVITY STUDY

The Evaluation of Software project established a sensitivity study component as a way to focus on software performance, in contrast to the round robin simulations that emphasized modeler contributions to the modeling process. A sensitivity analysis compares changes in output resulting from changes in input.

A series of simulations was conducted with each software package, for each of two building types. Sensitivity measures were determined for 25 parameters selected to represent various interests in the modeling algorithms.

Sensitivity to specific measures showed similar but distinct patterns between the two building types. Sensitivity to a given measure was often similar from one software program to another, but occasionally quite different.

6.1 Study Concept

The design of the sensitivity study called for a series of simulations, similar to the normal process for evaluating Energy Conservation Measures. A base building energy simulation was followed by simulations for a set of pre-defined "measures". The change in output (the energy savings) was determined for each measure. The procedure was then repeated for each of the other software packages. Differences in output sensitivity were ascribed to differences in the software.

Several methodologies were considered for this effort. The objective was to make the sensitivity results as meaningful as possible, with minimal influence from the modelers.

It was recognized that the results could be affected by the choice of models, as well as the software. Two modelers may be able to model the same building and obtain similar results - both as to total energy consumption and the distribution of that energy by calendar period and end use. But no two modelers are likely to create the same model for a given building, even with the same software; values selected for input parameters are likely to be distinct. Models constructed on different software will certainly differ, almost by definition.

Software-related differences arise from basic modeling approaches (such as bin versus hourly methods), absence or availability of specific features (for example, daylighting), and the particular algorithms used. Modeler differences are likely to arise from opinions about what the "target" results should be, assigning priorities to conflicting data, filling in missing data, personnel qualifications, experiential bias, and being swayed by how various software packages accept, use, and present information, including the modeler's attempts to compensate for real or perceived software deficiencies.

In fact, it can be reasoned that models of the same building constructed with two different software packages cannot contain identical input values if they are to give identical results. The modeler must use his experience to vary the models and in this manner each modeler individually approaches the desired result.

For the Evaluation of Software project, the procedure for the sensitivity analysis in effect came down to a choice between models with similar input characteristics, or models with similar output characteristics.

> A series of models can be constructed for a given building, each with a different software package, using nearly (but not entirely) identical values for the input variables. In general the output results for those models will probably not agree as well as more distinctive models built independently by several qualified modelers to conform to an output target. Models forced to conform with a common set of input values lack the "reality" of how models are normally constructed.
>
> Alternately, a series of models constructed independently to a common output target will not, in general, share common input values; and some of the input values used to achieve this result may not agree with the real world.

The conceptual choice in conforming the models for a sensitivity study is therefore whether it is better to set consistent input values, or seek conformity in the outputs.

The initial plan had been to select and use ten of the base building models developed during the three-cycle round robin sequence. The rationale was that these models had already been subjected to considerable effort to conform them to common bases - building descriptions, utility energy data, and ELCAP end-use data. The models had been prepared under nearly normal procedures by modelers conversant with energy conservation processes, software, and modeling techniques. Accordingly the base building models would be fairly similar and of good quality; at very least they would estimate similar energy levels. It was suggested that the results obtained in this manner would have the greatest significance and could be most readily evaluated.

On the other hand, those models proved to be more divergent than anticipated. The end-use energy profiles generated in Cycle 3 varied considerably from one model to the next, and the input parameter values used in the models were disturbingly different. Rather than use the round robin models, it was argued, they should be further modified with common values for the input parameters.

While there were positive reasons favoring both points of view, the project was able to support only one approach. A decision was made to start with Cycle 3 models, then conform them to a set of input parameter values. It was recognized that the output results might no longer agree with data either from ELCAP/CREUS or the utilities' billings.

The selected methodology therefore compares software packages through models portraying real-world buildings - rather than "adiabatic", MCS, or otherwise stylized buildings. But the input values have been modified for consistency.

6.2 Study Procedure

The Evaluation of Software sensitivity study was designed to obtain information about software performance by determining the changes in simulated energy that result from changes in specific input parameters, taken one at a time.

The sensitivity analysis called for 250 simulations once the base building models had been established: 25 parameters to be varied in each of ten models, representing five software packages and two buildings.

The software was the same used in the rest of the project - ADM-2, SEA, TrakLoad, VCACS, and DOE 2.1c/d. The two buildings were the same small retail building and large office buildings previously used in the round robin study. The 25 measures defined for this study were chosen to be similar to normal ECMs and to consider a variety of ECM types such as building envelope, lighting, HVAC equipment, and so forth.

Model Selection

The first step in the sensitivity study was to establish good base building models. During the three-cycle round robin simulation studies, models were constructed and refined by modelers who progressively adapted their models to reflect descriptive building data, more than two years of utility billing data, and about 15 months of metered end-use data from Bonneville's ELCAP and CREUS programs. The Contractor had originally expected to use ten of the models developed during the round robin.

The ten models selected were created by the following modelers:

Software	Small Retail	Large Office
ADM-2	Modeler (new)	Modeler A
SEA	Modeler J	Modeler B
TrakLoad	Modeler E	Modeler I
VCACS	Modeler D	Modeler K
DOE 2.1	Modeler F	Modeler F

The one new model was required because no ADM-2 model had been established for the small retail building during the round robin studies. Responsibility for the new model was assigned to Modeler A. In developing it, an attempt was made to observe the same three-cycle progression followed in the round robin studies, except that no ECMs were evaluated at Cycle 3. Results in Chapter 5 show data and graphics for this model along with the others.

These models proved to be more divergent than anticipated - both in input parameter values and output results. Therefore, a decision was made to modify the models with a common set of input values: values of key parameters were specified and inserted (insofar as possible) into the building model input files, before making the sensitivity runs.

Base Building Parameters

Input parameter values were selected for the base building models as shown in Table 6.1. Modelers were required to conform their models to these values before proceeding with the sensitivity simulations.

Because software packages vary, some adaptations of these values were presumed necessary, and modelers were allowed this discretion. For example, ADM-2 provides dynamic modeling of shading from overhangs, whereas the same effect must be approximated in SEA and VCACS by using a single composite shading factor. Some parameters are missing entirely in certain software packages, and the modeler was free to exercise judgement in compensating. For example, SEA does not detail water heating; but the equivalent can be calculated manually and included with other loads.

Values specified for most parameters were representative of the entire building. However, some values vary by zone or exposure, and the modeler was asked to maintain these nuances; for example, the wall U/R values in the large office building vary by floor. Other parameter values, such as supply air and lighting power levels, represent building totals; for example, the total wall areas specified reflect the gross square feet of walls in all zones for a given direction: one possible way to adjust an existing model, if needed, would be to apply a constant ratio to the wall area in each zone.

The "mandatory" parameter values did not cover all the data needed to complete any of the models. Modelers were invited to ask for further values (which none did) or else to exercise judgement in using or adapting the values already in the file for the Cycle 3 model assigned to them.

Because the model output might no longer conform to metered data from ELCAP or the billings of the utilities, modelers were admonished "Do not adjust the mandatory parameter values in an attempt to conform the annual energy consumption."

Modeler Assignments

Modeling assignments for the sensitivity study were given to a subset of the modelers who had participated in the round robin studies. The modelers were given computer file images of the 10 selected Cycle 3 base buildings, assigned as shown below. Modelers were also given the list of input parameters and values shown in Table 6.1 and asked to modify their models accordingly. Weather files were controlled as shown in the table, to minimize variations.

Software	Small Retail	Large Office
ADM-2	Modeler A	Modeler A
SEA	Modeler C	Modeler A
TrakLoad	Modeler E	Modeler D
VCACS	Modeler D	Modeler D
DOE 2.1	Modeler F	Modeler F

Table 6.1
Base Building Parameter Values for Sensitivity Study

Item	BUILDING SMALL RETAIL	BUILDING LARGE OFFICE
WEATHER FILE		
location:	Eugene, OR	Richland, WA
ADM-2	Salem (supplier)	Richland (supplier)
SEA	Eugene (modeler J)	Pendleton (modeler C)
TRAKLOAD	Eugene (supplier)	Walla Walla (modeler E)
VCACS	Eugene (modeler K)	Richland (modeler K)
DOE 2.1	Salem (modeler F)	Hanford (modeler F)
ZONES		
# of zones	EM	EM
ENVELOPE CHARACTERISTICS:		
conditioned sqft	5088	53000
height, ft	10, 11.75	8, 9, 15.2
EXTERIOR WALLS		
N walls gross sqft	800	5150
E walls gross sqft	35	6200
S walls gross sqft	940	5150
W walls gross sqft	720	6200
structural wall R *	1.81	(a)
WINDOWS *		
N window sqft	277	2400
E window sqft	35	2720
S window sqft	0	2300
W window sqft	100	2850
window U	1.04	0.66
window S C (composite) (b)	0.94	0.69
DOORS/FRAMES		
door/window frame sqft	40	1330
PARTITION WALLS		
walls	no	yes
ROOF, FLOOR		
floor loss (UA) Btu/hF	180	incl basmt wall 1600
roof area, sqft	5088	9900+3550
roof R	12.00	7.35;13.3
BUILDING MASS DENSITY	medium	medium
LIGHTING		
interior kW peak	8.80	110.00
apprx. annual kWh	31000	388000
exterior kW peak	0.50	8.00
apprx. annual kWh	2200	16000

Note: EM = use value in Existing Model

Table 6.1 - continued
Base Building Parameter Values for Sensitivity Study

Item	SMALL RETAIL	LARGE OFFICE
OCCUPANCY		
occupied days	M thru Sa	M thru F *
occupied hours	8 - 17	9 - 18 *
people peak	21	240
WATER HEATING		
gallons storage	40	140
Temp F	120	140
gal/day	32	320
for SEA, assume 65F deg rise		
OTHER INTERNAL LOADS		
kW peak	1.8	38.00
SETPOINTS degree F *		
heating	72	71
setback	60	64
cooling	75	74
setup	85	84
AIR DISTRIBUTION CFM		
occupied	6800	64000
night fans	cycling	cycling
outside air (occupied)	800	10600
infiltration (unoccupied)	400	900
economizer	no	(c)
SYSTEM/PLANT TYPES		
distribution	EM	2,4 pipe + single zone air
heat	resistance	resistance/boiler
cool	DX	chiller & twr
HEATING PLANT		
capacity: BTU/hr	210000	1500000
capacity: BTU/hr		150000
COP	1.00	1.00
COOLING PLANT		
capacity: BTU/hr	192000	2400000
COP	2.00	3.90
capacity: BTU/hr		96000
COP		2.74

* = may vary by zone or exposure
(a) = assume 80% @ R=14.2, 5% @ 11.0, 15% @ 4.9
(b) = for static shading model
(c) = partial effect in perimeter fan coil units

Sensitivity Measures

A list of input parameters was compiled for the sensitivity measures. Twenty-five parameters were selected as representative of a variety of interests found in modeling algorithms:

building orientation	exterior insulation
glazing	shading
in/exfiltration	lighting
water heating	HVAC heating/cooling
occupancy	seasonal variations
weather	

Input-output sensitivity was determined for each of the 25 measures, using the parameters and values specified in Table 6.2. The weather files used in evaluating the sensitivity measures were the same as those previously listed in Table 6.1.

Simulation Procedures

Each sensitivity measure was evaluated as a single-measure simulation. Measures and their valuation were selected to avoid ranges that could lead to zero-value or negative-value parameters. Modelers were advised to "lock in" as many parameter values as possible; for example, to define equipment sizing from keyboard entry rather than autosizing.

Modelers were asked to use available techniques to accomplish the desired measure changes. For example, VCACS does not have an azimuth setting as the other software packages do, but it is still possible to "rotate" the building (measure 1) by re-entering the wall directions. SEA will not simulate an economizer (measure 13) for the type of system in the small retail building, but an alternate base building that could be manipulated was used for that particular simulation.

Insofar as possible, changes in input variables were applied equally to all zones in a given building model. For example, in measure 4, "added insulation" was applied to all exterior walls except basements. Variation in U values from one wall to another (by zone or exposure) before the insulation was added was also reflected in a similar variation after insulation.

Table 6.2
Sensitivity Parameters and Values

Building orientation	
1. overall building orientation	rotate clockwise 90
Exterior insulation (envelope)	
2. floor	increase R value by 30%; (decrease loss by 23.1%)
3. roof	add R19 insulation
4. walls (all walls above grade)	add R11 insulation
Glazing and Shading	
5. glass area on S. wall	Sm Retl: convert: 30% same-R glass Lg Offc: decrease by 30%
6. glass R	increase 30%
7. shading coefficient	decrease 30%
Air supply	
8. outside air	50% more outside air cfm
9. supply/return fan operation, unoccupied	toggle cycling/continuous
Lighting	
10. interior lighting KW/sqft	decrease 30%, each hour
11. heat to space	decrease 30%
Water heating	
12. gallons of hot water per day	increase 100%
HVAC heating/cooling (note b)	
13. economizer(sensible) 45F to 65F OSA temp	toggle: yes/no (note a)
14. supply (delivered) air hold OSA cfm constant	increase 30%
15. cooling EIR/COP	increase 30%
16. heat pump, COP = 3.0 @ 47F	toggle system type
17. multi-zonesystem w/economizer & OSA temp reset, no discriminator	toggle system type (note b)
18. variable air volume system constant volume fan; inlet vanes	toggle system type (note b)
19. setpoint temperature - winter (heating), occupied no change in setback temperature	increase 5 degrees F
20. cooling equipment partial load	increase specified capacity 50%
Occupancy	
21. occupied hours	increase 2 hours (note c)
22. number of people; all zones	increase 50%
23. vacation period unoccupied	all of July
Weather	
24. location (entire file)	swap "Eugene", "Richland"
Building Mass	
25. walls, floors, and roof (combined measure)	change to heaviest ASHRAE groups or software categories

Note:

a. A central system may have to be invoked before simulating this measure because at least one of the software packages seems to be limited at this point.

b. Hot and cold deck temperatures of 120F and 55F.

c. On normally occupied days, start one hour sooner, run one hour later. Change all affected schedules (people, lighting, HVAC, etc as applicable).

6.3 Findings and Evaluation

The sensitivity study produced findings that derive from the base building models, sensitivity measures, and overall software performance. Base building models, after conforming them with common input values, showed more widely divergent outputs than the comparable Cycle 3 models. The goal of isolating the sensitivity study from modeler influences was only partially successful.

Sensitivity to specific measures showed similar but distinct patterns between the two building types. Sensitivity to a given measure was often similar from one software program to another, but occasionally quite different. Relatively small differences are probably due to model differences, influenced both by the modeler and the software. Larger differences may be due to errors in the software or by the modelers.

6.3.1 Base Building Models

When Table 6.2 values were used to conform the inputs, it established a new set of ten base building models distinct from their Cycle 3 counterparts. Most of the new base building models were similar to the previous ones, but there were also a few surprises.

Tabulated results of building energy simulations are reported in Appendix I.

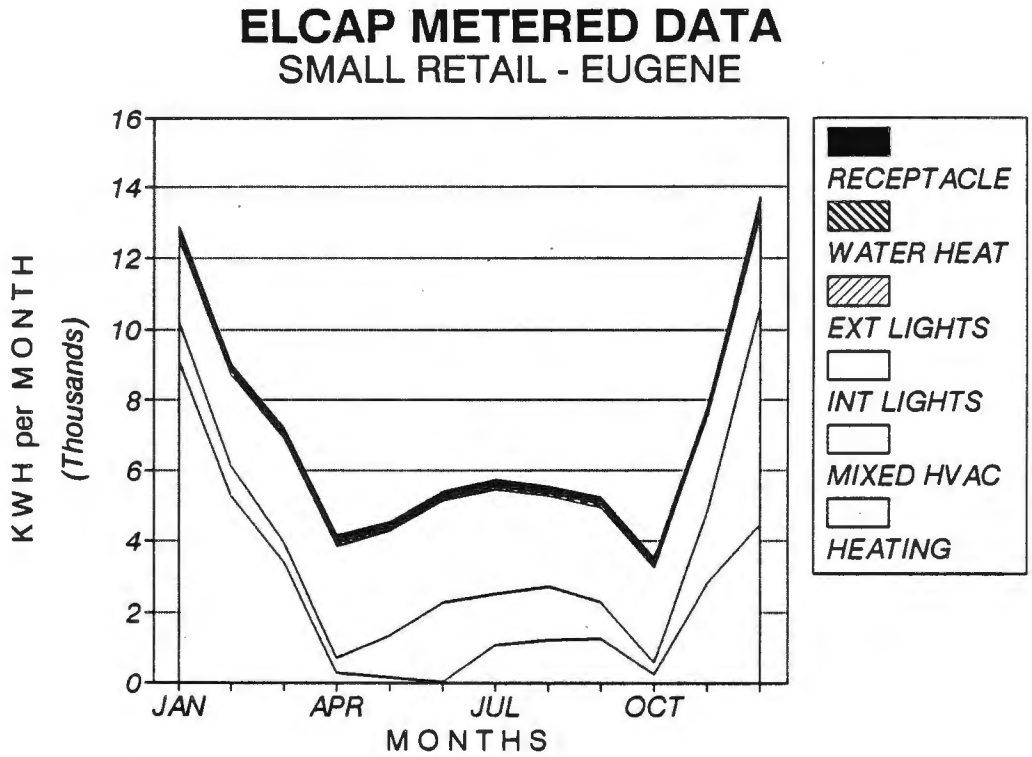
End-use energy profiles are shown in Figures 6.1 and 6.2. Figure 6.1 compares the profiles for the five base building models of the small retail building; Figure 6.2 compares profiles for the five base building models of the large office building. The broken line in each shows the monthly energy projected by the comparable Cycle 3 models. The applicable ELCAP energy end-use profile is also repeated in each building's set of graphs.

Changes in the base building energy projections were expected, but some of the changes were greater than anticipated. Looking ahead to what happens when sensitivity measures are introduced, it is obvious that results will be affected by the differences in the base building models.

Although common values were used for many input variables of the ten base building models, caution is appropriate in concluding that the differences in output energy levels reflect nothing more than software differences. Modeler influences may still be evidenced in least two remaining ways:

1) Implementation of the assigned input values was subject to many of the same modeler interpretations of data variables recognized earlier in the report for the round robin study;
2) Modelers were allowed some modeling discretion because not all input parameters were assigned master values.

In retrospect it probably would have been better to have assigned values for an even larger number of input variables, despite the difficulty of doing so, thus minimizing (but not eliminating) potential perturbation of the base building models by the modelers. This procedural change should be considered if in the future the sensitivity effort is repeated or extended.


ELCAP METERED DATA
SMALL RETAIL - EUGENE
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
JAN
APR
JUL
OCT
MONTHS
RECEPTACLE
WATER HEAT
EXT LIGHTS
INT LIGHTS
MIXED HVAC
HEATING

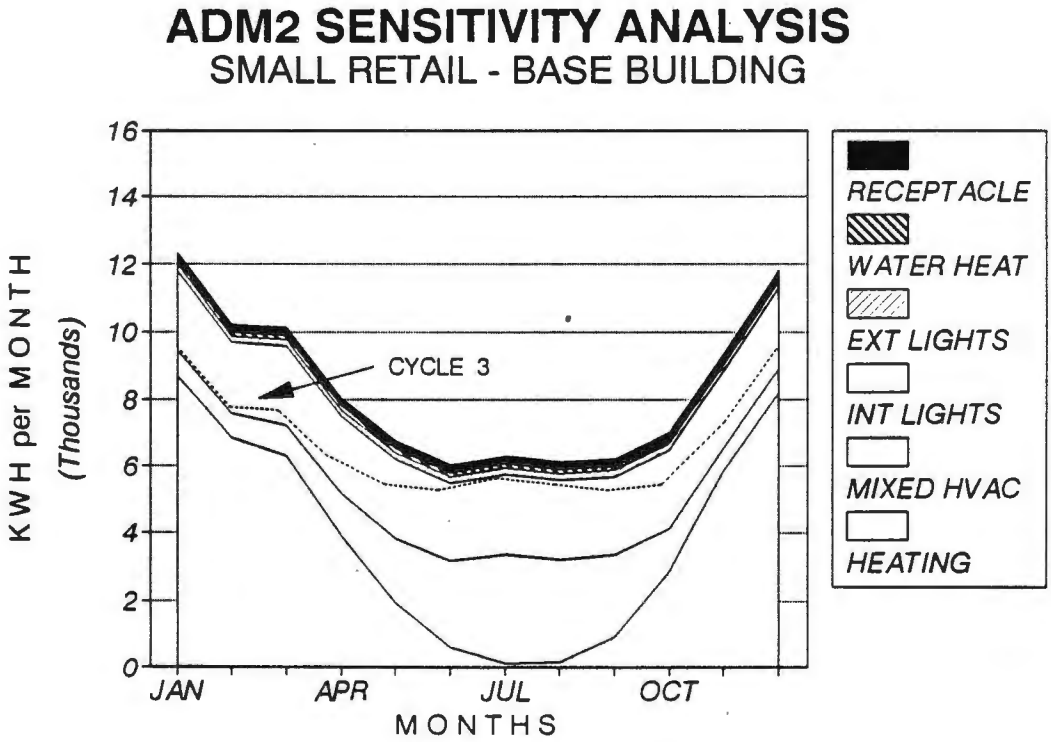
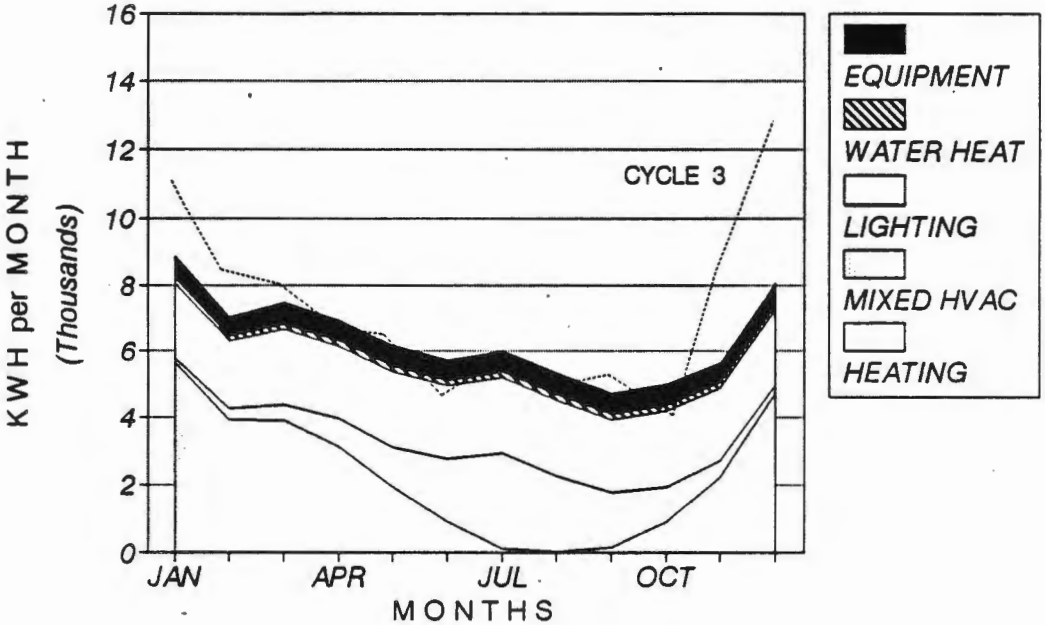

ADM2 SENSITIVITY ANALYSIS
SMALL RETAIL - BASE BUILDING
KWH per MONTH
(Thousands)
16
14
12
10
8
6
4
2
0
CYCLE 3
JAN
APR
JUL
OCT
MONTHS
RECEPTACLE
WATER HEAT
EXT LIGHTS
INT LIGHTS
MIXED HVAC
HEATING

FIGURE 6.1

VCACS SENSITIVITY ANALYSIS
SMALL RETAIL - BASE BUILDING



DOE 2.1 SENSITIVITY ANALYSIS
SMALL RETAIL - BASE BUILDING

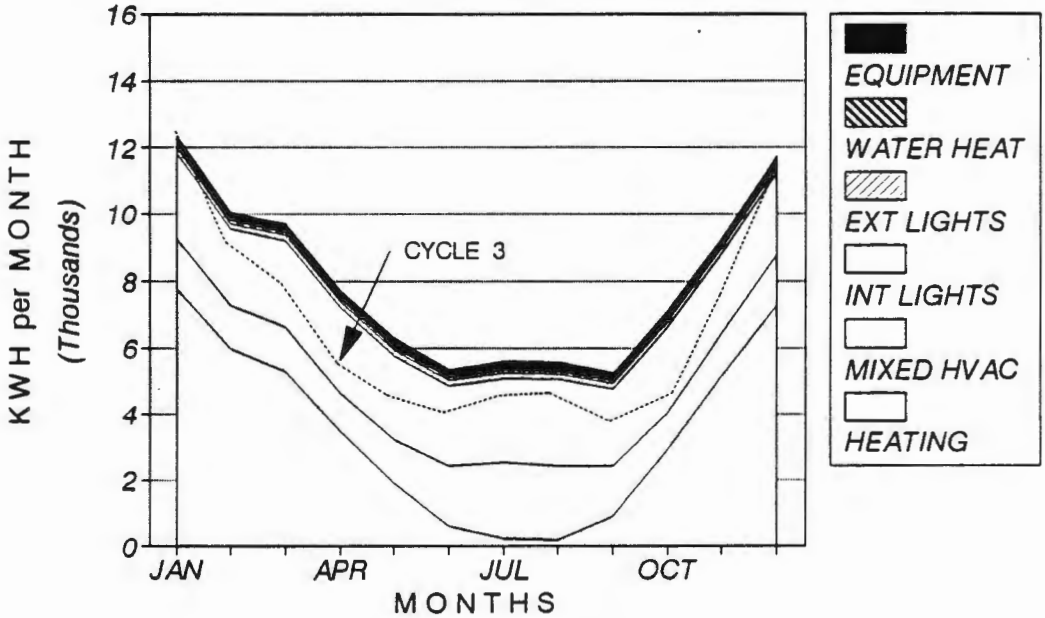
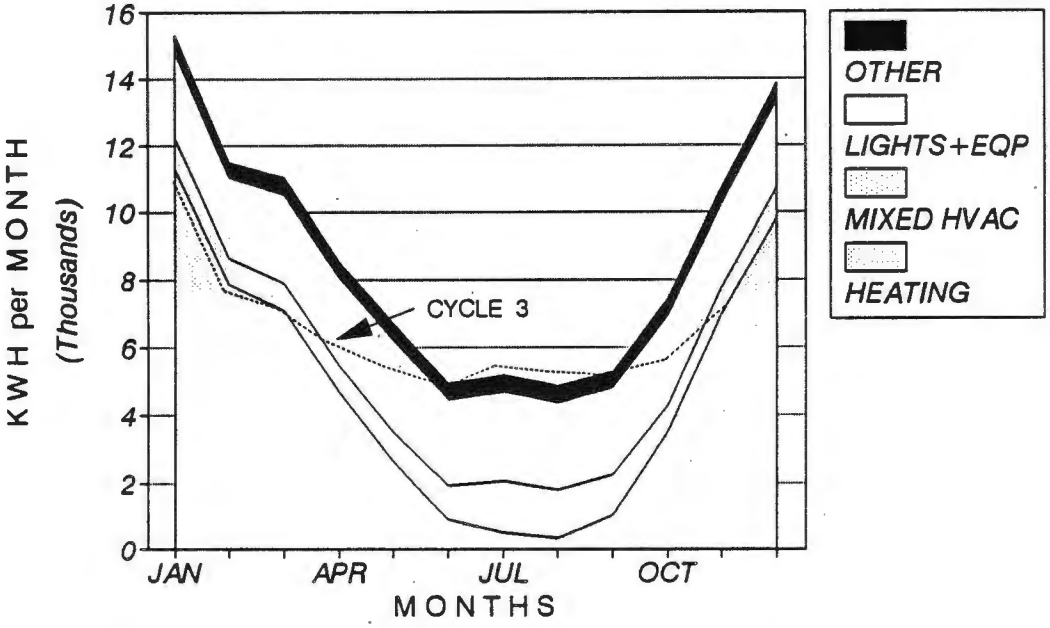


FIGURE 6.1 (continued)

SEA SENSITIVITY ANALYSIS
SMALL RETAIL - BASE BUILDING



TRAKLOAD SENSITIVITY ANALYSIS
SMALL RETAIL - BASE BUILDING

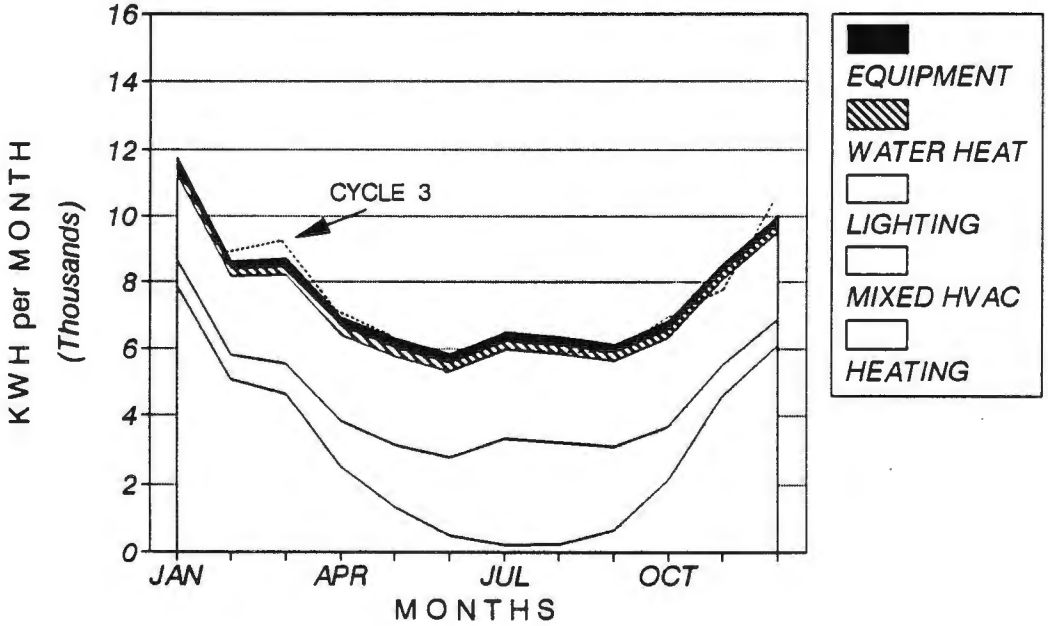
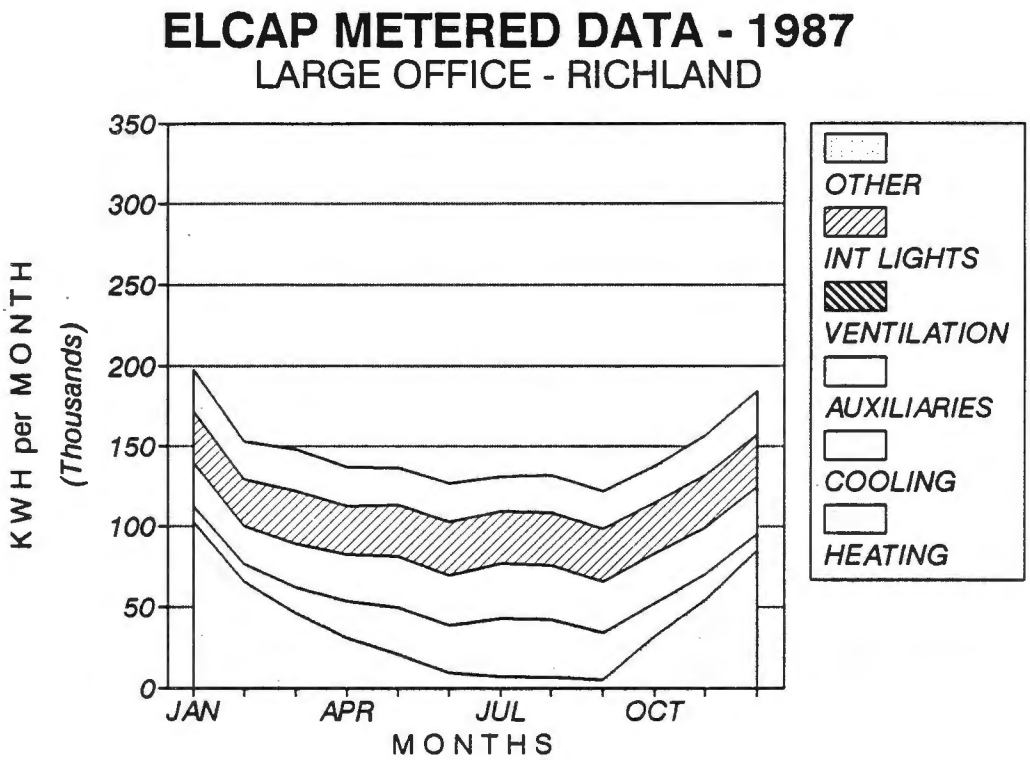


FIGURE 6.1 (continued)


ELCAP METERED DATA - 1987
LARGE OFFICE - RICHLAND
KWH per MONTH
(Thousands)
350
300
250
200
150
100
50
0
JAN
APR
JUL
OCT
MONTHS
OTHER
INT LIGHTS
VENTILATION
AUXILIARIES
COOLING
HEATING

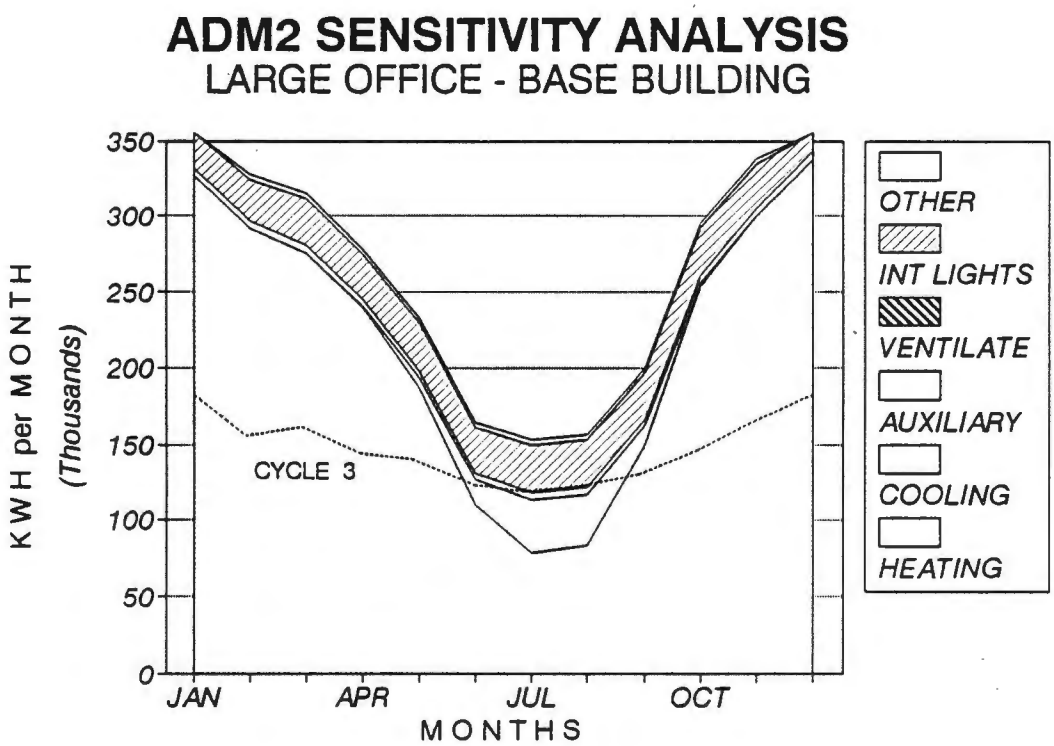
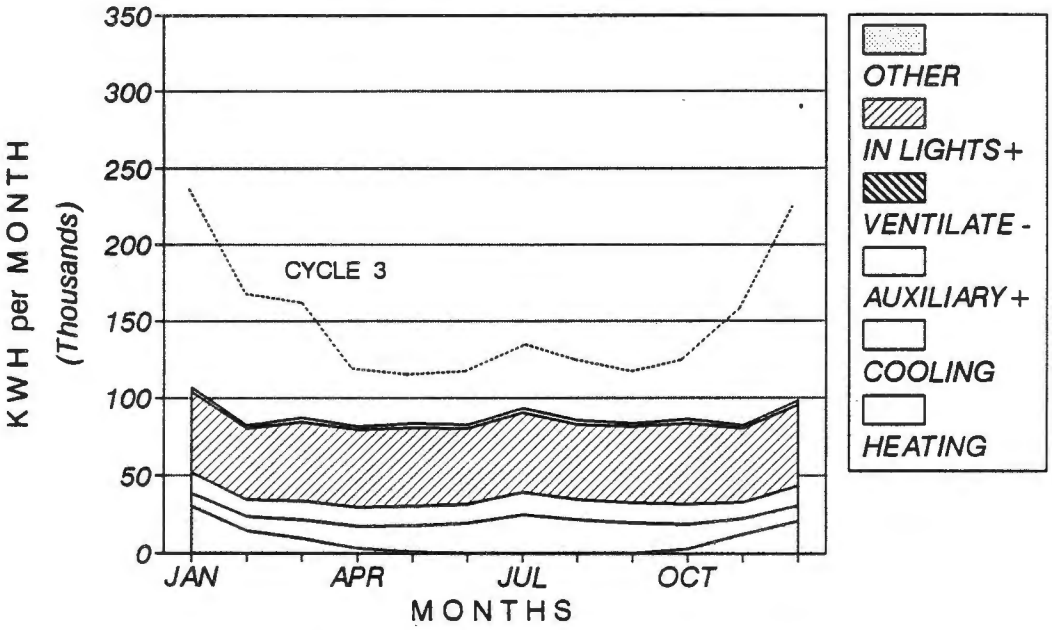

ADM2 SENSITIVITY ANALYSIS
LARGE OFFICE - BASE BUILDING
KWH per MONTH
(Thousands)
350
300
250
200
150
100
50
0
CYCLE 3
JAN
APR
JUL
OCT
MONTHS
OTHER
INT LIGHTS
VENTILATE
AUXILIARY
COOLING
HEATING

FIGURE 6.2

SEA SENSITIVITY ANALYSIS
LARGE OFFICE - BASE BUILDING



TRAKLOAD SENSITIVITY ANALYSIS
LARGE OFFICE - BASE BUILDING

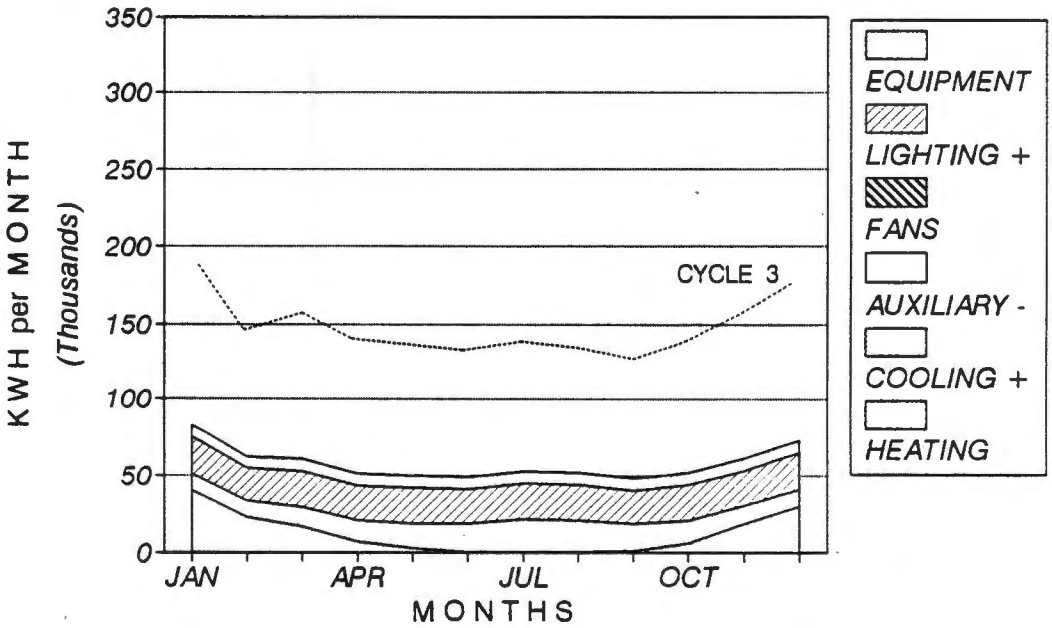
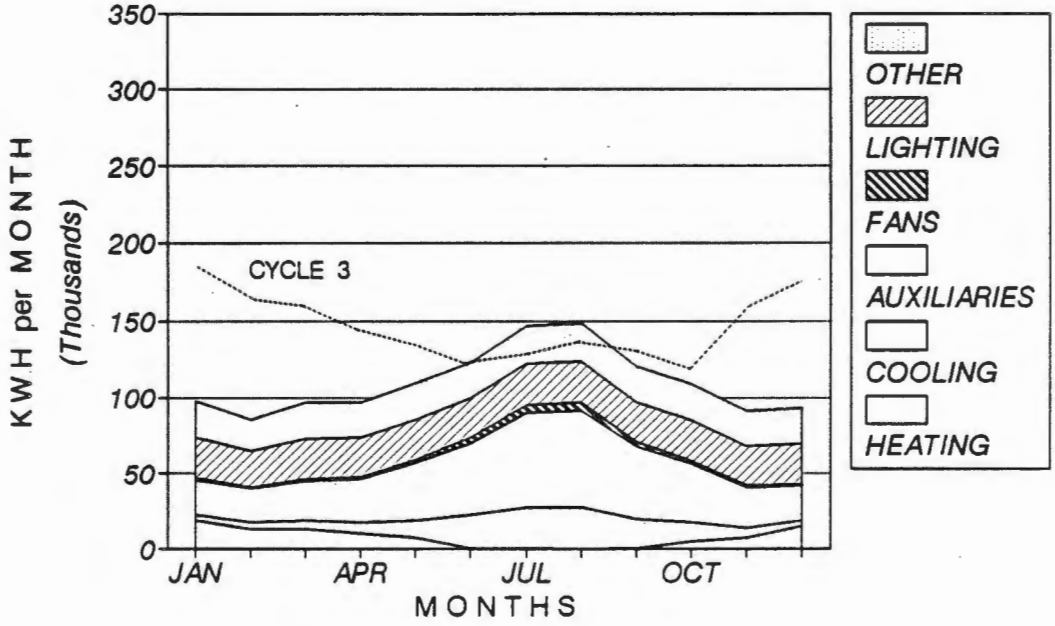


FIGURE 6.2 (continued)

VCACS SENSITIVITY ANALYSIS
LARGE OFFICE - BASE BUILDING



DOE 2.1 SENSITIVITY ANALYSIS
LARGE OFFICE - BASE BUILDING

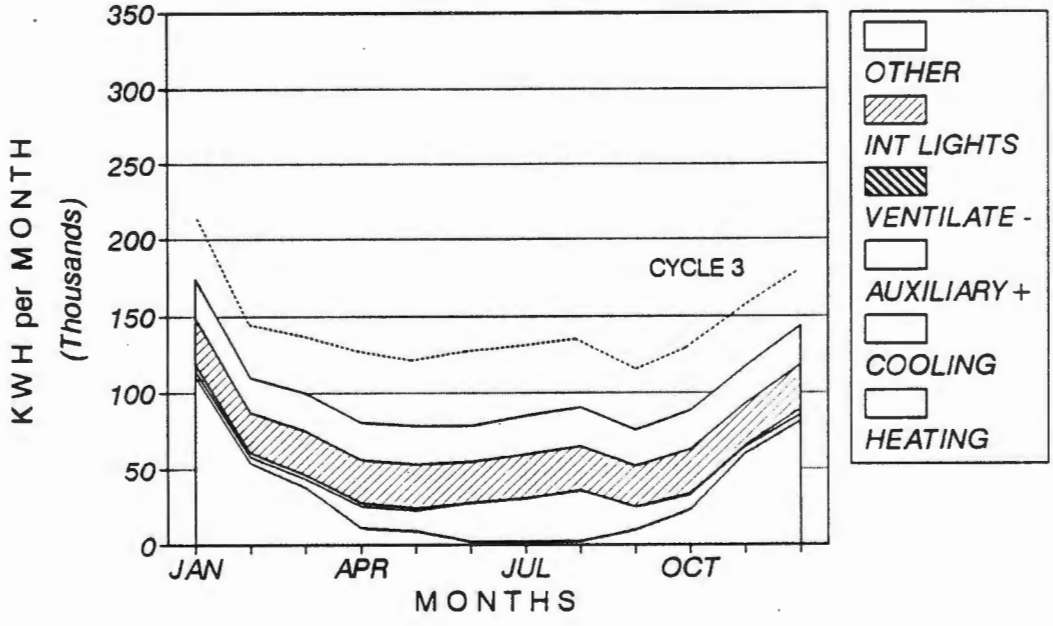


FIGURE 6.2 (continued)

In any event, **outputs** from the revised based building models ended up differing more than if the Cycle 3 models had been used. It follows that in some respects the sensitivity results may not have been fully representative of what would have happened in a "real" model prepared for a "real" engagement in which potential ECMs are tested and recommended.

On the other hand, the emphasis on uniform input values in the sensitivity models means that the input variable changes prompted by any sensitivity measure were quite similar in magnitude from one software package to the next. By emphasizing input values, the choice shifted attention to the output results. This was the accepted tradeoff.

When output results are compared, some base building energy estimates are found to be higher than before; others are lower. No concerted effort was made to determine which parameters were primarily responsible for the new energy levels or otherwise to analyze the reasons for the changes. However, Table 6.3 compares both annual energy consumption and average divergence for the ten base building models before and after the input variables were conformed. By any measure, the revised models show more scatter and greater departure from the targeted energy consumption than their Cycle 3 predecessors.

TABLE 6.3
SUMMARY OF SIMULATION STUDY BASE BUILDING RESULTS

		Annual Energy, kWh		Average Divergence Monthly		Average Divergence End-Use	
SMALL RETAIL		Cycle 3	Sens'ty	Cy 3	Sens'ty	Cy 3	Sens'ty
Utility/ELCAP		**85500**	**85500**				
Modeler A/A	ADM-2	82953	101525	20%	32%	46%	62%
Modeler J/C	SEA	81249	105888	18%	35%	36%	57%
Modeler E/E	TRAKLOAD	93999	93154	27%	26%	46%	46%
Modeler D/D	VCACS	85500	77754	7%	24%	48%	53%
Modeler F/F	DOE2.1	81097	97293	15%	26%	40%	49%
Mean		85417	95112	17%	29%	43%	53%

		Annual Energy, kWh		Monthly		End-Use	
LARGE OFFICE		Cycle 3	Sens'ty	Cy 3	Sens'ty	Cy 3	Sens'ty
Utility/ELCAP		**1767320**	**1767320**				
Modeler A/A	ADM-2	1761791	3223191	4%	78%	55%	162%
Modeler B/A	SEA	1776889	1073352	12%	39%	47%	64%
Modeler I/D	TRAKLOAD	1755029	706742	3%	61%	63%	61%
Modeler K/D	VCACS	1759674	1343283	11%	26%	30%	40%
Modeler F/F	DOE 2.1	1497993	1242758	6%	32%	33%	35%
Mean		1710275	1517865	7%	47%	46%	72%

The base building energy changes induced by the conformed input variables represent a form of sensitivity response in themselves. While the response evidences software differences, it may be further influenced by the modelers' work as well.

A clear example of the latter arose after Modeler C completed and submitted the SEA sensitivity model for the small retail building. The model projected 178,394 kWh for the annual energy consumption, compared to 81,249 at Cycle 3. The end-use energy profile also changed dramatically. Upon request the modeler checked the model again and found that the outside air and air supply volumes had been entered incorrectly. Data reported here in the tables and graphs are for the corrected model, which estimates the annual energy consumption at 105,888 kWh.

The foregoing had a profound impact on the output results. Although the problem was detected and has been corrected, it illustrates the potential for errors and interpretive differences even at this late stage in the modeling cycle. Less obvious problems are more likely to be retained in the final model.

Conversely, a significant energy shift in the TrakLoad model of the large office building appears to originate in the software. The changes here are equally dramatic, with annual energy reduced from 1,755,029 to 706,746 kWh; end-use energy profiles for the Cycle 3 and sensitivity models are repeated in Figure 6.3a to emphasize the changes.

A further example of how software can affect the results is found in the large shift projected by the ADM-2 model of the large office building. In this instance the critical factor was isolated with help from the software's HVAC system switch. During earlier cycles the modeler had trouble conforming this building to utility and ELCAP targets; excessive energy projections occurred whenever the model specified 2-pipe or 4-pipe distribution. The problem was handled at Cycle 3 by substituting a multizone system. However, the conforming parameters for the sensitivity model required a 2-pipe / 4-pipe system; when conformed with a 4-pipe system, the total building energy jumped from 1,761,791 to 3,223,205 kWh. The end-use energy profiles in Figure 6.3b highlight the HVAC energy increase.

Wherever there was a large change in estimated energy when a Cycle 3 model was adapted for the sensitivity study, the responsible modeler was asked to make a further careful review. The same is true wherever the shape of an end-use energy profile underwent a radical change. Major modeling errors presumably have been corrected; remaining inconsistencies are either minor, or due to errors and vagaries of the software.

While some smaller variations in sensitivity results undoubtedly include modeler components, the overall results are believed to be indicative of comparative software performance. Consequently, the sensitivity results that follow focus on software differences.

FIGURE 6.3a

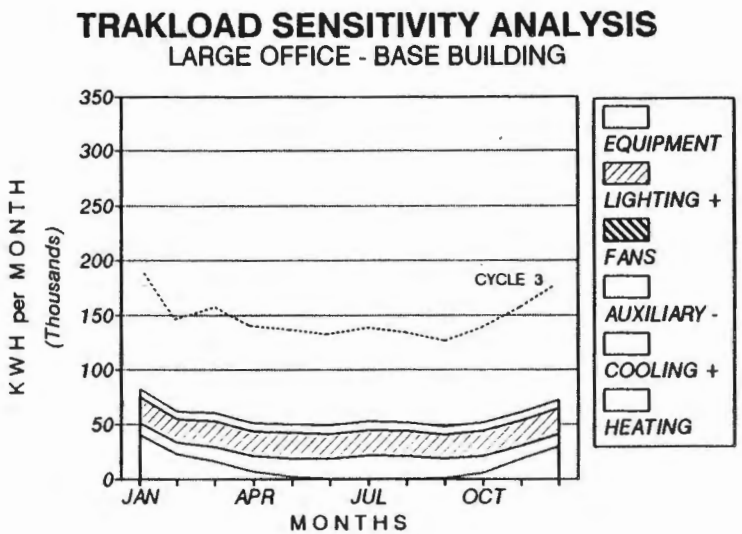
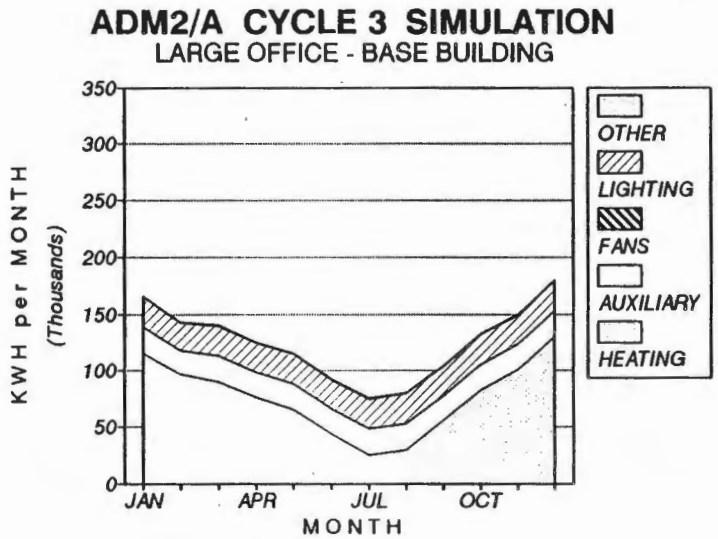
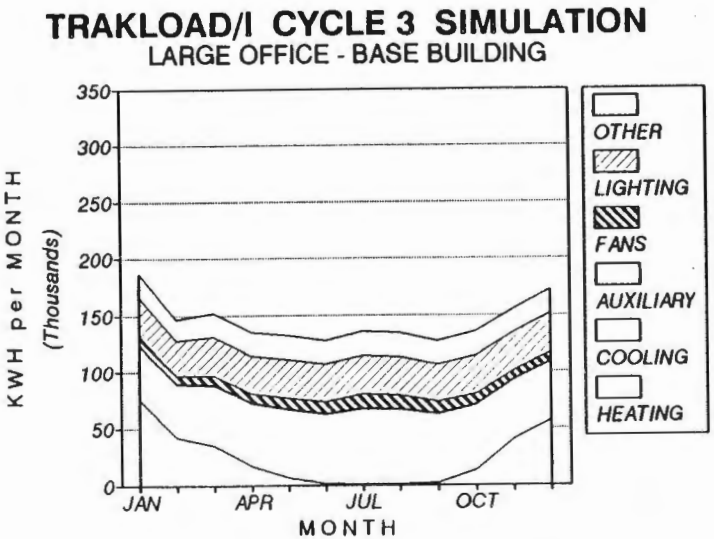
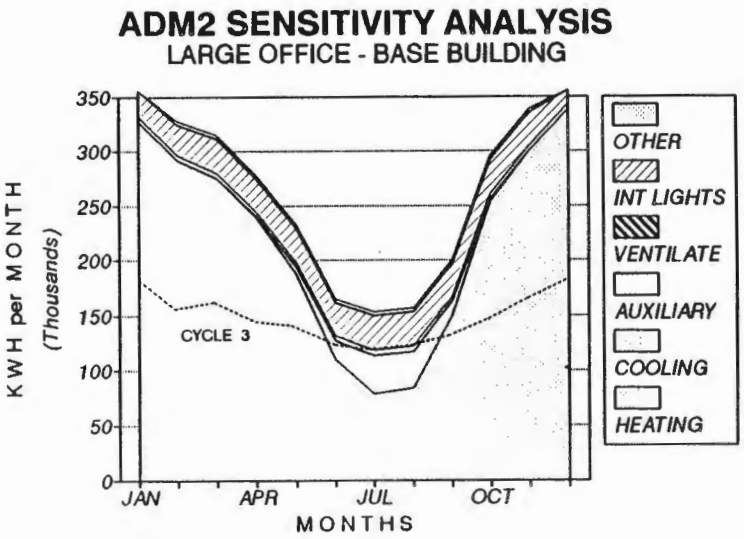


FIGURE 6.3 b







6.3.2 Sensitivity Responses

The ten sensitivity base building models were used to run the 25 sensitivity measures. Results are tabulated in Appendix J and summarized in Figures 6.4 and 6.5.

To complete the sensitivity simulations, modelers had to make accommodations; even then, a few items were skipped. Alternate base building models were developed for the SEA and VCACS versions of the small retail building; for example, the SEA alternate handled four air supply measures the initial model could not simulate; these measures have been flagged on the spreadsheet, and findings have been adjusted for uniform reporting. A few measures showed no change from the base building estimates; an example is the VCACS version of the small retail building, which was insensitive to building mass changes (measure #25). A few other measures could not be modeled at all, and have been reported as no change from the base building; an example of this is measure #13 on the DOE version of the large office building model: the software is not designed to model an economizer with terminal fan coil units.

Figure 6.4 reports composite information about the sensitivity runs for the small retail building. It uses strip graphs to compare the results obtained with the five software programs, one graph for each package. Starting with the base building (Measure #0), the 25 sensitivity measures are plotted along the horizontal axis, while the vertical axis shows their respective annual energy consumption, determined from the simulation runs. The horizontal dashed line across the width of each graph highlights the annual energy consumption simulated by the base building model.

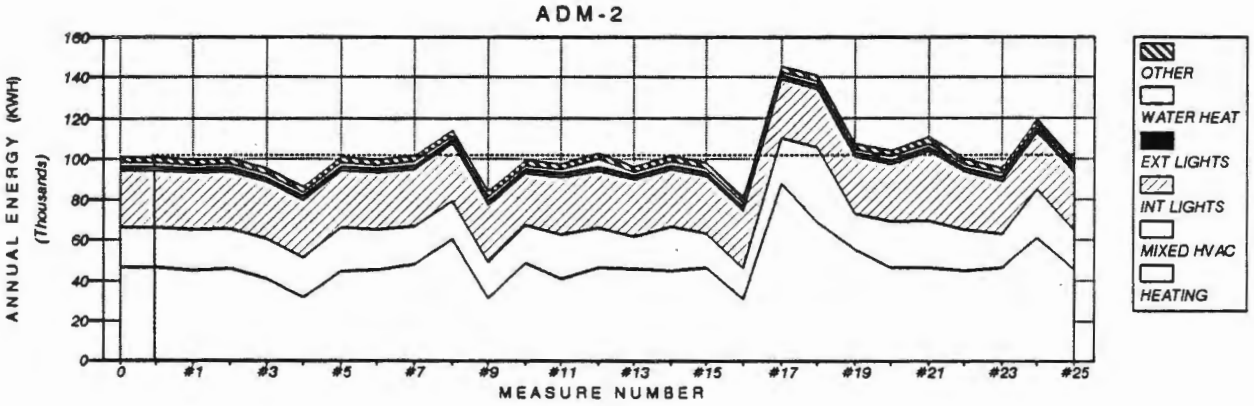
All of the strip graphs for the small retail building have the same vertical scale, to facilitate comparisons between graphs and between software programs. If each of the five models had responded the same, then each of the five strip graphs would have been identical. Instead they differ markedly. The graphs therefore provide "signatures" of the respective models and the software they represent; the visual differences provide a qualitative index of the differential sensitivities found in the software.

Figure 6.5 is a similar composite for the large office building. Once again, the five graphs show the comparative performance of the five software packages, and once again the results are markedly different.

The graphic software response profiles in Figure 6.4 can be compared with the comparable response profiles in Figure 6.5, despite different vertical scales. In other words, the composite profile for the ADM-2 small retail building model can be compared with the ADM-2 model for the large office building, and similar comparisons can be made for each of the other four software packages.

From the graphs it is immediately obvious that each software package/model yields a distinct response.

SENSITIVITY PROFILES - SMALL RETAIL



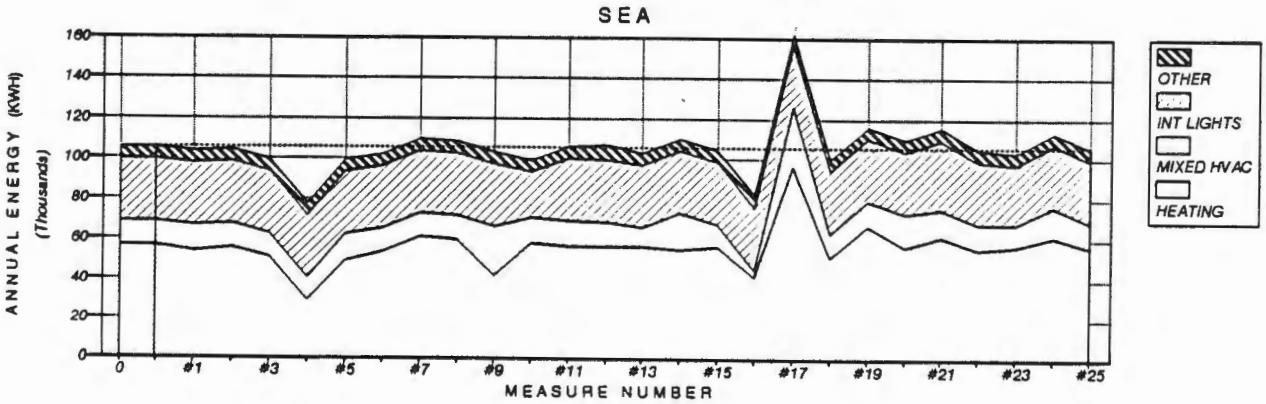
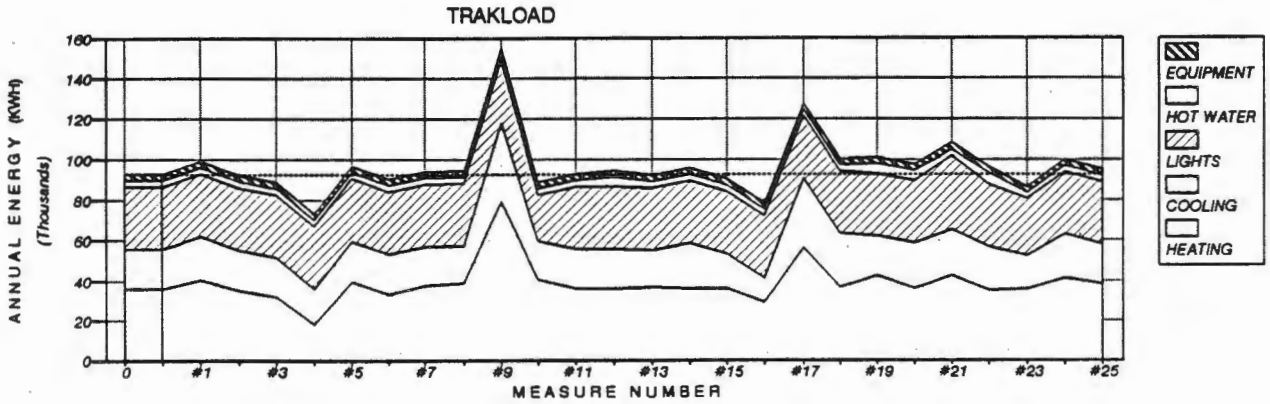
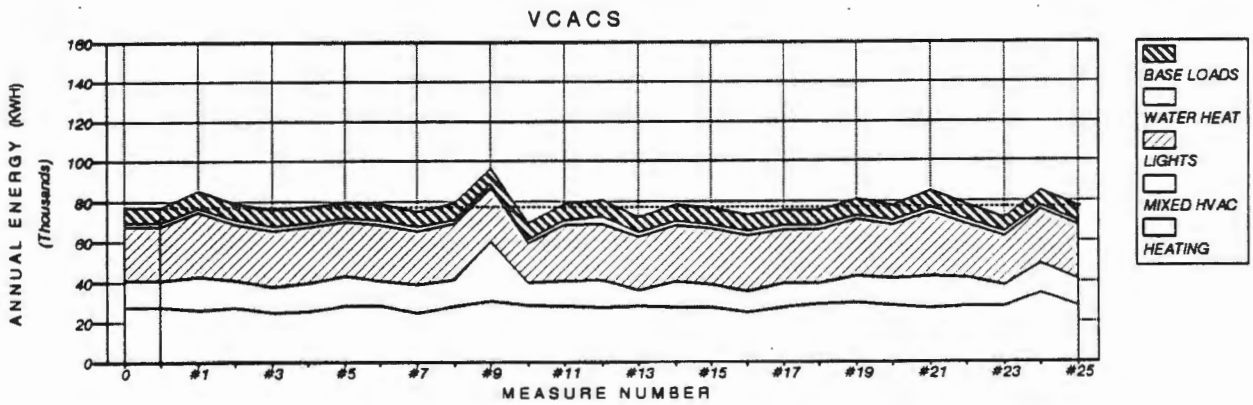


FIGURE 6.4


TRAKLOAD
ANNUAL ENERGY (KWH)
(Thousands)
160
140
120
100
80
60
40
20
0
0
#1
#3
#5
#7
#9
#11
#13
#15
#17
#19
#21
#23
#25
MEASURE NUMBER
EQUIPMENT
HOT WATER
LIGHTS
COOLING
HEATING


VCACS
ANNUAL ENERGY (KWH)
(Thousands)
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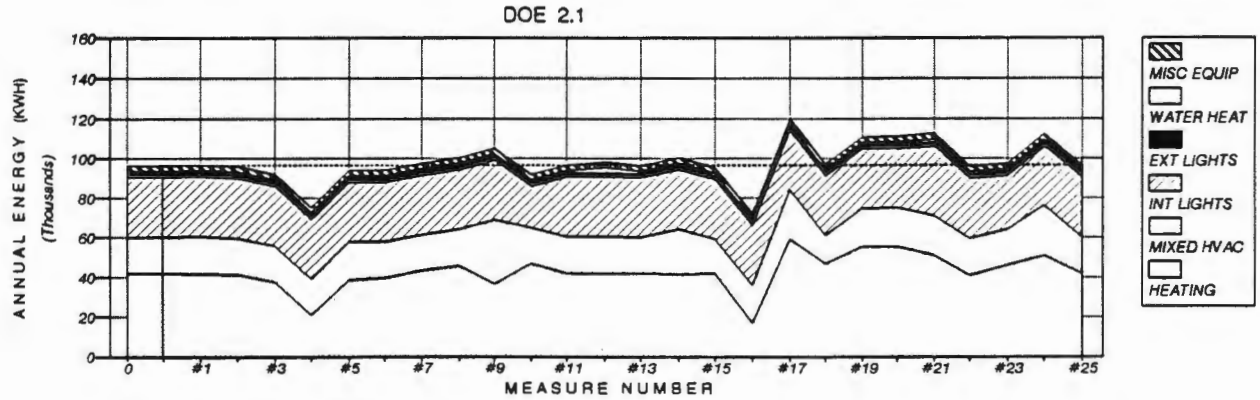
140
120
100
80
60
40
20
0
0
#1
#3
#5
#7
#9
#11
#13
#15
#17
#19
#21
#23
#25
MEASURE NUMBER
BASE LOADS
WATER HEAT
LIGHTS
MIXED HVAC
HEATING


DOE 2.1
ANNUAL ENERGY (KWH)
(Thousands)
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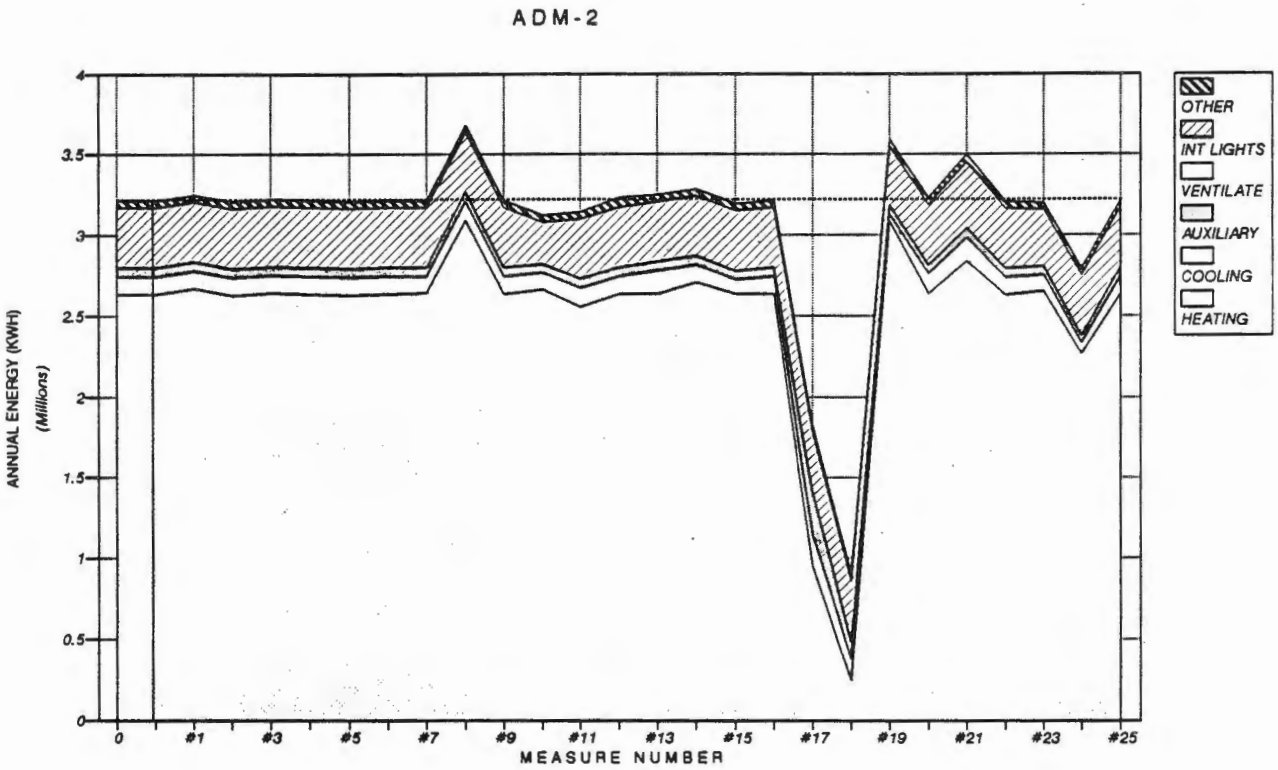
140
120
100
80
60
40
20
0
0
#1
#3
#5
#7
#9
#11
#13
#15
#17
#19
#21
#23
#25
MEASURE NUMBER
MISC EQUIP
WATER HEAT
EXT LIGHTS
INT LIGHTS
MIXED HVAC
HEATING

SENSITIVITY PROFILES - LARGE OFFICE



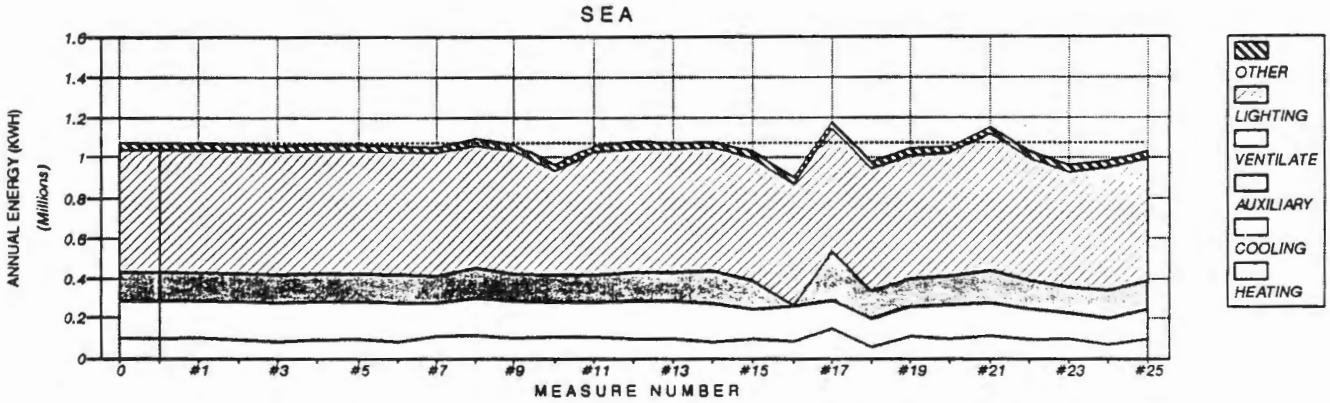
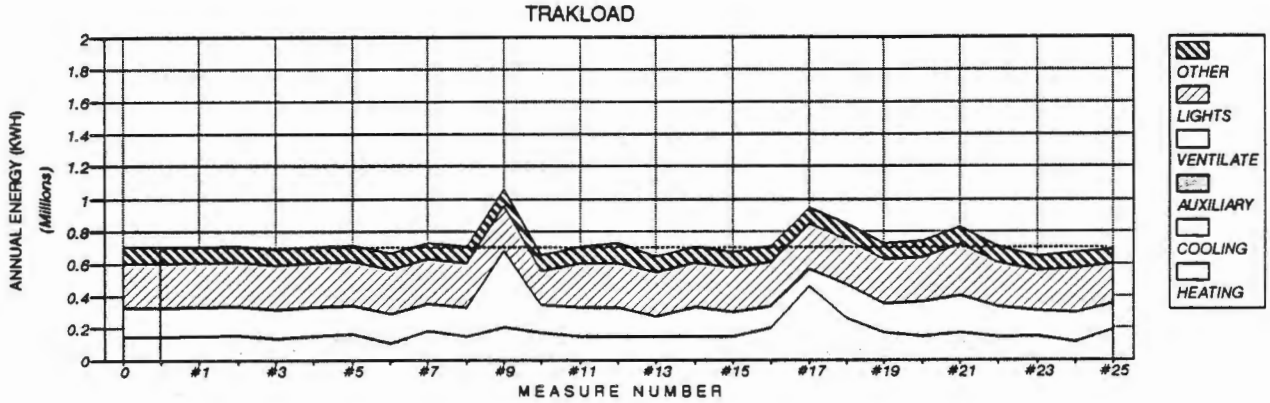
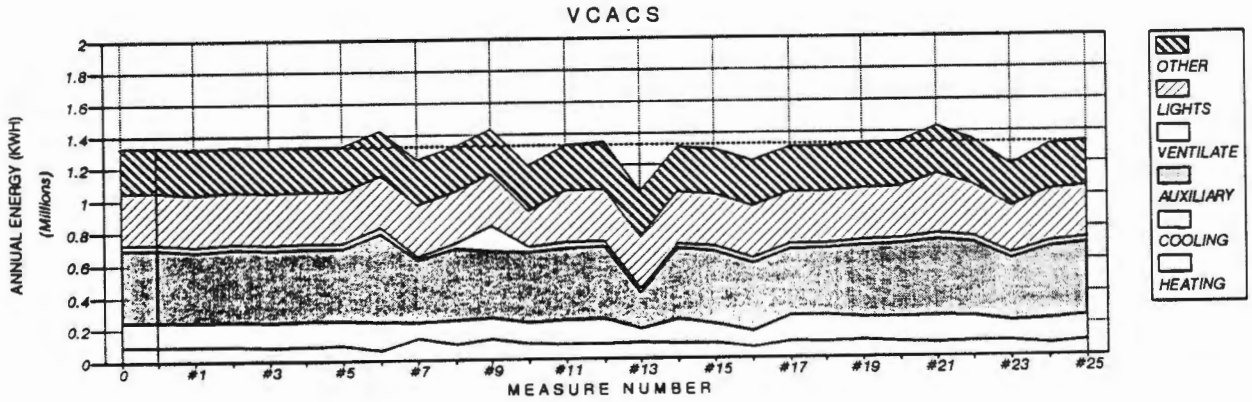
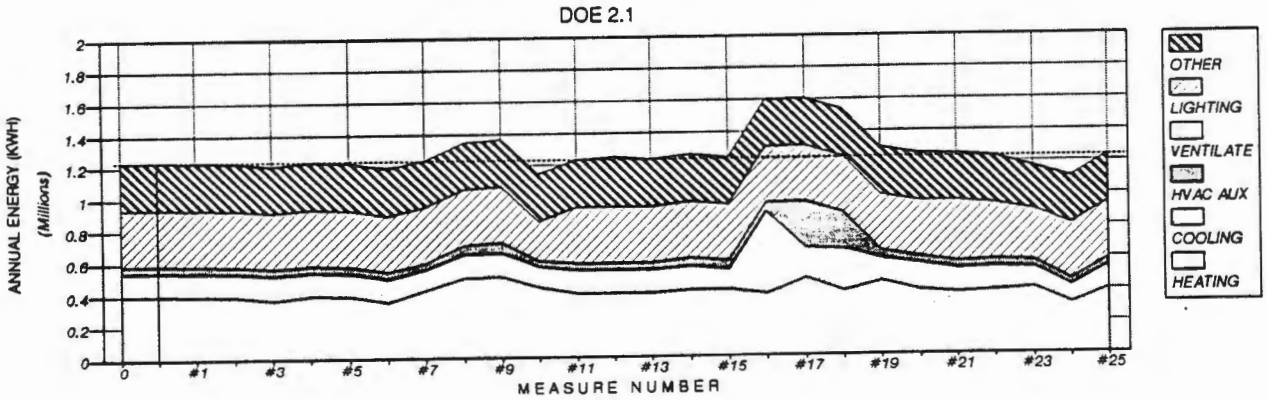


FIGURE 6.5


TRAKLOAD
ANNUAL ENERGY (KWH)
(Millions)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
#1
#3
#5
#7
#9
#11
#13
#15
#17
#19
#21
#23
#25
MEASURE NUMBER
OTHER
LIGHTS
VENTILATE
AUXILIARY
COOLING
HEATING


VCACS
ANNUAL ENERGY (KWH)
(Millions)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
#1
#3
#5
#7
#9
#11
#13
#15
#17
#19
#21
#23
#25
MEASURE NUMBER
OTHER
LIGHTS
VENTILATE
AUXILIARY
COOLING
HEATING


DOE 2.1
ANNUAL ENERGY (KWH)
(Millions)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
#1
#3
#5
#7
#9
#11
#13
#15
#17
#19
#21
#23
#25
MEASURE NUMBER
OTHER
LIGHTING
VENTILATE
HVAC AUX
COOLING
HEATING

It should come as no surprise that there are differences in sensitivity within each building group. Each software package elicits a different response. Differences in the base building models are sufficient to cause much of this, but further effects appear to be linked directly to individual sensitivity measures.

All other factors being equal, a base building model that simulates more energy consumption than other models of the same building do, is likely to show greater absolute energy savings when energy conservation measures are applied. That is, if a model exaggerates the energy consumption, it probably will exaggerate the energy savings as well.

This is part of what needs to be determined; it is in fact the absolute sensitivity of that model, combining modeler and software effects in the context of a particular building. From another perspective, however, it would be helpful to separate out the variations inherent in the base building model and look independently at the cause and effect relationships of the sensitivity measures themselves. Indeed, this was an underlying goal of the experimental method adopted in constructing closely similar base building models for each of the software packages. Despite that effort, some models ended up estimating more energy than others.

It would nonethelesss be helpful if all the base building models had a common output energy level, representative of the energy simulated during a "real" ECM evaluation. One way to gain this effect is to look at the percent change in building energy that results from a simulation measure. Percentages offer a further benefit: it is easier to display a range of results on a common scale.
To see the total sensitivity of the models, therefore, look at the total savings determined by the simulations. To see the relative sensitivity of the models, look at the percent change in savings. The Evaluation of Software project took advantage of both approaches in analyzing the sensitivity results. The presentations that follow use the percent change approach.

6.3.3 Sensitivity Analysis

From the preceding graphs it is immediately obvious that each software package yields a distinct response.

Figures 6.6 through 6.10 provide an opportunity to analyze the sensitivity results in greater detail, by looking at the percent change in building energy brought about by each sensitivity measure.

Figure 6.6 compares the eight sensitivity measures that focus on the building envelope. The upper graph shows the simulation results for the small retail building while the lower graph is for the large office building. The sensitivity measures and scales are the same in the two bar graphs, so the results can be compared between buildings and between the five software packages.

The page facing Figure 6.6 describes and interprets the eight building envelope sensitivity measures. (Actually, there wasn't enough room on the page to describe the measure changing building mass, so it's on page 35). Where the interpretation refers to "active parameters", it encompasses only primary effects; secondary effects may also strongly impact the building energy. For example, efficient lighting uses less electricity to produce a given level of illumination (primary effect) but since the lights also heat the building, the further consequence (secondary effect) may be to save energy for cooling and/or require substitute energy to heat the building.

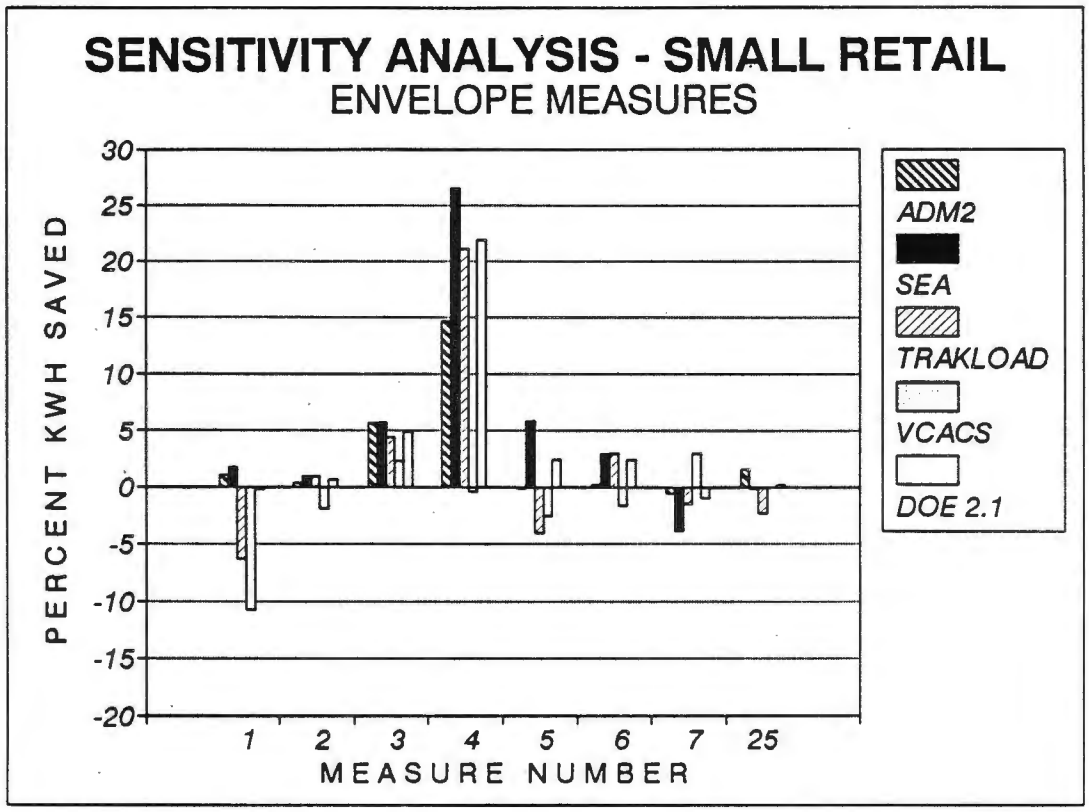
The same arrangement, including the facing page descriptions and interpretations, is used in the four following figures. Figure 6.7 compares the sensitivity measures that pertain to the building air supply. Figure 6.8 does the same for lighting and water heating. Figure 6.9 is for HVAC system and plant. Figure 6.10 is for building occupancy and weather environment.

In these bar graphs, separate patterns in separate bars show the sensitivity response for each measure and for each model/software package. Responses are expressed in percent change. Taller or shorter bars indicate a greater or lesser percent change in the simulated energy, or energy savings. But some bars for a given measure actually reverse direction; that is, for a given measure, some of the software packages may be simulating energy savings while others are projecting negative savings.

A word of caution is in order about the sensitivity results, however. Some of the differences may be more apparent than real. A modeler's ability to implement and simulate a given sensitivity measure was dependent in part on the conditions encountered in the base building model. Fan settings, for example, were not completely specified in the common input values and therefore could differ. In turn, that could affect how measure #9 (fan operation during unoccupied hours) would be entered and what the results would be. In two instances the sign of the simulated savings for this measure was reversed to accommodate the differences and provide an output with common significance.

In other instances, with other measures, similar accommodations may have been encountered but not reported. It is possible, therefore, that some of the reversals reported are spurious and that the responses of the several software packages are in greater conformity than the data and graphs show. Differences may also be affected by unstated modeling practices. But it would be unwise to rely on such factors to explain the differences. Additional analysis, in greater depth than the present project's scope permitted, would serve to identify whatever further adjustments if any may be warranted.

As an overall perspective, and despite potential further adjustments, the sensitivity results are deemed to be significant and should be taken at face value. Differences in sensitivity from one model to the next are evident and for the most part representative. Model differences still reflect modeler variables as well as software differences, but the modeler differences have at least been limited in the process. The result is that most of the sensitivity changes can properly be ascribed to the software.


SENSITIVITY ANALYSIS - SMALL RETAIL
ENVELOPE MEASURES
PERCENT KWH SAVED
30
25
20
15
10
5
0
-5
-10
-15
-20
1
2
3
4
5
6
7
25
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

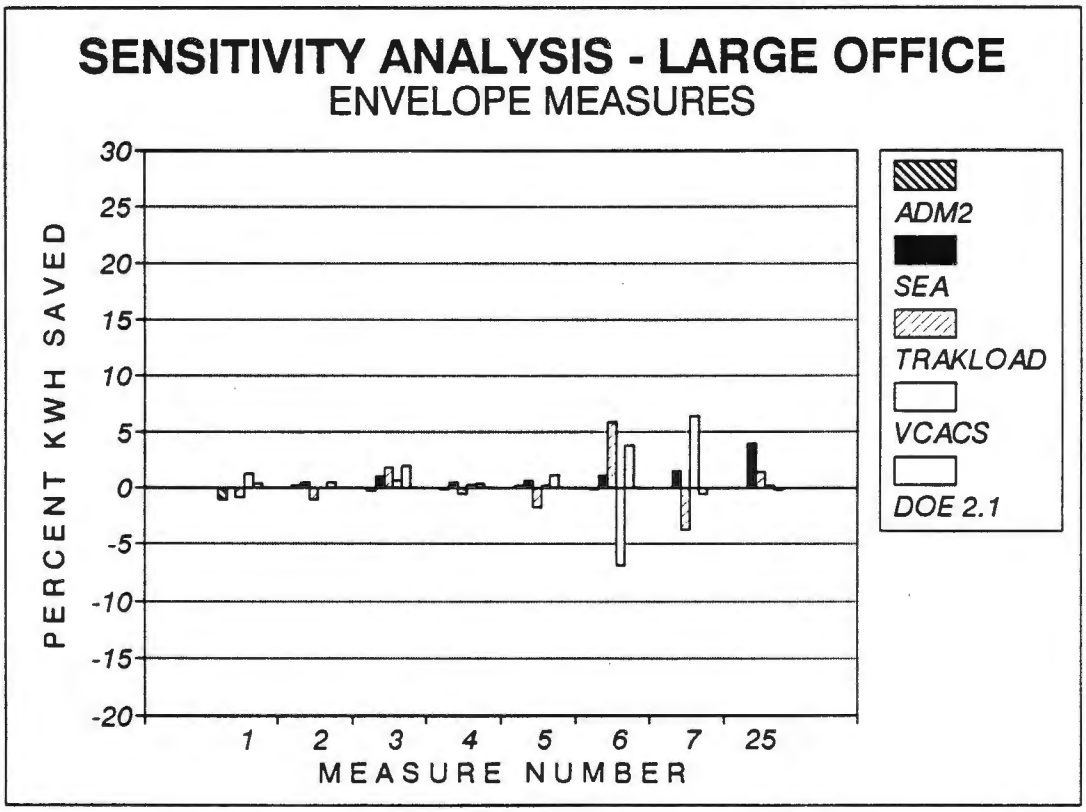

SENSITIVITY ANALYSIS - LARGE OFFICE
ENVELOPE MEASURES
PERCENT KWH SAVED
30
25
20
15
10
5
0
-5
-10
-15
-20
1
2
3
4
5
6
7
25
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

FIGURE 6.6

Envelope: Building Orientation

Measure 1. Overall building orientation:
Rotate building 90 degrees in clockwise compass direction (point the north face of the building to the east).
Energy consumption depends in part on solar exposure, which interacts with glazing, walls, and roof (in many software models the roof is flat and unshaded, so its load is independent of compass orientation). Active parameters are areas, thermal resistance, and reflectance/absorptance/transmission. To a lesser extent, energy consumption is likely to depend on wind direction, but most software does not model this feature.

Envelope: Exterior Insulation

Measure 2. Floor insulation:
Increase R value by 30% (or decrease loss by 23.1%).
Thermal insulation reduces heat transfer through floors. Active parameters are the R value, floor area and/or perimeter length, and temperature differences. The modeler may have to estimate average temperatures because most software will not calculate this factor; existing software also will not model the insulative and thermal capacity characteristics of the surrounding earth.

Measure 3. Roof insulation:
Add R19 insulation (add 19.0 to wall R value).
Thermal insulation reduces energy transfer through roof/ceiling structures. Active parameters are the R value, roof area, and temperature differences including solar effects.

Measure 4. Wall insulation:
Add R11 insulation to all opaque exterior walls above grade (add 11.0 to wall R values).
Thermal insulation reduces energy transfer through walls. Active parameters are the R value, roof area, temperature differences, and solar effects.

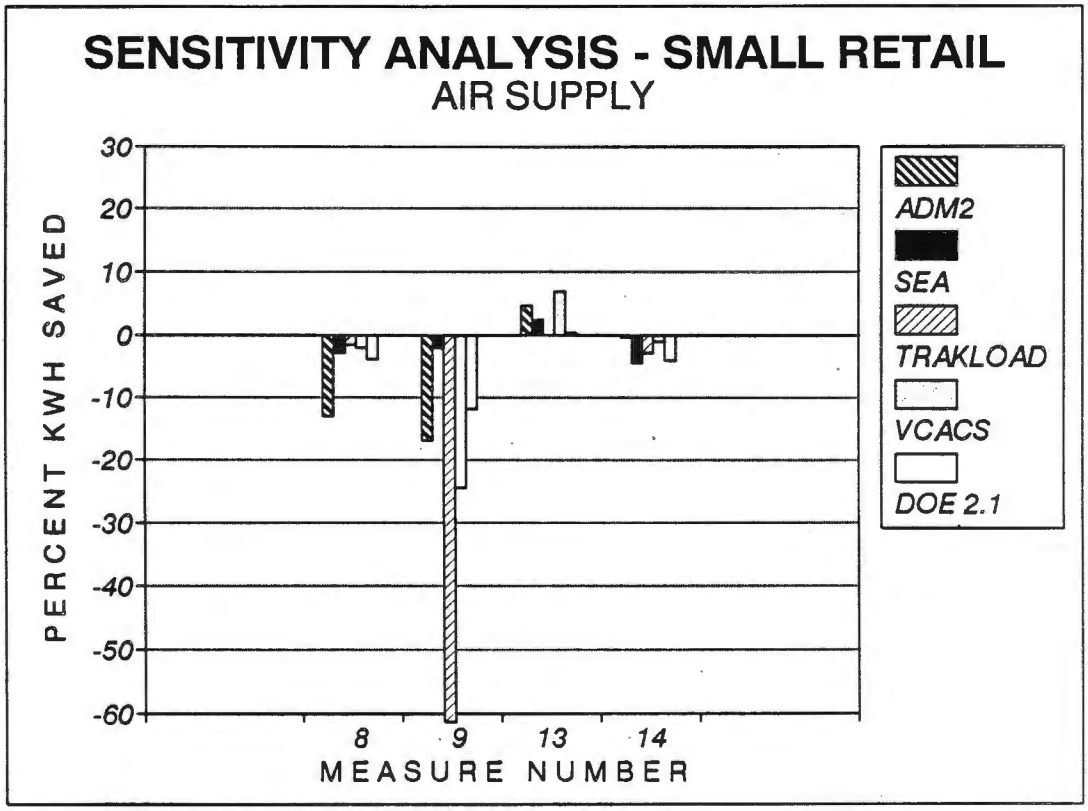
Envelope: Glazing and Shading

Measure 5. Glass area:
Change glazing area on south wall. (The entire south wall of the Small Retail building was opaque, so convert 30% of its area to glass of the same type used elsewhere in the building; for the Large Office building, reduce the existing glazing area by 30%. One is an increase and the other a decrease, so the response to the sensitivity measure should differ in the two buildings.)
An increase in glazing area increases energy transfer through (in and out) a building's windows, due to solar and other thermal effects. Active parameters are the area, thermal resistance, shading coefficients, and temperature differences including solar effects.

Measure 6. Glass insulation:
Increase thermal resistance of all glazing by 30%.
Thermal insulation reduces the energy conducted in and out of the building through the windows. In most models the active parameters are limited to the R value, area, and indoor/outdoor temperature difference.

Measure 7. Glass shading coefficient:
Decrease shading coefficient by 30%.
"Shading coefficients" are actually transmissibility coefficients: Lower values represent less radiation of solar and other energy through the windows. Active parameters are the shading coefficient, area, insolation, and (in some models) indoor-outdoor differential temperature.

FIGURE 6.6 (continued)


SENSITIVITY ANALYSIS - SMALL RETAIL
AIR SUPPLY
PERCENT KWH SAVED
30
20
10
0
-10
-20
-30
-40
-50
-60
8
9
13
14
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

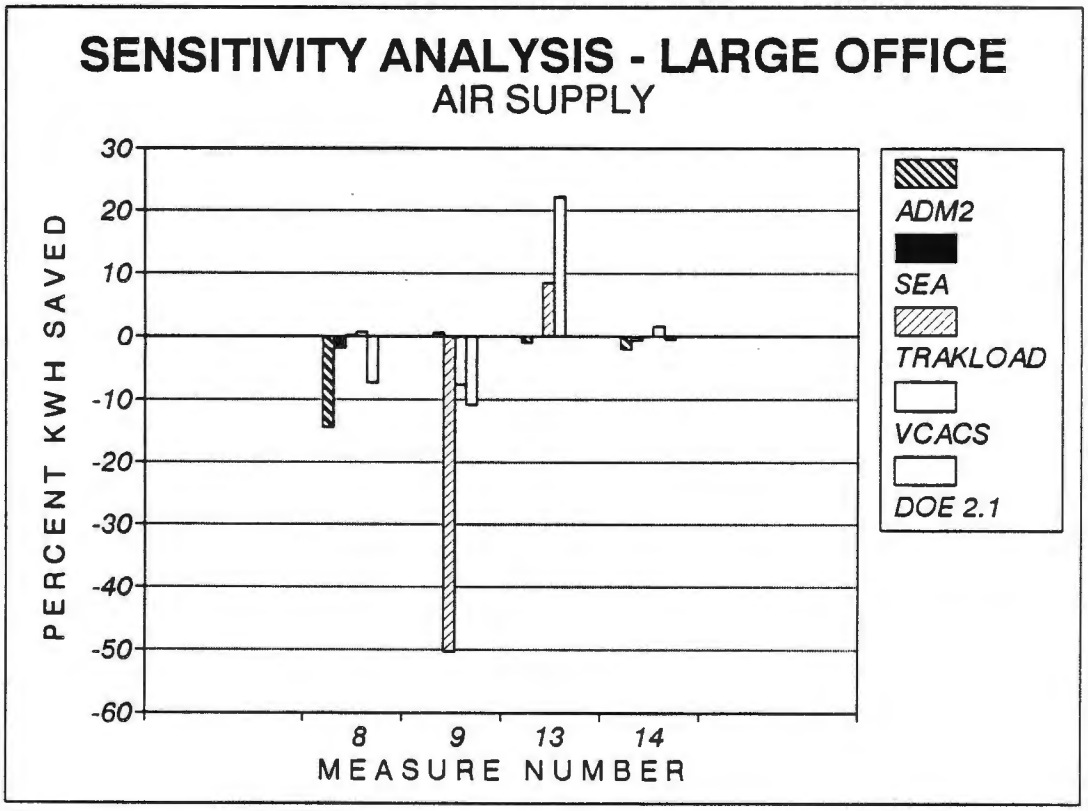

SENSITIVITY ANALYSIS - LARGE OFFICE
AIR SUPPLY
PERCENT KWH SAVED
30
20
10
0
-10
-20
-30
-40
-50
-60
8
9
13
14
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

FIGURE 6.7

Air Supply

Measure 8. Outside air:
Increase by 50% the CFM flow of outside air supplied to the building.

More outside air means more ventilation and fresher air, but more energy to temper it to indoor conditions. Active parameters are the CFM volumetric flow rate, the indoor and outdoor temperatures, and moisture content of the air. In some instances, untempered outside air is used for cooling; see measure #13.

Measure 9. Supply/return fan operation, unoccupied hours:
Toggle the fan mode between continuous and cycling.

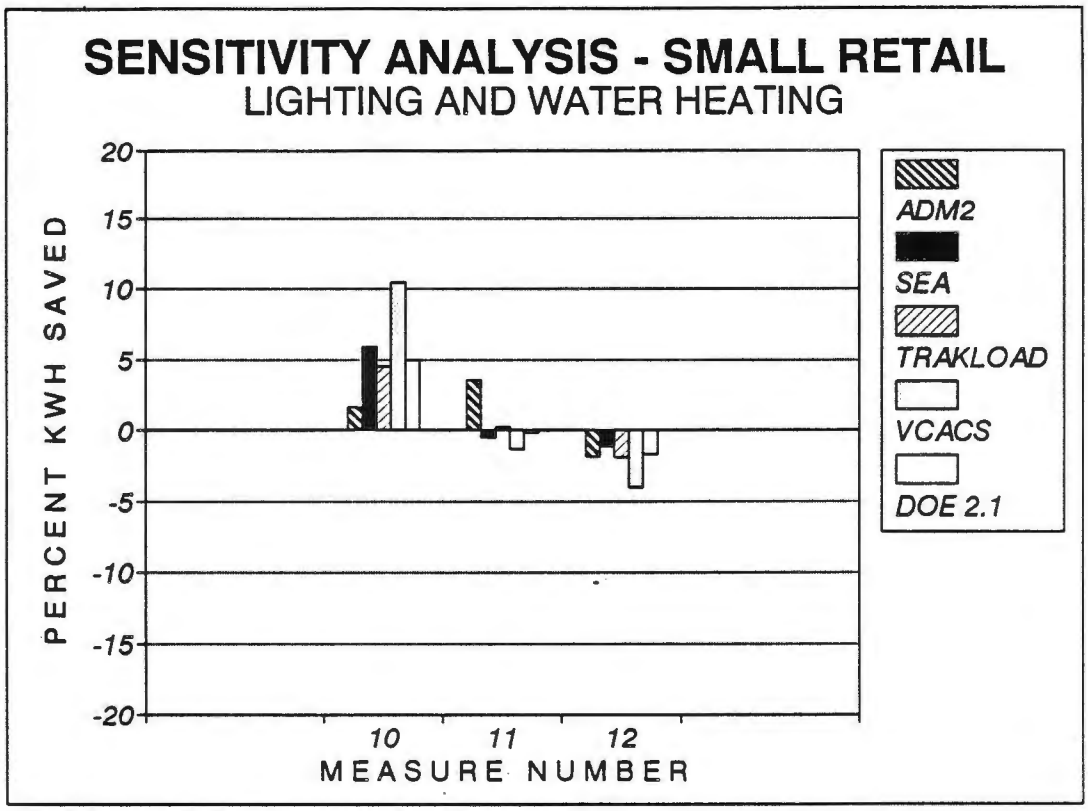
(Fans can be always off during specified hours, operate continuously, or operate only on demand for heating or cooling; some software can model only a subset of these features.) Turning fans off uses less fan energy. Active parameters are the fan horsepower, efficiency, and operating hours.

Measure 13 Economizer (sensible):
Toggle economizer on/off (yes/no) for economizer action while outside air temperature is between 45F and 65F (temperature limits, set arbitrarily, affect the results).

An economizer uses outside air to cool the building, when cooling is needed and air temperatures permit. The economizer reduces the energy required to cool the building. Active parameters involve a tradeoff between moving the outside air, and operation of the cooling equipment; air temperatures and volumes determine the amount of "economizer" cooling.

Measure 14 Supply air:
Increase the total air delivered to each zone by 30%, while holding the outside air CFM volume constant.

In most HVAC systems a fan (or blower)-driven air supply is necessary to effect the specified heating and cooling. An increase in the air supply requires additional fan energy, but allows more heat transfer from the heating/cooling system. Active parameters, once the heating/cooling load is met, are fan horsepower, efficiency, and hours of operation.


SENSITIVITY ANALYSIS - SMALL RETAIL
LIGHTING AND WATER HEATING
PERCENT KWH SAVED
20
15
10
5
0
-5
-10
-15
-20
10
11
12
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

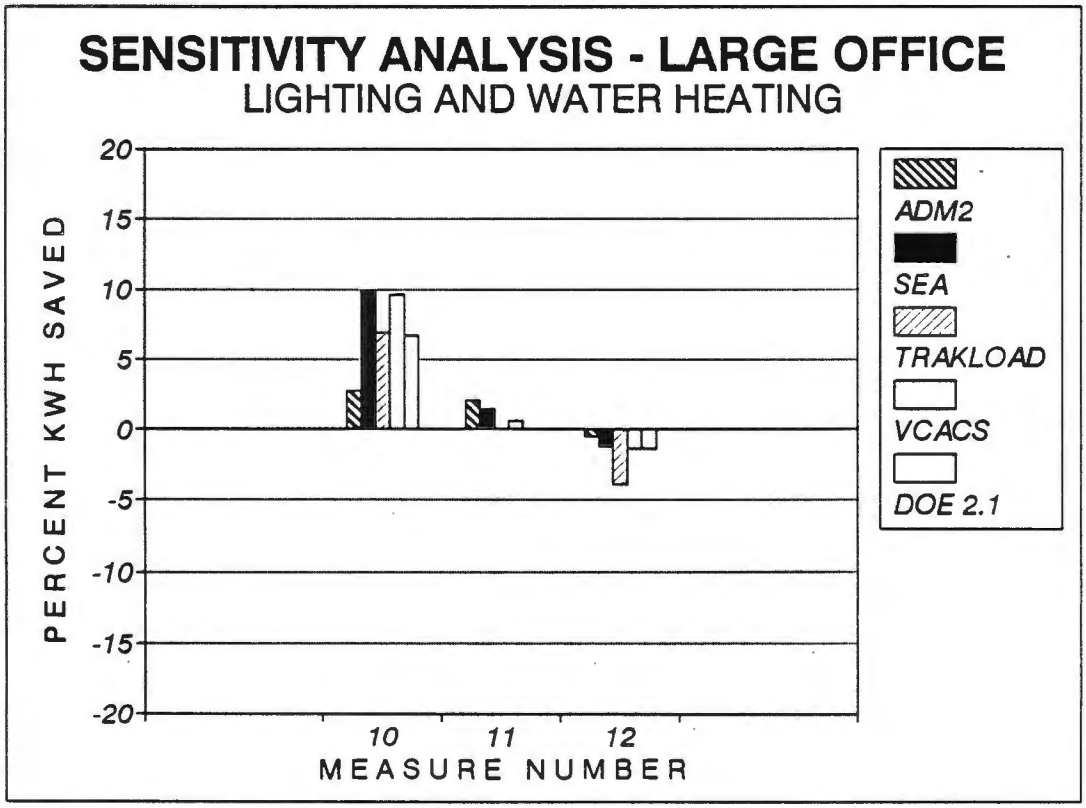

SENSITIVITY ANALYSIS - LARGE OFFICE
LIGHTING AND WATER HEATING
PERCENT KWH SAVED
20
15
10
5
0
-5
-10
-15
-20
10
11
12
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

FIGURE 6.8

Lighting

Measure 10. Interior lighting:
Decrease the kW/sqft lighting load by 30%, for each period.

Reducing the average lighting load reduces the total energy used for lighting; the level of illumination may be affected as well. Active parameters in some models may be kW/sqft, in others the total installed kW for the zone; and hours of operation.

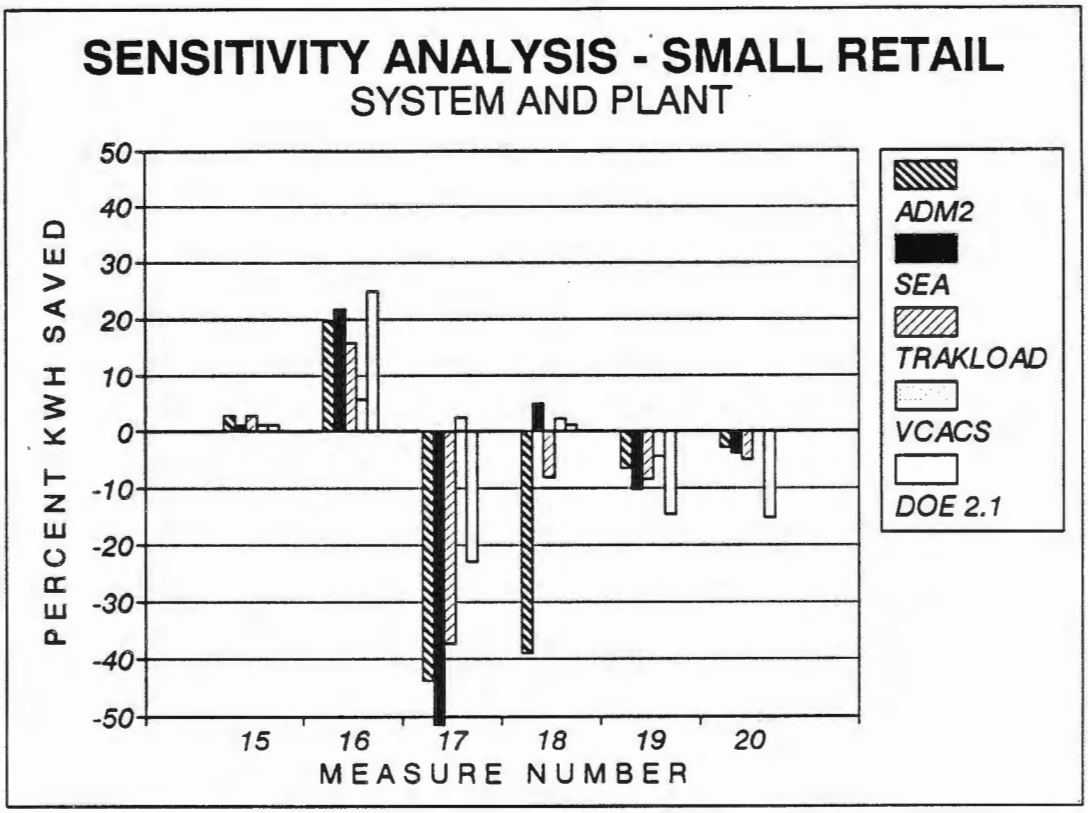
Measure 11 Lighting heat to space:
Decrease by 30% the percentage of lighting energy that is sensed as zone heat load.

Some HVAC building systems capture part of the heat generated by the lights before it can raise the room temperature; cooling may still be required, but accomplished more efficiently. Decreasing the percentage of lighting heat that enters the space may save energy if the building is mechanically cooled. Active parameters are the lighting power level, percent lighting heat entering the space, room/setpoint temperatures, and hours of operation.

Water Heating

Measure 12 Gallons of hot water per day:
Double the quantity of hot water used in the building each day (increase it by 100%).

Increasing the hot water consumption increases the energy required to heat it. Active parameters are hot water volume and temperature rise. Most software programs impose an assumed temperature rise (or assume an entering water supply temperature).


SENSITIVITY ANALYSIS - SMALL RETAIL
SYSTEM AND PLANT
PERCENT KWH SAVED
50
40
30
20
10
0
-10
-20
-30
-40
-50
15
16
17
18
19
20
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

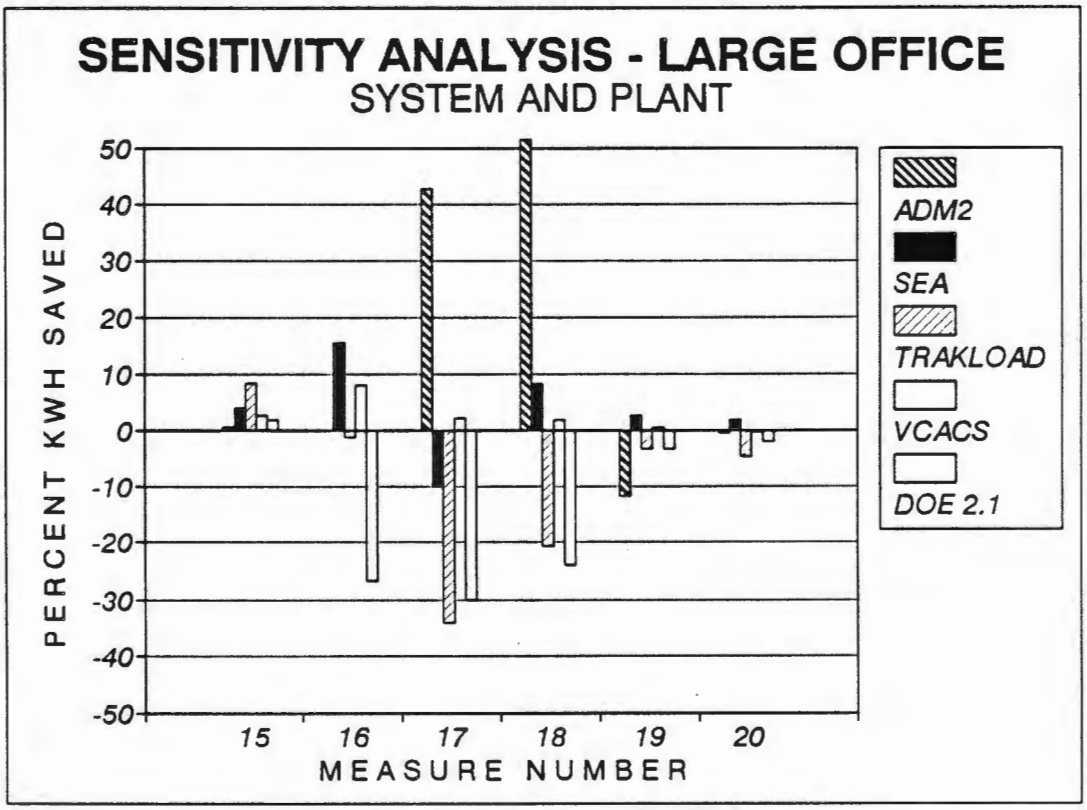

SENSITIVITY ANALYSIS - LARGE OFFICE
SYSTEM AND PLANT
PERCENT KWH SAVED
50
40
30
20
10
0
-10
-20
-30
-40
-50
15
16
17
18
19
20
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

FIGURE 6.9

System and Plant: HVAC heating/cooling

Measure 15 Cooling COP:
Increase the COP of the cooling equipment by 30%.

The Coefficient of Performance is a ratio of how much energy is extracted compared to the energy needed to perform the work. Some simulation models use related measures, such as EIR or EER. An increase in the COP reflects in reduced energy requirements during the cooling season. Active parameters are the COP, other equipment characteristics, and the cooling load.

Measure 16. Heat pump:
Convert the system type to heat with a heat pump that has a heating COP of 3.0 at 47F.

Compared to electrical/resistance heating, a heat pump uses less energy for heating. (If used for cooling, a cooling COP value may also affect the evaluation.) Active parameters are the COP, other equipment characteristics, and the heating load.

Measure 17. Multi-zone:
Convert the system type to heat/cool with a multi-zone system that also incorporates an economizer, OSA temperature reset, but no discriminator. Hot and cold deck temperatures, 120F and 55F.

A multi-zone system is capable of heating and cooling separate air streams simultaneously, and therefore often uses more energy that other systems. The software setting is switch that selects a different set of HVAC and control algorithms.

Measure 18. Variable air volume system:
Convert the system type to one that controls heat/cool with variable air volume (VAV) equipment, assuming fan discharge volume control with inlet vanes. Hot and cold deck temperatures, 120F and 55F.

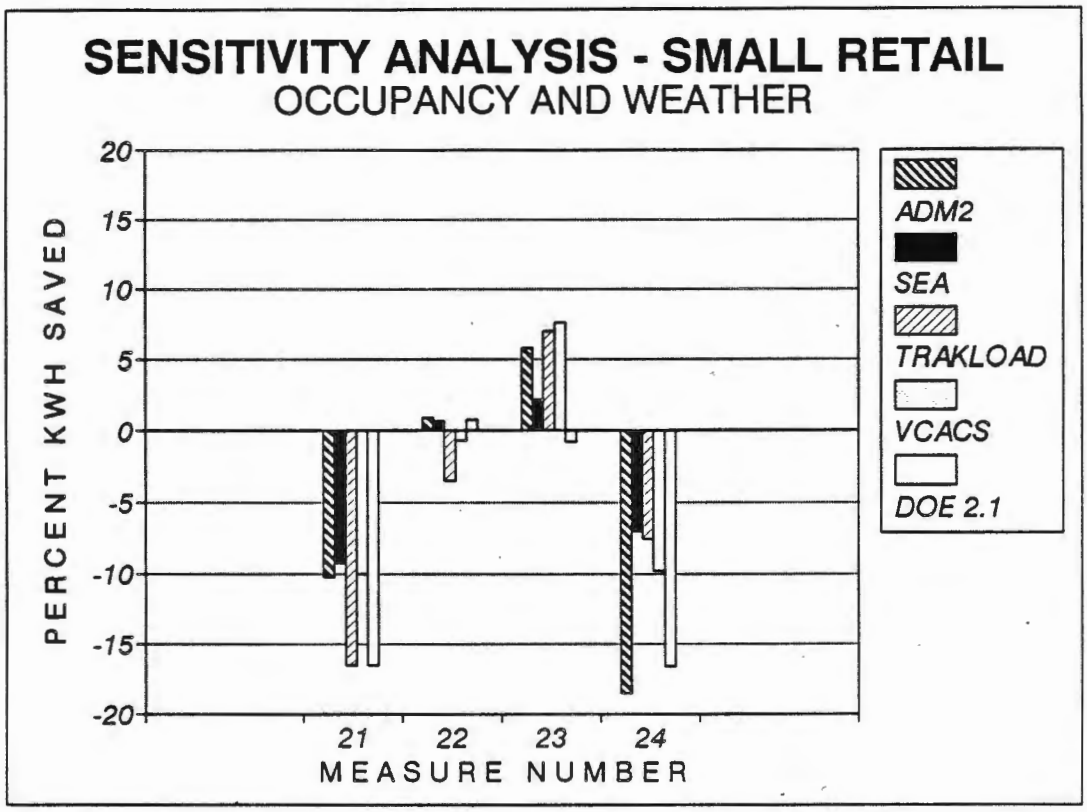
A VAV system delivers air at more nearly optimal temperatures and volumes than some other system types, and therefore often uses less energy. The software setting is switch that selects a different set of HVAC and control algorithms.

Measure 19. Setpoint temperature:
Increase the winter heating temperature by 5 degrees F during occupied hours, without change in the setback (unoccupied hours) temperature.

Higher temperatures require more energy for heating. Active parameters include differential temperatures and outside air volumes.

Measure 20. Cooling equipment partial load:
Increase the specified capacity of the cooling equipment by 50%.

Many heating and cooling systems are most efficient when they are operating near their rated capacity. Most energy simulation software packages account for this with a partial load performance "curve", either built into the software or use-adaptable. From that curve the software selects the equipment efficiency corresponding to the current operating level, and uses it to complete the energy calculations. Increasing the capacity rating of the equipment has the effect of shifting the operating point lower on the curve, into less efficient levels, and therefore increasing the building energy.


SENSITIVITY ANALYSIS - SMALL RETAIL
OCCUPANCY AND WEATHER
PERCENT KWH SAVED
20
15
10
5
0
-5
-10
-15
-20
21
22
23
24
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

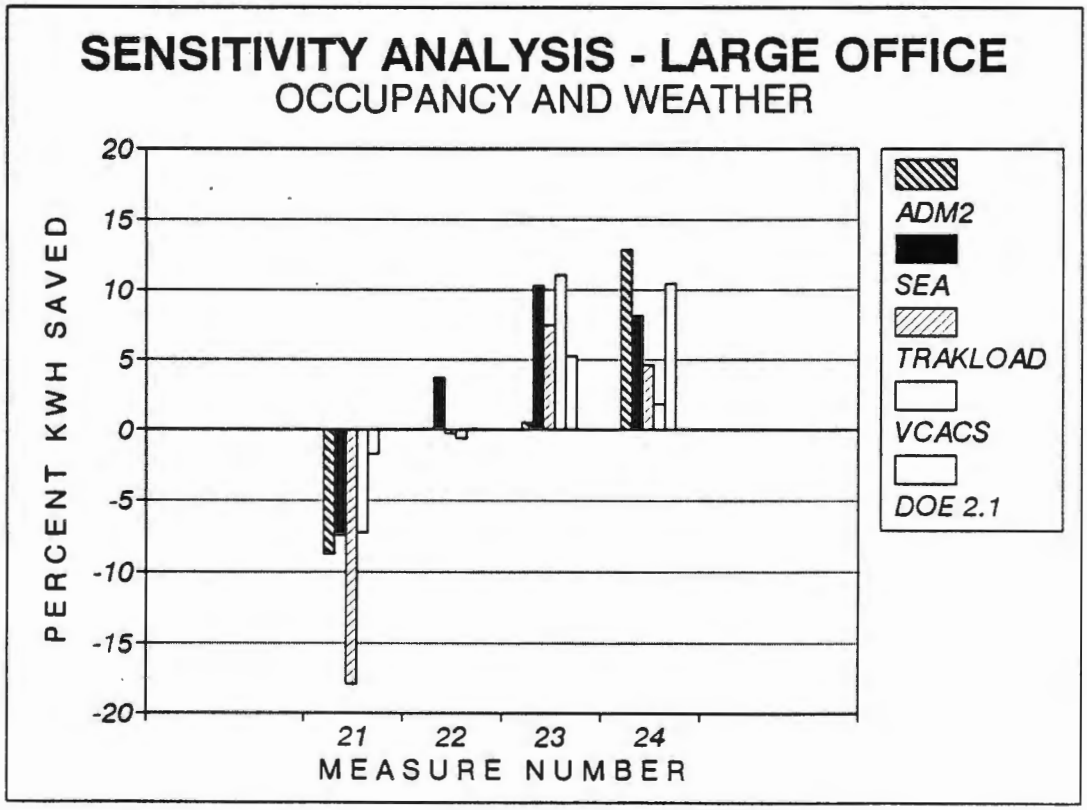

SENSITIVITY ANALYSIS - LARGE OFFICE
OCCUPANCY AND WEATHER
PERCENT KWH SAVED
20
15
10
5
0
-5
-10
-15
-20
21
22
23
24
MEASURE NUMBER
ADM2
SEA
TRAKLOAD
VCACS
DOE 2.1

FIGURE 6.10

Occupancy

Measure 21. Occupied hours (see note c):
Increase the period occupied on a normal day by 2 hours. On normally occupied days, start one hour sooner, run one hour later. Change all affected schedules (people, lighting, HVAC, etc as applicable).

Temperatures, ventilation, lighting, and other building environment factors are controlled at higher consumption levels during occupied hours, thus increasing the energy used in the building. On normally

Measure 22. Number of people:
Increase the number of people in each zone by 50%.

People increase the sensible and latent heat loads, usually increasing the energy required to cool the building.

Measure 23. Vacation period (seasonal variation):
Create an unoccupied vacation period during all of July.

If the building is unoccupied during a vacation period, the effect is similar to reducing the hours the building is normally occupied, except that the energy savings are attributable only to the vacation period.

Weather

Measure 24. Weather file - location:
Compare the energy consumption when simulated for a building's normal location and for an alternative location; in this instance swap the "Eugene"and "Richland" weather files.

Weather files represent the conditions at a specific location; other locations may be warmer or colder, and therefore have different requirements for heating, cooling, and total building energy.
For the two communities indicated, summer and winter temperatures are more extreme in Richland than Eugene. Using "Richland" in place of "Eugene" should increase the simulated energy; the reverse substitution should decrease simulated energy.

Building Mass

Measure 25. Walls, floors, and roof:
Change input parameters to specify the heaviest building sections (according to ASHRAE groups or software categories).

A thermally massive building stores heat and slowly releases it, which offers the potential to shift heating and cooling from when heat/cool is needed to other hours of the day when heat/cool can be provided more efficiently and economically. The software may use one of several approaches for interacting the changing temperatures with the building materials and their heat capacitances. Increasing the building mass will often reduce the building energy requirements.

6.4 Additional Observations

The focus of the sensitivity study is on software performance, not on software applicability, availability, or preference. From the standpoint either of the management of energy conservation programs or the reliability of software, the desired outcome is that any software used to simulate a particular building or energy conservation measure will yield accurate results, comparable to those estimated by all other software.

This is not what the Evaluation of Software sensitivity results show, however. Instead, it may be concluded that the several software packages, under the conditions examined, do not consistently give equal performance or lead to the same recommendations for energy conservation measures.

It would be a large jump from there to a conclusion about which results are "right" or "wrong", and which software packages are consequently "better" or "less satisfactory". To ascertain why there are differences and what all of the differences are would be an equally large jump. An attempt is made in a later chapter of this report to rank the performance of software packages, but by and large such findings await future study projects.

A few observations can be made, however. Where the differences were the most dramatic, answers - at least partial answers - have been suggested.

It has already been established that the base building models used for the sensitivity study differed from the Cycle 3 models from which they were modified. Some of the changes, both in total simulated energy level and in end-use profile, were sharply different, beyond expectations. It may be constructive to see what significance can be found in a closer examination of the most obvious changes.

In several instances modelers were asked to simulate measures that the software did not support directly. As noted however, the modelers were able to obtain the desired results by changing the input data form. For example, some software packages support economizer action for central HVAC systems but not for single zone packaged units. To determine the sensitivity for this specific measure, the modelers created an "alternate base building" using central system HVAC, and then compared the results with and without an economizer. The tabular reports indicate this distinction, and the graphic figures have been adjusted to show the net differences. In this instance, the modelers were able to avoid the dramatic differences which might otherwise have occurred.

In the large office building series, obvious changes in annual energy consumption occurred in the ADM-2 and TrakLoad models. The ADM-2 estimate nearly doubled from Cycle 3 while the TrakLoad estimate was reduced by more than a factor of two.

The graph for the ADM-2 base building sensitivity model shows a massive increase in heating energy, which changes the shape as well as the height of the curve. As explained earlier, this effect was encountered only with 2-pipe

and 4-pipe HVAC systems and therefore is presumed to arise from an error in the software coding. Unfortunately this overstatement leads to several further errors in the results. The energy savings reported for sensitivity measures 17 and 18 are excessive because both measures call for changes to HVAC distribution types that avoid the software problem; for the same reason, measure 16, which specifies a heat pump, would have shown excessive savings except that the software was unable to model it at all. For all other measures the energy savings is understated because it is expressed as a percentage, and the base building total is excessive.

In the TrakLoad model for the same building the general form of the curve was unchanged from Cycle 3, except for the loss of fan energy, but the overall energy consumption is less than half of what it had been. No specific reason for the shift has been identified, but it obviously had a profound effect on the sensitivity results as well. In this instance responses to some of the sensitivity measures may be overstated, where a given measure is independent of but still computed as a percentage of a much reduced building energy base.

The VCACS model for the large office building doesn't show as large a reduction in the annual energy figure, but the end-use energy profile doesn't even begin to match the ELCAP data or any of the other models. In Cycle 3 there were two VCACS models for the large office building: one each from modelers D and K. The "D" model was probably the "better" of the two, but the "K" model was selected and adapted for the sensitivity study. One might argue that enough parameters were **mandated** for the model that it wouldn't make much difference which of the Cycle 3 models were selected. However, the general <u>form</u> of the "K" model not only shows up in the base building model for the sensitivity runs, but in addition its summer hump has been magnified until that model differs radically from the other models. It may or may not give a good comparison of the <u>software</u> sensitivity. It is intriguing to speculate what the same input revisions would have done for the "D" model.

Why the dramatic differences? After all, many of the input values, though specified, were picked to parallel what the modelers had used in their earlier simulation models. And why would values for specific input parameters affect one model so much more than another? These are questions raised but left unanswered by the Evaluation of Software program. They remain for a more extensive analysis project.

The sensitivity study has generated and captured copious data. An obvious next step would be to distill the data into measures and conclusions that are easier to handle. This goal is closely allied with the goal for setting overall "Performance Index" figures of merit. The performance index concept and related summaries are considered in Chapter 8.

CHAPTER 7: SOFTWARE SURVEY AND COMMENTS

Knowledge about any topic comes largely from the accumulated experience of others. The Evaluation of Software project sought to add to what is known about building energy simulation software by soliciting comments from software vendors and users. Most comments came from those participating in modeling assignments for the project

An important result of those efforts is a tabulation comparing the features of the software studied. It can be used as a checklist when other software is reviewed.

7.1 Checklist

The tabulation on the next four pages summarizes features of four of the five software programs reviewed in the Evaluation of Software project. Information requested for the fifth software package, DOE-2.1, was not received.

Data for the tabulation were obtained from software vendors, vendor promotional materials, software manuals, and software users. Information from the simulation analysis and other study components described earlier in this report was also incorporated as appropriate.

Although the information is thought to be representative, the survey was not comprehensive; unintended errors and omissions are possible. Readers who apply the information should verify its accuracy and applicability to their interests.

Indeed, not all of the input data agree. Where opinions were sought, reviewers were asked to respond to a continuum ranging from "poor" to "good"; ranges (gray) and median (black) responses are shown in the tabulation. There were a few objective differences as well; for example, several reviewers said TrakLoad does not allow the user to modify (enter) part-load equipment performance curves, but one respondent claimed otherwise.

Reviewers were asked to base their responses on the most recent versions of the software. Software development is dynamic, however; further changes may have been released since then. SEA was updated a little over year ago, about the time its supplier went through a major reorganization. Despite recent revisions in TrakLoad, a further release was anticipated for summer 1990. Although VCACS is still supported, no further releases are planned; the supplier now offers ENTREE instead. PC-DOE, a microcomputer version of DOE-2, is no longer available. During the course of the project, ADM Associates announced a version of DOE-2.1D for upper-end personal computers. Similar changes are common occurrences with other building energy modeling software as well.

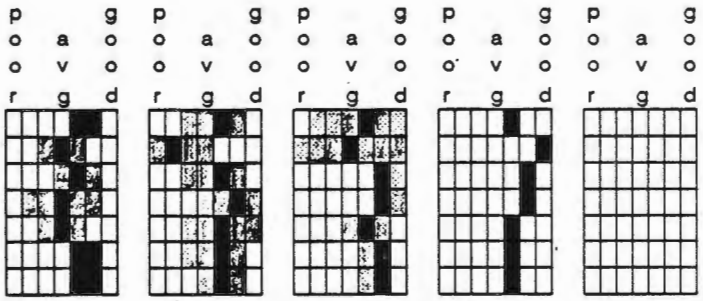
TABLE 7.1

SOFTWARE: COMPARATIVE DATA

General Information

	ADM-2	SEA	TrakLoad	VCACS	DOE 2.1
Software name	ADM-2	SEA	TrakLoad	VCACS	DOE 2.1
Type of model (w)	hourly	bin	bin (y)	typ day	hourly
Number of reviewers	2	4	3	1	0
Current version number	4.1	6	3.1	9.0 v	
Release date	7/88	10/88	10/87	7/87	
Cost of basic engineering simulation software, $	595	195	795	r	
Cost of enhanced simulation software, $	n/a	n/a	1485	n/a	
Cost per additional weather file, $	100	none	15 n	Y	

Opinion of:



Hardware/Software Requirements

	ADM-2	SEA	TrakLoad	VCACS
Minimum memory size, Kbytes	312	256	256	512
Coprocessor required	Y	N	N	Y
Coprocessor supported	Y	N	Y	Y
Initial disk storage requirements, Kbytes	940	1150	600	1340
Number of initial files	9	~70	70	212
Source code available	N	N	N	N

Documentation/Support

	ADM-2	SEA	TrakLoad	VCACS
Published validation studies/reports provided/available	L	N	N	N
Access to phone help	Y a	N	Y	Y
Manual/User Guide	Y: 2	Y e	Y	Y
Number of pages (include appendices)	121 + 115	150	202	365
Table of Contents	Y	L	Y	Y
Index	Y	N	N	N
Input default values listed	Y	M	Y	Y
Printed input forms provided	Y	P f	Y	Y
Computational algorithms presented and explained	P	P	Y	Y
Tips provided for adapting to non-simulated features	L	L	L	Y
Weather file content explained	N	Y	L	Y

Y yes N no L limited P partial n/a not applicable

lower case letters refer to notes on the last sheet of the table

TABLE 7.1 - page 2

Weather Files	ADM-2 hourly	SEA bin	TrakLoad bin (y)	VCACS typ day	DOE 2.1 hourly
Number of weather files supplied with initial purchase	1	7-10 g	7-10	7-14	
Additional weather files available from supplier	Y	Y	Y	Y	
Weather file format	binary	ASCII	binary	binary	
Typical size of weather file, Kbytes	140	4.5	1.0	1.3	
User accessible/modifiable weather files	N	Y	N	N	
Weather file creation program provided	N b	Y	Y n	N	
Data Input					
On-screen display of engineering units	N	Y	Y	L	
On-screen helps for user input	N	Y	Y	Y	
Graphics used to assist input	N	N	N	N	
Default values displayed on screen	N	Y	Y	N	
Default values specific to building types and sizes	N	N	N	Y	
Program conducts consistency checks on input data	Y	Y	Y	Y	
Input data can be saved to disk during data entry	Y	Y	N	Y	
Add/delete zones after initial file	Y	Y	Y	Y	
Number of input data files	1	10 x	1	9 x	
Typical space for input files, single zone building, Kbytes	4	3	3	50	
Easy routine to print out input data file	N	P h	Y	Y	
Output Reports					
Report energy consumption by month	Y c	Y	Y	Y	
Report energy consumption by end use	Y c	Y c	Y	Y	
Output graphics available on screen	N	Y i	N o	N s	
Output graphics available in hard copy	N	Y i	N o	Y	
Spreadsheet data output	Y d	Y d	Y o	Y s	
Summary text output	Y	N	Y p	Y	
Audit report text output	N	N	Y p	Y	
Easy modification of output text	N	N	P	Y	
Technical Capabilities					
Maximum number of zones	10	1000 j	5	6	
Zone titles/descriptions (user's text stored in file)	N	Y	N	Y	
Flexibility scheduling occupancy, lighting, equipment, etc	Y	N k	L	P	
Building orientation other than N-E-S-W	Y	Y	Y q	Y q	
Flexibility in wall orientation other than orthogonal	N	N	Y q	Y q	
Maximum number of outside "wall" surfaces per zone (l)	4	5	4	4	
Air distribution/control system types simulated (t)	12	19	14	8	
Heating system types simulated (t)	8	6	6	14	
Cooling system types simulated (t)	8	6	10	5	
Multiple heat/cool equipments per zone	N	N k	N	N	
Multiple heat/cool fuels	N	N k	N	N	
User modified equipment performance/partial load curves	N	Y	N	Y	
ECMs specifically simulated	N	N	~70 p	128	
Parametric analysis of ECMs with automatic/batch runs	Y	N	Y	Y	

TABLE 7.1 - page 3

Features Specifically Simulated	ADM-2 hourly	SEA bin	TrakLoad bin (y)	VCACS typ day	DOE 2.1 hourly
Daylighting	N	N	N	Y	
Photocell switching	N	N	N	N	
Evaporative cooling	N	N	Y	Y	
Cooling towers	Y	Y	Y	N	
Refrigerated zones	N	N	Y	N	
Refrigeration equipment	Y	L	Y	Y	
Rejected heat recovery	N	L	Y	Y	
Domestic water heating	Y	N	Y	Y	
Solar space heating	N	N	N	Y	
Solar water heating	N	N	N	Y	
Latent heat loads	Y	Y	Y	Y	
Humidification to setting	N	N	P	Y	
Dehumidification to setting	L	L	L	L	
Minimum outside air	%	cfm/sqft	Y	Y	
Warm-up with scheduled O.A.	N	N	N	N	
Air cool-down (flush)	N	N k	N	N	
Natural ventilation	N	N	N	N	
Thermo-syphoning/chimney effects	N	N	Y	N	
Air direction/speed effects	N	N	Y	N	
Cooling economizer, temperature	Y	Y	Y	Y	
Cooling economizer, enthalpy	Y	Y	Y	N	
Heating economizer	N	N	N	N	
Air source heat pump	Y	Y	Y	Y	
Water loop (California) heat pump	Y	Y	Y	N	
External water source heat pump	N	Y	N	Y	
Water source temperature settings	N	Y	N	N	
Ground source (coupled) heat pump	N	N	N	N	
Ground temperatures in weather file	N	N	N	N	
Solarium	N	N	N	N	
Natatorium/swimming pool	N	N	N	Y	
Dehumidification heat recovery	N	N	N	N	
Zone to zone heat exchange (partitions)	Y	Y m	Y	Y	
Economic Analysis					
Utility energy/demand data entry & display	N	N	Y	Y	
Billing rates file/entry	N	Y u	Y	Y	
Time-of-day rates	N	N	Y	N	
Energy charges computed	N	Y	Y	Y	
Demand charges computed	N	N	Y	Y	
ECM costs entered	N	N	Y	Y	
Payback period analysis	N	N	Y	Y	
Life cycle cost analysis	N	Y	Y	N	

Y yes N no L limited P partial n/a not applicable

TABLE 7.1 - page 4

Notes:

a	Phone support for first 30 days
b	Weather creation program available to European customers but not in U.S.
c	Reports do not show non-HVAC by month or Total Btu by month
d	Undocumented
e	Manual provided on disk
f	Printed input forms provided for systems
g	Number of weather files varies with region, up to 20
h	Easy printout applies only to building file, not system or plant
i	Requires color screen
j	Number of zones is subject to disk space limitation
k	Program allows more than one model to be joined, to achieve this effect
l	Some programs allow an extra "roof" surface to be defined and oriented
m	Static temperature specified for adjacent zone
n	Weathermaker option $195
o	Lotus/Symphony compatible output provided
p	With enhanced version
q	One-eighth compass intervals
r	No longer actively promoted
s	Compatible with capture by commercial "Graph-in-the-Box" software
t	Controls options may effectively increase number of types available
u	Constant (single-step) energy rates only; no demand rates
v	Subsequent versions marketed as "Entree"
w	Bin type models use modified bin methodology and monthly bins; typical day models use occupied and unoccupied hourly simulations of one "profiled" day each month
x	Number of files created; may include files other than input data
y	Some capabilities vary with level of enhancement

Software Vendor Interviews. The project focused on a small number of software packages; individual contacts were initiated with the respective suppliers. A letter of introduction and invitation were sent to each of the four PC-based software suppliers (i.e., for ADM-2, SEA, TrakLoad, and VCACS); letters were also sent to the suppliers of DOE-2.1 and MICRO-DOE. Only two of the letters were acknowledged. Appreciation is expressed for the interest and assistance provided by ADM Associates Inc. (ADM-2) and Morgan Systems Corporation (TrakLoad) through extensive telephone conversations.

Printed Sources. Considerable information about the software appears in promotional materials and manuals designed for user guidance and reference. This type of information was available for all five software packages, although its scope and usefulness varied. Documentation is part of the evaluation conveyed by the checklist.

Software Survey Sheets. An informal survey instrument was developed to obtain further information about the software packages. The multi-page form was sent to each of the subcontractors and each of the software suppliers; responses were invited, but optional. Of 14 potential responses from modelers on the Evaluation of Software team, 9 were received. Only one of the software vendors responded - the supplier of SEA.

7.2 Software Supplier Inputs and Comments

Letters of inquiry were sent to the source supplier of each software program studied in the Evaluation project, including both mainframe and personal computer versions of DOE 2.1, as follows:

ADM-2:
ADM Associates, Inc.
3299 Ramos Circle
Sacramento, CA 95827

SEA:
Ferreira & Kalasinsky Associates, Inc.
PO Box 101
East Mansfield, MA 02031

TrakLoad:
Morgan Systems Corporation
2560 9th , Ste 211
Berkeley, CA 94710

VCACS:
VOLT Energy Management Systems
4900 S.W. Macadam Avenue
Portland, OR 97201

DOE-2.1:
Building Energy Simulation Group
Lawrence Berkeley Laboratories
University of California
Berkeley, CA 94720

MICRO-DOE:
AcroSoft
3120 S. Wadsworth Blvd Ste #1
Denver, CO 80227

Previously supplied, but no longer available:

PC-DOE:
CA Systems International, Inc.
One Union Square
143 Union Boulevard
Lakewood, CO 80228

The letters invited written and oral responses, as in these excerpts:

> Your firm is one of several supplying computer software for simulating energy in commercial buildings. The utility of the simulations depends on how accurately the building energy is modeled and estimated.
>
> The "Evaluation of Software" project is studying such software. It is anticipated that the efforts will: Analyze the impacts of model-users on simulation results, estimate the absolute errors in simulation results, and facilitate selection of simulation software programs for use in future energy conservation programs.
>
> Simulations for the study will use the latest versions of the software packages and will be conducted by experienced modelers. You may want to be sure our files include your latest sales promotion materials and pricing.
>
> Your insights and contributions to this study will be most appreciated.

Suppliers typically responded only by sending their most recent sales brochures. However, telephone contact was established with ADM Associates (ADM-2) and Morgan Systems (TrakLoad). A further initiative with VOLT Energy Management Systems (VCACS) resulted in an in-person interview at their offices.

Specific information sought during these exchanges included identifying data for the supplier and software; software distribution, users, and applications; and the features, advantages, and limitations of the software. Particular attention was given to validation studies and reports offered by the suppliers. The following paragraphs are comments from suppliers, and responses to observations made by suppliers.

SEA: SEA, Version VI, offers color graphics, simulates over 40 different HVAC systems. Different multiple systems with different operating hours and different controls can be analyzed. Primary plants with multiple and different chillers can be simultaneiously studies as can multiple heating plants with different operating schedules. Over 30 different reports ... can be selected.

ADM-2: Program was developed primarily for California market; still shows references to Title 24 including summary energy results that use California-only conversion factors to convert energy forms.

Makes no internal provision for economic evaluation, ECM comparisons, or report text.

ADM-2, continued:

Hard copy of input data available only following full calculations on simulation run.

Solar calculation uses weather file data for location "A" and adjusts it for location "B".

ADM Associates talks about and apparently uses established routines to graphically display output results using Lotus 1-2-3, but has not released the routines for general use.

Trakload: Provides continuing improvements - eight since 1987. Future plans include more utilities.

Supplies default values by a 6 building types, economic analysis, energy audit report options, graphics using interface worksheet files, embedded macros for Lotus 1-2-3 and Supercalc.

Program reads ASCII weather file containing bin weather data from Air Force Manual and ASHRAE. User can read and modify weather file using Weathermaker program. File contains: weather station, latitude, altitude, dry bulb termperature bins, summer DB/WB, annual WB, winter DB, winter wind speed, 12 month wind speed, 12 month sunshine.

Heating demand determined from extra iteration; cooling demand from highest temperature.

Supported by one manual with four sections and appendix: about 200 pp.

VCACS: Permits "skip" options. These are alternative settings that specify calculations to be made for every hour, or at intervals of 2, 3 or more hours. The option allows a modeler to obtain quick, rough results from the simulation for a trial run, or slower, more precision results from a final run.

8760 hours of annual weather data from NOAA weather tapes used to profile typical 24-hour periods for each month.

Software is applicable specifically to multi-family, commercial and small industrial units.

Addresses energy effects though modeling of: demand and time-of-use energy consumption; deadband thermostat operation; night temperature float-down and morning start-up due to thermal mass effects; internal temperature float due to undersized equipment; heat recovery options; part-load performance simulation of primary equipment; hourly and daily scheduling of building loads and internal functions.

Gives multiple options for report graphics, program text and print style.

Calculates existing end-use energy consumption and demand. Retrieves extensive library of pre-defined measures. Calculates energy and cost savings for conservation devices.

Addresses energy effects though modeling of: demand and time-of-use energy consumption; deadband thermostat operation; night temperature float-down and morning start-up due to thermal mass effects; internal temperature float due to undersized equipment; heat recovery options; part-load performance simulation of primary equipment; hourly and daily scheduling of building loads and internal functions.

Provides summaries of before and after energy use; graphs of energy use savings; printed report.

VCACS was targeted for the utility market and strong support, and is commensurably priced. Engineering firms needing little or no support may be able to obtain a discount. The same is true for ENTREE, which is now offered in place of VCACS.

7.3 Subcontract Applicant Responses.

As part of the process for selecting the simulation contractors for the Evaluation of Software project, an advance letter requested information about the experience those firms had had with the software packages. Most of the responses were minimal, but a few are repeated below. Note that some pertain to the modeling process, others more specifically to the software.

- Usually problems that do arise are concerned with accurately modeling equipment configurations in real buildings when standard components are combined or controlled in innovative or non-standard ways. These problems can normally be addressed by changing default values or routines in the program.

- Most problems due to level of detail of input available/required. Solution has been to use particular program best suited to sophistication desired.

- Time consuming, even for minor changes.

- Yearly totals are easily matched; monthly usage is difficult to track. Match as closely as possible, explain outliers.

- Some models produce results which are not intuitively obvious. You examine profiles and if acceptable leave it.

- Many ECM's are not directly modelable in the software. Estimate savings and adjust related parameters to give result.

- Limited use of audit alternatives to produce interactive results. Have rerun programs by adjusting one or more inputs and calculating interactive results.

- With the exception of Micro-DOE2, limitations are generally flexibility of the schedule/profiles, utility rate structures, envelope component types, and system choices. Resolution is typically annualized averages. The next big thing is technical documentation - for which there is no resolution other that trial and error iterations and lots of experience.

- SEA: Limitations - Temperature and occupancy schedules.

- TrakLoad: Bug in heat pump night cycle - Fix in postprocessing.
  BESA/ASEAM: Poor on night cycle - adjust night setback temperature.
  ADM-2: Too limited parameters - Use DOE 2.
  MicroDOE: Slow - use limited period runs. Too much output - postprocessing program for reports. Can't do VVVT with heat pumps - use DDS/VAV with reset and fixed COP on electric boiler.

7.4 Modeler Comments

Modelers working on the Evaluation of Software project were encouraged to make comments about the software and their modeling experiences. Selected comments follow. Comments have been edited for brevity, while attempting to convey the modelers' original thoughts. Modelers' opinions do not necessarily agree with those of the investigator.

Software Selection

A thoughtful and critical evaluation of the various tools must take into account the purpose and constraints of the tools, information and modelers.

At the start of the project, it is important to choose the right software for the energy analysis. Small buildings with simple operation and simple systems are more suited to bin type analysis, while buildings with complex operation and complex systems are more suited to hourly analysis. It is not so obvious, however, that the level of effort, detail of information and control of uncertainties must suitably correspond to the software to be used.

Even with good quality software, however, the experience and judgement of the modeler is crucial to a good analysis.

By their nature, all bin type programs have limited ability to analyze buildings with complex schedules, calculate electric demand, simulate heat pumps and economizers, a very common HVAC system in the Pacific Northwest. Experience with bin type programs underlines their limitations in complex buildings, including buildings constructed with heavy materials, solar-driven buildings (small office type buildings in Central Oregon), accurate prediction of night set-back, limited HVAC option (California water-source or well water heat pumps), limited number of wall exposures, windows, etc.

Hourly programs are much more flexible and powerful, but require more user experience and more modeler and computer time.

We select the software for each model depending on special requirements of the project and strength of the software. Each modeling program has some degree of limited flexibility. The modeler may have to manipulate the input data to fit the model. An example is with equipment part load curves. The actual curve may differ significantly from the curve already in the program. To compensate for this, the equipment's full load power can be adjusted to produce an average energy use closer to the true consumption. Some hourly programs, like MICRO- DOE2, allow the modeler to input the actual part load curve which will increase the accuracy of the model. This is a good example of one of the criteria used in selecting the appropriate software for a given project.

Trying to get programs to accurately model unconventional problems has forced us to learn a great deal about the algorithms in the programs. Part of our preferences among programs stem from this knowledge of their internal working. Among bin programs our preference for TrakLoad is based both on the program's more sophisticated approach to sun load correlations with air temperature as well as its modeling of nighttime building temperature float.

Given the larger context for modeling, certain technical details make some programs more suited for some types of buildings and systems. Both TrakLoad and SEA are good for quick analysis of a building. TrakLoad has a very good input format that makes input quick and easy. However, its dynamic defaults must be watched very carefully. For example, if the boiler size is left to default over several runs, automatic re-sizing of the boiler can give false results due to the varying part load performance of the boiler.

Our preference is to use TrakLoad for small projects for which the time necessary to model with DOE2 is not justified. Where the project is complex or the answers must be correct, we will use DOE2. Our needs frequently require detailed simulation of operating details of buildings and differential energy use for subtle changes in HVAC systems. Thus only programs that have very good variable choice ranges and flexibility work for us. DOE2 comes closest to meting our needs, although we have had to stretch its capability to model common problems, such as VVVT systems.

DOE-2 and BLAST are probably the best pieces of energy analysis software available, primarily because of the publicly funded development and large user base providing feedback.

DOE-2.1: Although other powerful hourly codes are available, DOE-2.1's flexibility, its widespread use, and its continuing improvement and support by the US Federal Government, makes it the program of choice. In addition, the firm has a library of programs to determine typical (average) and peak load profiles from DOE-2.1 simulations.

An hourly model such as the DOE-2 is a very powerful tool but it cannot be expected to provide good results unless sufficient time, information and control over uncertainties is provided. In most cases, the selection of

appropriate software is or should be influenced by a lack of time, a lack of detailed information or the existence of large uncertainties and uncontrolled variables. All consideration of software details should take place in this larger context.

MICRO-DOE2 was the most flexible. Heat pumps can be assigned to specific HVAC types; regrigeration equipment can be assigned to zones with specific HVAC types. Refrigeration did not work in the MICRO-DOE2 version of DOE2.1C (may be fixed with recently received update) - Buildings with refrigeration loads were run on the BPA mainframe. Comprehensive building models may take from 3 to 5 hours per run plus printing time. For a series of runs we would come to the office 'round the clock to keep the process moving along.

General Comments and Features:

As a general observation the market for energy analysis programs is not large enough to sustain the development and continuing maintenance of high quality tested models without public funding.

Software requires operating system environment of MS/PC DOS version 2.0 or higher. For the Evaluation of Software project, DOE 2.1 was run on a VAX mini computer; Micro-DOE is personal computer version of DOE 2.1.

Good documentation can cover a multitude of software sins.

The size of a weather file is an estimator of how detailed the data in it is. For this reason, a weather file for an hourly program is larger than one for a bin program. Other variables that potentially affect file size are the number of parameters and/or bins, their precision, and the computer storage format (ASCII usually takes more space than a binary format).

Software-related comments

ADM-2: An hourly program derived from an older version of DOE-2. Its strength is ease-of-use for data entry. However, this also limits building configuration options and the early bugs embedded in DOE-2 are also in the ADM-2 code. For example, ADM-2 does not model economizers or heat pumps properly, because of incorrect assumptions about winter operations.

ADM-2: High "data input density", allows values for extensive input parameters to be entered from relatively few "screens". Extensive data on one screen provides good cross-referencing visibility in entering data and minimizes the number of keystrokes. Entries on each screen are made and revised simply by overtyping, without extra "Enter" keystrokes. These are positive features that seem to favor acceptance by experienced modelers.

ADM-2: The modeling does not let me make the seasonal changes in outside air that I want, so I have increased the minimum outside air and increased the cooling setpoint to compensate for the additional outside air during the summer.

ADM-2 Errors: Output that implies "Total Energy" doesn't really mean it;
Non-conditioning energy is omitted from monthly energy totals.
When cooling should be zero, program computes it at 0.1 kWh/hour/zone, but only if a cooling capacity is stated.
Units [feet] are not specified anywhere for exterior shading fins and overhangs.
Reference manual says fan temperature rise defaults to 1.815F per Table 5; but screen shows 1.82 for "static supply pressure" defined on p. 49 of manual as inches of water.
User's manual p. 56 Table 2 shows total fossil energy for columns 219-227; with output option /A2 instead repeats coluumns 92-99.
A change inlighting in an isolated zone served by one HVAC system changed heating and cooling energy in an unconnected second system.

SEA: Advantages - speed of calculation, ease of running conservation measures. Disadvantages - General simulation, inflexibility of HVAC, people, lights, equipment schedules.

SEA: Least flexible in modeling to fit a specific building - Most severe restriction is the requirement to input one operating schedule which covers HVAC, people, lights and equipment. Problems occur if these elements operate on differing schedules which the most often do, especially evaluating conservation measures. We have adjusted the respective percentasges to keep light and equipment consumption values constant while changing the HVAC hours of operation although this perturbs the simulation since the load levels are changed during the occupied and unoccupied hours.

SEA: Permits models to be built up from several models with differing occupancy, systems/plant, etc. [However this feature was not used by any of the modelers, due perhaps to inconvenience, failure to save full input files (above), modeler unfamiliarity, or other reasons.]

SEA: It is not possible to model separate systems and plants for each corresponding zone in a multiple zone building.

SEA: Since a BIN program relies on many simplifying assumptions it is appropriate to use a similar level of simplification for the impute -

- Zoning was kept simple.
- Small details of the envelope were ignored, for example the doors
- Schedules were kept simple; with only occupied and unoccupied periods, detailed information cannot be used.

SEA: The limited operating time did not allow for setting the HVAC, Occupancy, and lighting schedules independently. The different days per week were averaged and the 3 hours before opening added and the 1 hour after added. The lighting load was spread out over the entire time. No change was made for the occupancy number since it would not have a significant impact.

SEA: Since our version of SEA cannot differentiate between people, lighting, equipment and HVAC schedules, we have simulated the operation of the HVAC system only during operational hours and have included infiltration during the unoccupied period to equal the outside air CFM to account for nighttime ventilation air.

SEA: Has no provision for calculating utility charges from utility rate schedules. Only simple consumption can be calculated, which is only a rough estimate of the more complex monthly demand and stepped consumption rate schedule in effect for the building(s) in this project.

SEA: Fails to compute full input data in "the" data file; uses several input files, only one of which (building envelope and occupancy) is identified to uses. Automatically overwrites separate system and plat data files.

SEA: Seems better adapted for floppy disk data storage than for hard disk.

SEA: If software decides manual entry CFM is inadequate, it will override original entries without reporting them; but original entries remain in file. Increased CFM demand is not identified with heating or cooling mode.

SEA: When wall U-values were changed to improve the match with annual metered consumption, the peak heating consumption for the simulation was lower than the peak metered consumption. I suspect that the BIN procedure does not accurately account for thermal mass effects and solar effects. Matching annual end use was chosen as a priority, at the expense of matching descriptive data and metered monthly peaks.

SEA: Exterior lighting and hot water consumption have been calculated separately and have not been included in the simulation model. [The software does not provide explicit input or reporting of these end uses.]

SEA: Documentation has no information on how demand is calculated. Therefore the model is expected to be of very limited value in predicting demand savings.

SEA: The monthly demand simulation was judged to be not accurate enough to be usable.

SEA: Uses several approaches to on-screen help; inconsistent nomenclature. Change in system type requires full re-entry. "Duplicate" file command does not duplicate SYS data.

SEA: Heat pump supplemental heat - switchover selection, but no stepped or modulating take-over [2-stage temp-control, not demand controlled.]

SEA Errors: Input window asks for gross area for surface, but hardcopy output gives net area. Interacts incorrectly with printer spooler: cancels print in process is screen is advanced to next module.

TrakLoad: Runs quickly because it uses bin weather data; although not as accurate as hourly methods, this is sufficient for smaller, simpler buildings.

TrakLoad: Wide range of systems and equipment available compared to many other bin-type programs. Easy to use input screens available in four different levels of complexity. Reliable algorithms adapted from DOE-2 and ASHRAE.

TrakLoad: Overall we have had good performance from this program, although we have not recommended its use in environments where the user has minimal engineering knowledge.

TrakLoad: Initiates ECMs for Auditor by displaying options. Good manual. Building file storage and retrieval system is easy to use. Pop-up help, input parameters, calculator the inputs results, etc.

TrakLoad: This program is easy to use; the novice can rely on defaults for U-values, etc. It could be a great program if enhancements were made.

TrakLoad - suggested enhancements: User naming of zones; alphanumeric listing of building on file (menu); greater precision for input data; different operating schedule per zone. More that one roof type per zone; reintroduce "Doors" as separate component; accommodate door open/close effect. Rename label to "GROSS Wall Area/Story"; incorporate "misc. conduction" for a crawlspace, walk-in freezer. Exterior lighting consumption with "AVG hrs/day On"; light default wattage should include ballasts, include 2-tube 8-foot fixtures. Incorporate night setback on all HVAC types; separate fan/motor efficiency into fan and motor components. Include (air and water source) heat pump as central HVAC choices; heat pump with economizer and strip heat temperature control; other heat pump improvements. Include "% of total" by end-use in Engineering Usage Report. WeatherMaker option is difficult to use.

TrakLoad: A weakness is the inability to model a variety of equipment loads with different diversity factors. TrakLoad has only one use factor for equipment and lights. Watts/square feet can be easily over or under estimated.

TrakLoad: Rounds output reports: [a 53% error was cited for a small increment of lighting change]. Need to be aware of this rounding and make adjustment; still not very accurate.

TrakLoad: Exterior lighting is included with interior light in output report (bad point).

TrakLoad: Numerous input fields are interactive with other fields adn automatically change their values unless locked in. This autosizing can cause real simulation problems. The program does flag these fields for individual evaluation.

TrakLoad: A heat pump model will not simulate certain equipment features. Economizers cannot be installed when simulating a heat pump system. This can be a limitation on estimating overall savings.

TrakLoad: Will not let you enter a larger window percentage than wall.

TrakLoad: Configures zones on a per floor basis and then duplicates the zone's "footprint" in as many floors as there are in the building. Small Office building had considerable differences in square foot dimensions between floors, heating and cooling capacity, and equipment load. For these reasons it was decided to model the building as two separate buildings, and then combine the consumption results.

TrakLoad: Uses the number of stories as a multiple for some entries and not for others.

TrakLoad: When modeling heat pumps during a building's unoccupied hours, the program ignores the heat pumps and substitutes electrical resistance heating. We have accounted for the variances by making an estimate based on the relative heat pump efficiency.

TrakLoad: Its assumption that heat pump compressors will not operate at night during system shutdown elevates night heating use. We deal with this by adjusting night heating electricity use in spreadsheet postprocessing of the results.

TrakLoad: We have used the TrakGraph option with TrakLoad extensively and have added to the spreadsheet macros to combine building parts and adjust end use energy by month for part shutdown operation, such as in schools.

TrakLoad Error: Return from F1 help option is to one field lower than where you began.

VCACS: Relatively fast, especially on 386 PCs. Easy to use once the user is experienced. The "hourly" methodology allows consideration of electric kW demand and associated multiple block rates in lieu of typical cost/kWh average. [Note: VCACS is a typical day model with hourly simulations]

VCACS: Structured with specific ECMs in mind. All the user need do is specify the measure and enter the appropriate ECM data (rather than going back and modifying the base building data). Each plan is stored uniquely, then run in batch mode.

VCACS: Structured ECM's and other input values are cumbersome to override, but the option is provided. Other limitations are fixed: four walls maximum, six zones maximum, truncated input values, certain hot water calculations only for multiple family housing. Also lacks good on-line helps.

VCACS: Uses an ECM installed cost data file. ECMs were first run using "average" cost data from the file. The results were disappointing or inappropriate. All ECMs were rerun by substituting data from '89 Means.

VCACS: There is no way to "prioritize" ECMs once they have been entered as plans, short of running all plans (complete with accurate cost data) to determine results, then completely re-entering each selected plan from scratch.

VCACS: A major concern is using fuel history (monthly energy bills) to ratio end-use consumption for the base building and then evaluating ECMs - the results are not predictable. The accepted procedure, for the experience user, is to "benchmark" the base building without entering the fuel history - using the history data as an off-line guide and for "hand calculations" of end-use consumption.

VCACS: When analyzing ECMs w/ a base building using fuel history, using the automatic energy ratioing feature affects end-use energy not related to the ECM, e.g.: Lighting consumption changes significantly while evaluating a caulking/weatherstrip measure. Therefore, for Cycle 3, we removed the fuel history from the base building and revised the base building data to more closely match the annual end-use data.

VCACS: Does not ratio demand kW with input of billing history as it does for energy kWh. This is why so much effort was made to get the base model to track demand before entering the history.

VCACS: Unique rate structure (Eugene) with first kWh block based on kW demand. VCACS rates will not handle this monthly calculation, so had to average the monthly demand to determine average first block.

VCACS: Problems with utility rate files properly accepting new rates.

VCACS: No unique input for glass U value and shading coefficient; pick glass type closest to actual, or edit the data statement (typical user would not do this).

VCACS: Introduces sizeable rounding and truncating errors. Detail values may not add to totals given by the program.

VCACS: I experienced printing results problems, so had to resort to screen dumps of appropriate tables, etc.

VCACS: Printing results are not straight-forward and may be difficult for the casual user. Energy cost results by end-use or fuel type is not readily available. Our evaluation relied totally on "screen dumps" for all input and output data. An option require purchase of a graphics software package, which imports ECM data for pie charts and bar graphs.

VCACS Errors: Crashes with entry of some "out of range" values and on some reverse screens (returning to a prior screen during data entry). Re-boot necessary if Page Down or Page Up used instead of Enter for data entry at beginning of a new file (causes continuous loud sound from speaker); those entries are valid after first two or three screens. Screen for external fuel types not coordinated with documentation and program use: for electricity, program rejects "B" entry per screen prompt, and substitutes "A" (gas); undocumented "E" solves the problem.

DOE-2.1: The occurrences when at least one zone was outside the throttling range for the Large Office building was not related to specifying the CFM. The problem was solved by specifying a throttling range of 4 and changing the heating and cooling thermostat schedules to start one hour earlier. Doing this allowed the fan coil units to more easily meet the hourly loads and specifically the morning pick-up loads.

DOE-2.1: Although it is capable of finding the monthly demand peaks for any fuel used in a building, it does so regardless of what time of day this peak occurs. To rectify this, we use a spreadsheet database application which reads the DOE-2.1 output and finds the peak for the appropriate seasonal time-of-day windows of the desired rates schedule. This method was used for example to determine peak demand reductions and incentives for adoption of daylighting fenestrations and controls.

DOE-2.1: Economizer control for two- and four-pipe fan-coil systems is not available. To modify the systems to a central fan system would alter the input to such an extent that the comparison would not be worthwhile. I did not simulate this parameter.

DOE-2.1: Does not directly provide a monthly end-use summary, but one can be derived by combining several output reports.

DOE-2.1: The Building Energy Performance Summary (BEPS) Report does not always agree with the end-use totals or sum of component consumption reported on other schedules. The discrepancy was most pronounced for the Large Office, as follows (Cycle 3 base building):

Building Energy Summary	Category	Category Schedule Total
527 398	Space Heating	440 700
288 084	Space Cooling	351 700
98 488	HVAC Auxiliaries	
17 184	DHW	17 184
492 449 (a)	Lighting	417 196 (b)
76 551	Vertical Transport	
202 467	Misc. Equipment/Other	372 110
1 702 622	TOTAL	1 598 890
	Monthly Total	1 674 435

(a) interior and exterior
(b) interior only

MICRO-DOE2: Due to the high degree of flexibility and numerous options, more precise results can be obtained. Thus, when simulating energy conservation measures, you don't have to "fool the program" to model the ECM, because the ECM and the parameters it uses are usually available as options.

MICRO-DOE2: The program has a large number of reports that may be selected to help spot problems in the model which would otherwise go unnoticed.

7.5 Additional Comments

Building energy simulation software of interest to the Evaluation of Software project has frequently been referred to as "software packages". This is because software typically is supplied in several or many computer files "packaged" to work interactively. Often this includes program files, data files, output files, and "scratch" files (temporary run- time storage files). Executable program files are frequently arranged to call one another though one or more selection menus. The number of files in a package may range from as few as two or three to several hundred, depending on the software design.

The number of files in a software package is usually "transparent" to the modeler, and therefore unimportant to him. An exception may be file management needs; for example, files maintained on disk normally consume a certain minimum disk space no matter how large the file - 2 kilobytes is a likely minimum for a hard disk. Therefore many small files may lead to inefficient use of disk storage space. A related problem can arise from the gradual (or rapid) accumulation of the many small output files that some software packages generate.

A software-related problem arises with some energy simulation packages if the modeler must save multiple files to capture a complete record of a building model, and the problem is especially acute if the supplier fails to identify which files are which: SEA is a notable example and VCACS may be as well.

One goal of the Evaluation of Software project was to determine the accuracy of commercial building energy simulation software. The comparisons and comments in this chapter address that goal in one way. The extensive comments bear withness to unwanted limitations, problems, and errors in all of the software examined; the same overall condition is believed to affect other building energy simulation programs as well.

Those problems place even more responsibility on modelers. As one commenter noted, "We have found that modeling in general is more often an art rather than an exact science. Good assumptions by the modeler are required to prepare an accurate building simulation. For example, modeling software often lags behind advances in HVAC equipment and control technology. In this situation, the modeler must manipuate data input to account for the software's limitation."

CHAPTER 8: PERFORMANCE INDEX

A performance index is used to summarize the findings of the Evaluation of Software project and to facilitate comparisons with software programs in addition to those studied. The index is in two parts. A qualitative procedure is keyed to the software survey; a quantitative procedure builds on the sensitivity study. The results are helpful but need to be applied cautiously because the standards for the index are arbitrary and because some software packages may be better suited for certain types of buildings or analyses than for others.

8.1 Index Concepts

The preceding chapters report several approaches used to evaluate building energy simulation software: round robin comparisons of base building modeling, similar comparisons of ECM modeling, sensitivity studies, and surveys. Although the approaches were not pursued exhaustively, considerable data were accumulated.

As a guide to the selection of software, the results provide no overall, intuitively obvious conclusions. Even if preferences among the five software packages were to be identified after carefully studying the data, no way has been presented to extend the evaluation to still other software programs.

Moreover, a procedure for evaluating software needs to be limited in scope so that the time and cost consumed in the evaluation will be suited to an operating context.

What is desired is an overall measure of software performance that can be determined easily and then used to summarize the findings and compare the results. There is no "natural" measure of composite performance, but it is possible to establish a procedure and standard for this purpose. A Performance Index is proposed to establish a figure of merit.

Any performance index that meets these guidelines will be dealing with a complex set of relationships; simplification will come in part by looking at less than all possible data and in part by presenting only part of the information. In one sense, therefore, the selection of a performance index is arbitrary, and the values reported by it are equally so. In another sense, however, it is possible to use what has been learned during the Evaluation of Software project to synthesize an index which at least characterizes aspects of the most important information.

The proposed Performance Index offers two procedures for evaluation and comparison, one qualitative and the other quantitative.

The qualitative approach is a standardized checklist procedure keyed to the software survey reported in the previous chapter. It uses descriptive measures to address diverse yet apparent features such as scope, cost, and speed. For any given software package, the reviewer need only collect data comparable to what was reported in Table 7.1; conclusions depend on the reviewer's subjective comparisons and judgment.

The quantitative approach is a rating procedure based on the sensitivity study and uses objective measures. For now, the comparison is relative, but with further experience it may be possible to establish an absolute standard. The quantitative procedure is described at greater length in the paragraphs that follow. It reports either a single numerical index or a small set of such values that indicate how well the software handles one or more test (representative) files.

8.2 A Quantitative Index Procedure

The quantitative performance index approach provides a comparative evaluation of the accuracy of the software used in this study. The sensitivity study (Chapter 6) is the source of data for developing the comparison.

Considering the issues raised by the sensitivity analysis, software performance accuracy should be treated as influenced by a combination of software and user contributions. User impacts in the sensitivity study were controlled compared to the round robin efforts. Consistent comparisons were expected to follow from establishing common base building parameters and a specific range of change for each of the 25 different sensitivity variables. However, some results appear to be divergent; the range of the variation was explored in the report of the sensitivity analysis.

For the purposes of the performance index comparison the sensitivity data were used as gathered; this study did not analyze or adjust for the divergent results. Variations by software and by sensitivity variable (measure) were expected. Reasons for specific variations have not been determined.

The sensitivity study compared the percentage of change in the values for each variable analyzed. The Performance Index uses the same percent change values to evaluate software performance, since they appear to be the closest comparable measure available from this study.

The Performance Index ranks the several software packages, one measure at a time, using relative accuracy compared to a common base. To apply the procedure, one software program is selected as the base and the percent change sensitivity results of the other software packages are compared with it. The selected base software is assigned the lowest rank. The next closest percent change value either positive or negative (absolute difference) determines where the next higher rank is assigned. This continues through the five software packages. Ties receive half the sum of points for two positions. By totaling and averaging the points for each of the 25 sensitivity measures, a composite estimate is developed of the overall accuracy of each software package.

This procedure was first developed using DOE 2.1 as the base comparison. When DOE 2.1 is assigned a zero rank order, the results are as shown in Table 8.1. The table shows two sets of rankings, one for the small retail building and the other for the large office building, and an average of the two. The average rankings are reported as the index numbers. Figure 8.1 shows the same results graphically, except the DOE 2.1 values (zero) have been omitted.

Several observations about these results should be noted.

1. The index numbers compare changes in building energy due to the sensitivity measures: how a "target" software package compares to the simulation results of the "base" software package. Low index numbers imply relatively similar results.

2. In the ranking system described, the "base" software will always have a Performance Index of 0. Other software packages will show ratings in a range of 1 to 4. The sum of the rankings (for 5 software packages) will be 10, with an average value of 2.5 for the "non-base" software. The more similar the software packages are, the more they will individually approach the 2.5 index value.

3. In the Evaluation of Software project, the software studied (other than DOE 2.1) developed average index values ranging from 2.16 to 2.90. SEA was the "best" and VCACS was the "worst", when compared with DOE 2.1.

4. In the Evaluation of Software project, distinctively different Performance Index values were determined when the software programs were used to model the large office building rather than the small retail building: the index value dropped considerably for VCACS but rose modestly for each of the other three. The differential responses provide another indicator of software/model differences.

8.3 Other Quantitative Index Procedures

The ranking procedure described above produces a useful comparison, but it emphasizes a comparative rather than absolute standard. That is, the results are dependent on which software package in the group is selected as the base for comparisons.

Any of the other software packages could have been substituted as the comparison base, in place of DOE 2.1, with consequential shifts in values. The only reason for assigning the comparison role to DOE 2.1 is that it is the best documented, most widely recognized of the simulation software currently available. If DOE 2.1 is accepted as the standard of comparison, then the index values in the preceding table and figure are germane. On the other hand, weaknesses have also been recognized in DOE 2.1, and noted in part earlier chapters of this report.

TABLE 8.1 PERFORMANCE INDEX: RANK ORDER DETERMINED FROM DOE 2.1 EVALUATION B

		SMALL RETAIL					LARGE OFFICE				
		ADM2	SEA	TRAKL	VCACS	DOE 2.1	ADM2	SEA	TRAKL	VCACS	DOE 2.1
		A	C	E	D	F	A	A	D	D	F
MEASURE	CHARACTERISTIC										
1	Orientation	1	2	3	4	0	4	1	3	2	0
2	Floor loss	3	1	2	4	0	2	1	4	3	0
3	Roof insulation	2	3	1	4	0	4	2	1	3	0
4	Wall insulation	3	2	1	4	0	3	2	4	1	0
5	Glazing area	1	2	4	3	0	3	1	4	2	0
6	Glazing R value	3	1	2	4	0	3	2	1	4	0
7	Shading coefficient	1	3	2	4	0	1	2	3	4	0
8	Outside air supply	4	1	3	2	0	2	1	3	4	0
9	Fan operate, unocc	1	2	4	3	0	2	3	4	1	0
10	Lighting energy	3	2	1	4	0	4	3	1	2	0
11	Lightg heat to space	4	2	1	3	0	4	3	1	2	0
12	Water heating	1	3	2	4	0	3	2	4	1	0
13	Economizer	3	2	1	4	0	2	1	3	4	0
14	Supply air	4	1	2	3	0	3	1	2	4	0
15	Cooling COP	3	1	4	2	0	2	3	4	1	0
16	Heat pump	2	1	3	4	0	2	4	1	3	0
17	Multizone system	2	4	1	3	0	4	2	1	3	0
18	VAV system	4	2	3	1	0	4	3	1	2	0
19	Heating setpoint	3	1	2	4	0	4	3	1	2	0
20	Cooling partial load	3	2	1	4	0	1	4	3	2	0
21	Occupied hours	2	4	1	3	0	3	2	4	1	0
22	Occupants	2	1	4	3	0	1	4	2	3	0
23	Vacation schedule	2	1	3	4	0	2	3	1	4	0
24	Weather files	1	4	3	2	0	2	1	3	4	0
25	Building mass	3	2	4	1	0	1	4	3	2	0
		2.44	2.00	2.32	3.24	0.00	2.64	2.32	2.48	2.56	0.00
						AVERAGE	2.54	2.16	2.40	2.90	0.00

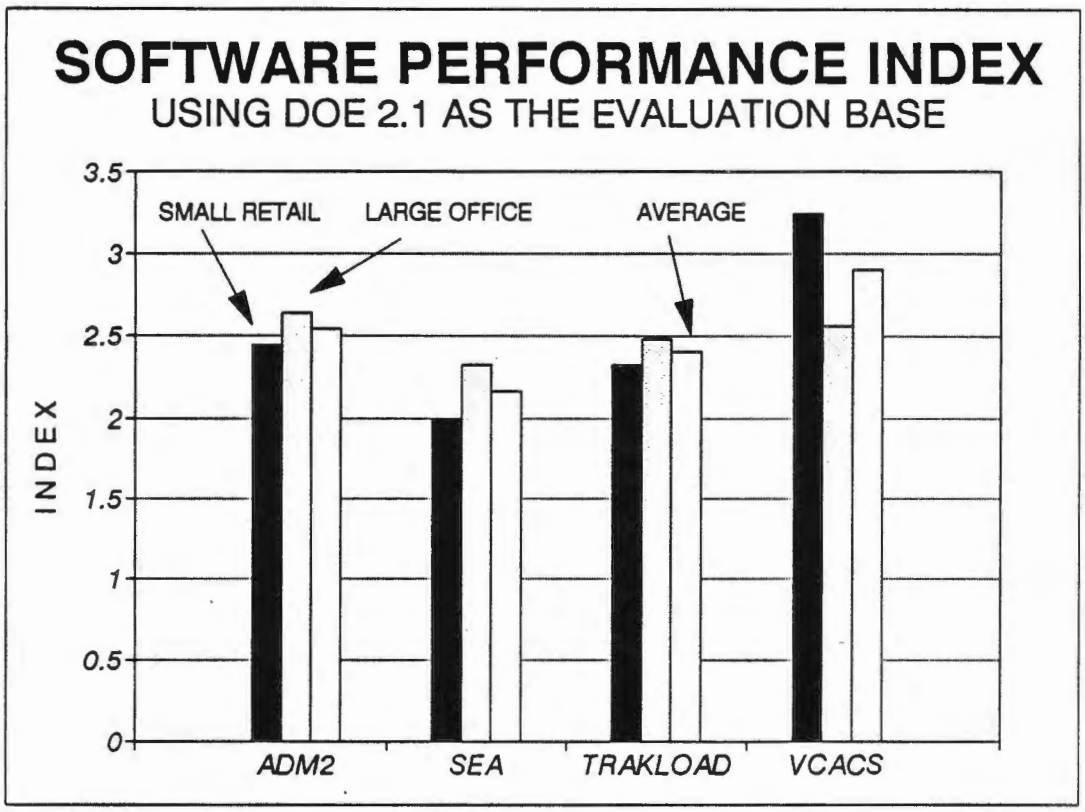
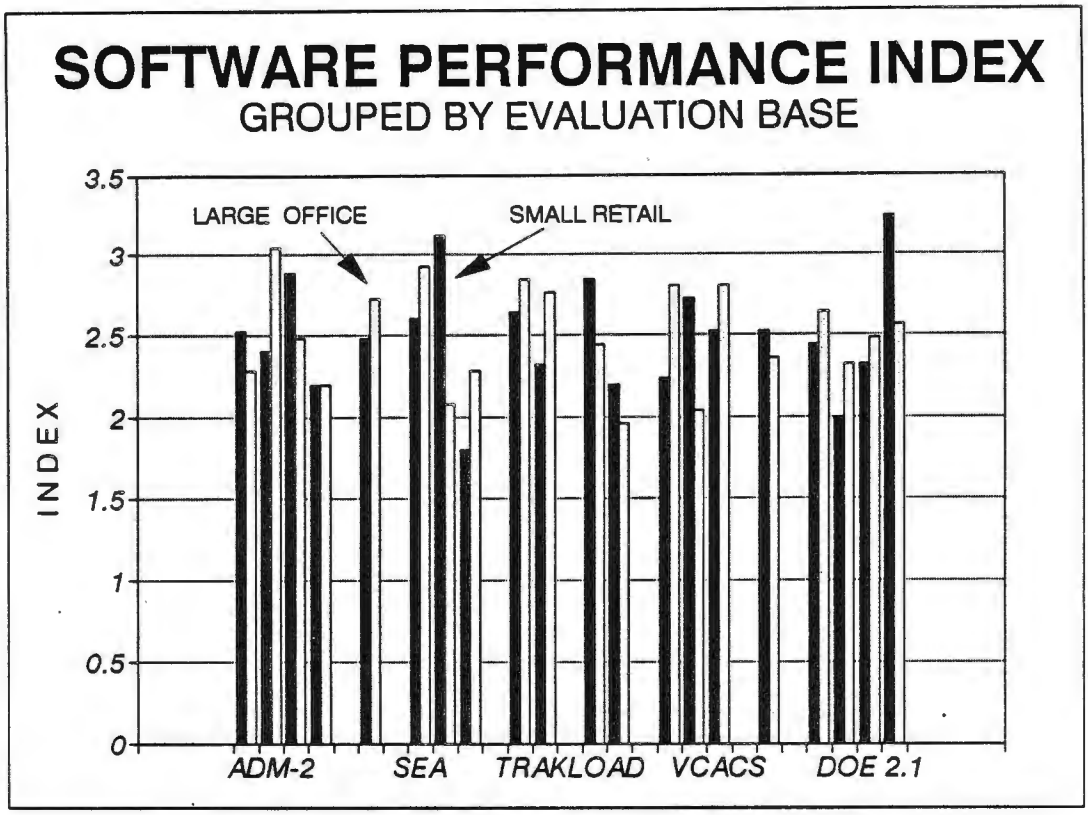


FIGURE 8.1

When the software comparison base is permuted, the following Performance Index results are obtained:

BASE =	DOE 2.1		ADM-2		SEA		TRAKLOAD		VCACS	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank	Index	Rank
ADM-2	2.44	3	0.00	0	2.48	2	2.64	3	2.24	1
SEA	2.00	1	2.52	3	0.00	0	2.32	2	2.72	4
TRAKLOAD	2.32	2	2.40	2	2.60	3	0.00	0	2.52	2.5
VCACS	3.24	4	2.88	4	3.12	4	2.84	4	0.00	0
DOE2.1	0.00	0	2.20	1	1.80	1	2.20	1	2.52	2.5

The extent to which ranking values and rank orders change with even simple variations in the procedure is explored further in Figure 8.2. The upper graph shows the same variation in index values tabulated in the previous paragraph, except that the distinction between the small retail building models and the large office building models has been retained; the identifiers on the horizontal axis indicate which software package was used as the comparison base, and the four sets of vertical bars show the corresponding index values for the other four software programs.


SOFTWARE PERFORMANCE INDEX
GROUPED BY EVALUATION BASE
LARGE OFFICE
SMALL RETAIL
INDEX
3.5
3
2.5
2
1.5
1
0.5
0
ADM-2
SEA
TRAKLOAD
VCACS
DOE 2.1

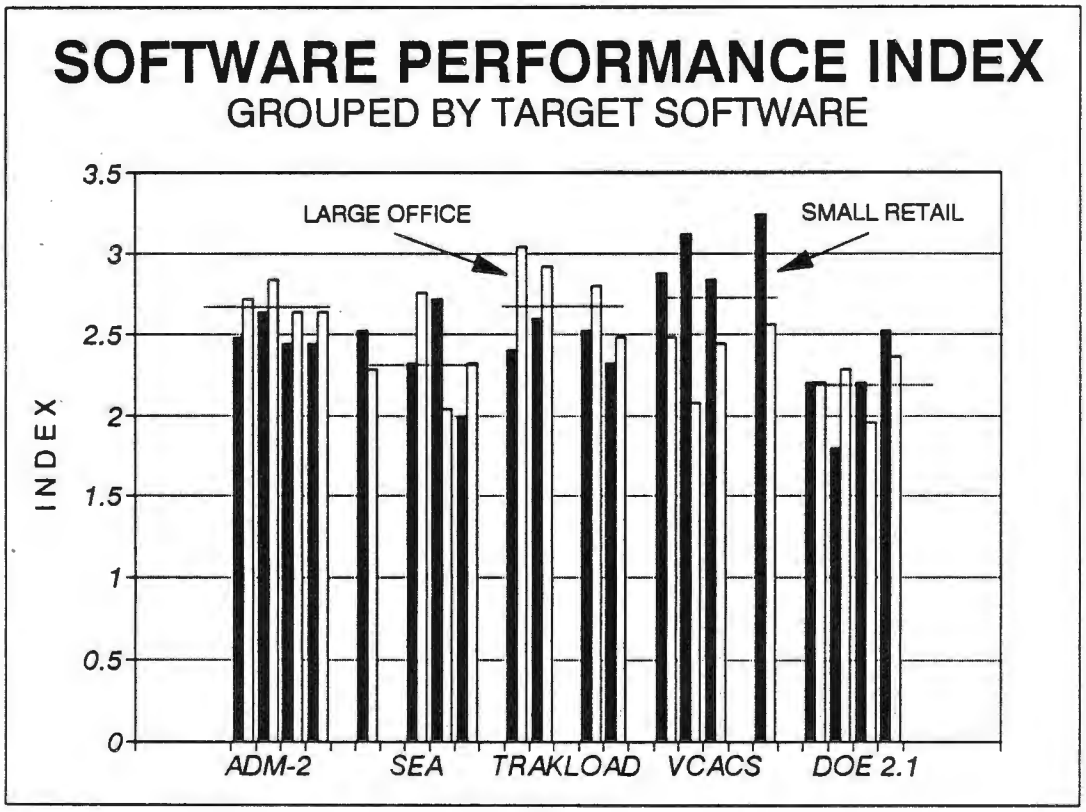

SOFTWARE PERFORMANCE INDEX
GROUPED BY TARGET SOFTWARE
LARGE OFFICE
SMALL RETAIL
INDEX
3.5
3
2.5
2
1.5
1
0.5
0
ADM-2
SEA
TRAKLOAD
VCACS
DOE 2.1

FIGURE 8.2

The lower graph in Figure 8.2 inverts the relationships and yields even more interesting results. In this figure the horizontal axis indicates the **target** software packages for which Performance Index values were derived. The vertical bars in each group show the corresponding indices when the other four software packages are used successively as the comparison base. The broken horizontal lines indicate average index values; overall, DOE 2.1 clearly exhibits consistently lower index values than VCACS. TrakLoad consistently shows higher index values for its large office models than it does for its small retail models, while VCACS reverses that pattern. On the average, SEA comes closest to the performance of DOE 2.1. These differences are considered to be significant; they contribute to the credibility of the method.

The Performance Index results also depend on which software packages are in the group, and how large the set is.

Suppose that a ranking process such as this is to be adopted as a general index of software performance, using DOE 2.1 for the comparison basis. The goal is to use the process to derive figures of merit not just for the five software packages already reviewed in the Evaluation of Software project, but also any other building energy simulation software of interest.

An immediate difficulty arises when the sample size increases from 5 to 6. When the procedure is used to compare six software programs, the ranking scores determined for five elements are no longer germane. To substitute a new software package for any of the five programs already evaluated would be to narrow the comparison base and also change the ranking values.

The difficulty is minimal. The ranking values have no absolute significance; they serve only to determine rank order for any given comparison. Any software package can be subjected to the procedure; its ranking value and rank order can be determined relative to the five (fixed) software packages used in the procedure. The six-element result, if desired, can be used for making a selection decision as readily as the five-element result.

Note, however, that six-element scores are not interchangeable with five-element scores. The rankings presented in Table 8.1 are not applicable to a six-element analysis.

It is easy, however, to extend the five-element analysis to a six-element basis using the data developed in this project: merely repeat one of the five software packages and consider all the tie scores it causes. The duplicated original-group software will always have an average six-element index value that is 0.5 points higher than it had in the five-element index. Specifically, if DOE 2.1 is used as the comparison base and ADM-2 is duplicated to enable the six-element analysis, its average index will increase from 2.44 to 2.94. The average ranking value will increase from 10/4 = 2.5 to 15/5 = 3.0. Individual index values for the software packages not duplicated may increase by more or less than 0.5, and therefore the rank order can also change (although a change is unlikely).

This is illustrated by the following:

	5 - Element Analysis				6 - Element Analysis			
	Sm Retail Index	Lg Office Index	Average Index	Rank	Sm Retail Index	Lg Office Index	Average Index	Rank
ADM-2	2.44	2.64	2.54	3	* 2.94	* 3.14	* 3.04	3
SEA	2.00	2.32	2.16	1	2.36	2.64	2.50	1
TRAKLOAD	2.32	2.48	2.40	2	2.76	3.04	2.90	2
VCACS	3.24	2.56	2.90	4	4.00	3.04	3.52	4
DOE2.1 **	0.00	0.00	0.00	0	0.00	0.00	0.00	0

* = duplicated element: averaged ranking
** = comparison base

8.4 Performance Index Procedure

It is assumed that a Performance Index will be used to evaluate building energy simulation software on a continuing basis. It is therefore suggested that the Performance Index be based on the six-element analysis outlined above, and that ranking values be accumulated against the possibility that they might eventually form the basis for absolute comparisons. The procedure for evaluating a further software package entails the following steps:

1. Maintain a rankings data base for 6-element analysis. The rankings data at the top of this page provides an initial entry.

2. Prepare Small Retail and Large Office base building models consistent with the Building Description Files and sensitivity base building parameters established by this project.

3. Conduct building energy simulations for each of the two models, for each of the 25 sensitivity measures defined in Chapter 6.

4. Record the percent change in energy consumption represented by each of the sensitivity measures, for each of the two building models.

5. Substitute percent change data from step 4 in place of the duplicate data set for ADM-2; the necessary data are in Appendix J.

6. Determine absolute differences in percent change, and average the results, using DOE 2.1 data as the comparison base; rank the results in the manner shown in Table 8.1 (extended for the sixth software package).

7. Record the new rankings data.

8.5 Analysis and Comments

Definition of the Performance Index and procedure presented in this chapter was deferred during the Evaluation of Software projected until findings were available from earlier stages of the overall study. The goal was to take advantage of what was learned to establish the most meaningful performance index procedures and parameters.

An effort was made to distinguish between two types of evaluation: one says "Of the X software packages looked at, package Y was the best for the following reasons", and the other says "The X packages suggest the following general evaluation approaches and factors". Since the evaluation effort concentrated on a rather small sample of all the software packages available in the marketplace, the first approach was discarded as largely irrelevant . The second approach may be a bit presumptive for the same reason, but it seems to be what is needed. The emphasis, therefore, shifted from establishing an absolute selection criterion to that of setting up a uniform evaluation process that reviewers can use for their specific applications and requirements.

When the time came to make the Performance Index decisions, results were available from hundreds of simulation runs - from both the round robin and the sensitivity analysis. Combining the software review procedure with the sensitivity analysis approach seemed to offer the best compromise for characterizing the building energy simulation software; it joins a descriptive comparison with an appreciable but not overwhelming simulation requirement. The selected measures are believed to be meaningful predictors of software performance. While a statistical basis for determining confidence is lacking, the results appear to be representative of the differences in software highlighted by the study analysis and noted by modelers.

The sensitivity analysis data used for the Performance Index include both small and large differences between software packages. Both are given equally weight by the smaller < larger process that establishes rank order. Consideration was given to the possibility that these differences might be weighted by magnitude rather than rank order, but if that is important then it follows that the large divergence in specific values makes it impossible for this study to obtain more accurate performance indices.

Some individual results have up to 500% difference from the DOE 2.1 value, while other results are very close. Detailed comparison of the deviation of specific results cannot be analyzed from this study; a follow up study would be needed for that purpose. Additional modeling of sensitivity runs on a large sample of software would provide data for a more accurate comparison between software packages. In that even, the present study establishes a procedure to complete a more controlled evaluation.

A further variation of the ranking procedure has been suggestion but not developed. In this variation the individual software packages would be

ranked by comparing them to a base established by the averaged values of all five packages. The underlying assumption is that the mean value is a better approximation of the "correct" value than any one of the packages alone could provide; the assumption suggests that the mean value provides a better value even than DOE 2.1. Indeed there are reasons for moving in to that basis, both theoretical and pragmatic; in Table 6.3, for example, the mean value indeed provides a better estimate of base building energy consumption relative to ELCAP data, and the same effect should hold for individual ECM values. Furthermore, the suggestion eliminates the need to rate the base (comparison) software as perfect (rank zero); that avoids the disparate ranking values found in the previous examples and leads to a common basis in which all the software packages earning similar ranking scores. This suggestion therefore warrants further attention and development.

The Performance Index procedure which has been defined can nonetheless be used to compare software package "X" with package "Y". Their respective ranking values are determined with respect to the six-package (or five-package) evaluation base, and then compared.

What the procedure cannot do is to identify either a ranking value or rank order that represents a particular level of "goodness" or acceptability, e.g, any program that scores "x" or lower is acceptable. Over the long run, as scores are accumulated, it may be feasible to establish that standard, but it will be a judgment call.

Several potential pitfalls are recognized in establishing an evaluation index and figures of merit. Not the least of them is that software packages behave differently under different conditions, such as different building types or a different building file. This is, however, a typical problem for any benchmarking effort. The goal was to establish a benchmark which is representative of the various conditions under which software will be used. By subjective standards it appears the goal has been met.

Using the quantitative benchmark results in the following comparison of software performance, with the most consistent software ranked first:

DOE 2.1
SEA
TrakLoad
ADM-2
VCACS

The Performance Index provides a useful way to compare not only the software sampled under the proposed contract, but also a simple way to derive performance figures for other energy simulation software in the future. It also offers another tool for further comparisons of how modeler decisions affect the performance of the simulation software.

Each of the several alternative methods for setting performance index values would lead to a different numerical base and index. One of the methods should therefore be selected as the consistent procedure for determining the Performance Index, so the index numbers will take on added significance as the process is more widely applied.

CHAPTER 9: LITERATURE REVIEW

A selective literature review was conducted to take advantage of what has already been accomplished and what is already known about the validation of building energy simulation software for commercial buildings. Previous investigations and their findings help avoid unnecessary duplication, highlight unanswered questions, and allow concentration on remaining concerns. The literature review helped shape the activities of the Evaluation of Software project.

Printed materials about building energy simulations were collected from sources such as ASHRAE, SERI, the California Energy Commission, and software suppliers, with emphasis on efforts to compare and validate energy simulation models. Published information has been condensed for presentation here.

While the earliest evaluations of energy simulation software for commercial buildings focused on mainframe computers, desktop computers are now converging on the original capabilities of that hardware, and software for the "personal computers" is gradually being upgraded to eliminate earlier errors and encompass more extensive capabilities. DOE-2.1, for example, is now available in PC format from two suppliers.

At the same time, more validation studies are becoming available for widely used programs such as ASEAM and TrakLoad, although work on other software and cross comparisons of even these validation efforts often are still missing from the literature. Bonneville is working on the Commercial Retrofit End Use Study (CREUS) which in part is a parallel effort comparing simulated energy consumption from ASEAM with energy data measured in the field. Other jurisdictions such as the California Energy Commission have been approving specific software based on their own evaluations (see Appendix K).

The validation studies encompass varied methodologies, but most of them involve comparisons between several simulation models or between models and the actual buildings the models represent. A frequently noted result is significant divergence between the various energy estimates. Reasons given for the divergence include conceptual or coding errors in the software, modeler interpretations and errors, and variability of input parameters.

9.1 Modeling Significance

Building energy simulation modeling and analysis were recognized in the literature as significant for several reasons.

The direct application of building energy modeling to energy estimates and analysis of energy conservation measure alternatives was of course the primary

interest of the various authors. In one study (ACEC)[1], eighty percent of the participants said simulation justifies the cost. Many were surprised that performing a model simulation could be useful even for small buildings for which the analysis usually had not been done.

"Energy conservation may require greater sophistication in the design of HVAC systems as we use the computer to model how and not just how much energy moves or is moved around a building." (Meckler)

"Modeling was most helpful as a tool for the comparison of various energy conservation strategies and not for trying to predict the actual future load of a building." (ACEC)

There are also sidestream benefits to modeling. The same study (ACEC) pointed to the significance of developing "hands on" modeling experience; hence, participating in modeling was beneficial for developing modeling experience (capabilities building).

However, "Although [simulation programs are] helpful tools, they have a long way to go. I think experienced intuitive conclusions are still often more accurate because they can take more variables into consideration."

Overall, participants in energy conservation modeling approaches were positive toward the experience, felt that additional cost effective savings were achieved, would re-use successful energy conservation measures in future design projects, and would utilizes similar design approaches in the future. (ACEC)

9.2 Descriptive Comparisons of Software

Building energy simulation software was evaluated in many ways. Where several software programs were being considered, it was common for studies to list and compare the features that can be presented descriptively. Materials reviewed from ACEC, ASHRAE, and Arthur D. Little contributed considerably to such interests. Some sources also chose to consider what features software ought to offer in the future.

Many of the performance features in software packages are used primarily to model energy conservation measures. The ACEC report noted 27 distinct ECMs used in the Energy Edge program; 15 of them are represented in the sensitivity measures adopted for the Evaluation of Software project. The Evaluation of Software sensitivity measures are also represented in 75 of the 102 ECMs funded by Energy Edge[2]. Energy Edge Performance features are listed and ranked in Table 9.1; the same study identified additional features desired by modelers, which their current software was incapable of modeling, shown in Table 9.2.

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(1) See Appendix A for full names and citations

(2) ACEC, p. 5-7; see Chapter 6 of this report.

Table 9.1
Satisfaction with Simulation Model User and Performance Features

Measure/Software Feature	% of Time Users were Satisfied
Method of analyzing heat transfer	100
Calculation method	97
Available data for construction materials	93
Models multiple thermal zones	90
Choice of HVAC system types	88
Calculates variable internal load factors	87
Ease of reporting results	86
Choice of HVAC plant types	86
Models building shading	86
Partial load Elec/Mech equipment	85
Choice of load reports	83
Choice of systems reports	82
Accuracy of Results	81
Calculates wide variety of external loads	81
Reaction of other professions	79
Performs economic calculations	79
Models special features	77
Technical support available	75
Program documentation	73
Choice of control options	73
Cost of the program	71
Economic evaluation	70
Ease of modeling the building	68
Time to learn the program	67
Models building mass	59
Models more than one Secondary system	50
Models daylighting	44
Calculates passive cooling	44
Graphic input/output	42
Calculates passive solar heating	39
Models motion detectors	33

Table 9.2
Additional Features Desired

Daylighting	Better documentation, error detection
Occupancy sensors	Indirect evaporative cooling
Passive solar	Ground-loop heat pumps
Certain air economizer uses	Dimmer controls
Certain waste heat recovery	More available HVAC types
Special kitchen and laundry equipment	More thermal zone options
Water source heat pumps	Better incorporation of energy management systems

Software users were generally pleased with the ECM features provided in the programs they were using; however, they were less satisfied with features "that stretch the capabilities of even large mainframe computer systems or require assumptions about user behavior patterns rather than mathematical analysis." (ACEC)

Meckler called for distinctive features that include quick estimates with minimal input, more detailed capabilities for advanced HVAC systems, and economic evaluation of efficient combinations of heating and cooling equipment.
Software development is an ongoing process. "Graphic input and output - unsatisfactory for most programs used in Edge - is getting better in the latest generation of programs." (ACEC)

Some of the comparisons were pointed toward specific software packages, as the following comments (from Arthur D. Little) illustrate. The study concentrated on ADM-2 and Micro-AXCESS but made other comparisons in addition:

> ADM-2 limitations are single terminal system and 10 zones, lack of cool storage, and absence of help menus; but it was commended for detailed calculation of loads, user interface, and documentation.
>
> Micro-AXCESS cannot model cogeneration and was marked down for building loads limitations, poor format and limited output, and very limited documentation; but it handles complex buildings with 40 zones, multiple systems, cool storage, and is widely used by electric utilities.
>
> MICRO-DOE was criticized for slower computational speed than the other two. "MICRO-DOE provides the greatest range of capabilities [but] requires the use of an English-like special language for input data", prepared off-line, and consequently is more difficult for users to master.

9.3 Software Selection

Descriptive comparisons of software were often a starting point for rating or selecting software. "The prospective user of commercial building energy analysis programs should first carefully define the kinds of applications of interest and then match the various program characteristics to the requirements. Once the program has been selected, the user should be dedicated to understanding it and to working within its inherent limitations." (Arthur D. Little)

The ASHRAE software inventory includes a section devoted to programs for energy analysis (pp 48-71). It contains 79 listings for residential and commercial programs. [Neither DOE 2.1 nor ADM-2 is listed in this section of the inventory.]

No single selection of a software package is likely to meet all modeling needs; programs have been customized for particular interests and applications.

Meckler uses a family of four programs for his work: "No one program satisfies all our needs, and as a result, we use utilize one or more of four separate programs in energy analysis work. None of these programs duplicates the others."

Performance characteristics are but one dimension of what the software needs to offer. Accuracy is another. Reliability needs to be engineered into the product through a verification process, and then confirmed through validation testing. Even without testing, much can be done to understand the likely reliability of the program. The extent to which vendors offer software verification and validation provides a further basis for software selection.

"Ask the vendor to supply data for some of the large jobs used to develop quality assurance tests; make sure they can actually be duplicated." (Evans)

9.4 Software Verification and Validation

"The performance of any software is judged by its productivity and its reliability. The process of establishing the reliability of a computer program is called verification. Government agencies, technical societies, and companies are active in the production of guidelines and standards for verification." (Richter)

The terms validation, qualification, and verification are given varying definitions in the literature.

> "Verification of an engineering computer program is the process that establishes for each tested capability: Use of valid technical models and algorithms; range of qualified applications and parameters; reproducible and accurate results; and reproducible and accurate performance of the computer system used for test runs." Richter goes on to offer recommendations for the contents of a verification report.
>
> "Verification is a procedure to ensure that the model is built according to specifications and to eliminate errors in the structure, algorithm, and computer implementation of the model." "Sensitivity analysis of simulation models can also be of some help in validation; this method relies on the fact that, in general, reasonable changes in model parameters or operating conditions should not lead to unreasonable changes in model performance." (Neelamkavil).
>
> Validation can be achieved by collecting evidence to support the validity of concepts, methodology, data, results, and inference; this may be demonstrated from retrospective, predictive, and structural perspectives. Verification refers to the correctness, consistency, and completeness of model implementation with respect to the design specifications, whereas validation is concerned with the correctness and consistency of a model with respect to the real-world system under study. (Neelamkavil)

No one method of verification or validation is universally recognized or followed, but they should be recognized as complementary and supportive; they are useful tools "for defining and producing cost effective, maintainable software." (Peters)

Validation depends on the control exercised over possible sources of error: weather, occupant behavior, modeler error, handbook error - which are external error types; and on modeling algorithm discrepancies, numerical solution inaccuracies, and coding errors - which are internal error types. Work in validating building energy analysis simulations has resulted in a methodology that uses three kinds of tests: analytical verification, empirical validation, and code-to-code comparisons. (Wortman)

Software development needs to be well managed to achieve reliable, quality performance software in a cost effective, timely manner. Kert wants readers to take advantage of parallels noted between software development and the development of a hardware product.

Peters says an appropriate starting point is with the software vendor's reliability engineering and management efforts. Software development is a process in logic that has been viewed as a progression of analysis, design, and coding; but in fact "most software either starts out without any blueprint or is quickly modified without updating the blueprints. The development of structured analysis, structured requirements definition, structured analysis and design technique, and other methods respond to this analysis need. The comparable design responses are found in structured design, structured systems development, and Jackson's design method.

Reliability engineering tools are being developed to monitor the evolving reliability of software programs under development. Software reliability is a measure of how closely user requirements are met by a computer program in actual operation. Users are likely to demand that software developers prove their products meet maximum failure intensity limits. (Musa)

Evans wants vendors to supply quality assurance problems that test the program's capacity, along with solutions obtained by a third party with which comparisons can be made. "A vendor should ... produce a list of the quality assurance tests that have been run and describe how the solutions were evaluated; the solutions should be checked."

Analysis software differs from business software because "the accuracy of an analysis program must be unimpeachable [and] it is much more expensive to develop, maintain, and support; in addition to paying a higher initial price, users of analysis software must also pay for maintenance and support." "Many vendors charge an annual update/maintenance fee for their software; even if no actual improvements are made on the program in the course of a year, its developer will be working to correct problems that have arisen during that time." (Evans)

"Many standards stress procedures that require a test plan for development of a program and emphasize the specification of acceptance criteria and expected

results for tests, [but] users in industry must rely [primarily] on results-oriented documentation and verification." Reliability is measured by comparing the accuracy of the results from the program with results from another source. (Richter) "The best strategy seems to be to test models to increase or decrease our confidence in them by exploring their limitations in comparison with the other known alternatives." (Neelamkavil)

Testing is an important, and sometimes overlooked, part of the software engineering environment. Dowd believes testing should be implemented at the start of any software lifecycle. The goal of software testing is the elimination of errors. By planning to test the different parts of the final system, actual testing will be performed with fewer problems. The developers of the test plans and test procedures should be from a different organization than the software developers or designers, for reasons of objectivity and fresh perspective. The testing or quality assurance activity should be part of each phase of the software lifecycle; requirements, specifications, design, test case design, implementation or integration, configuration management, and maintenance. Definition of testing requirements and procedures and results should be documented at each stage of the lifecycle, including documentation of the analysis and design processes themselves.

The cost of testing software has been acknowledged as about 50% of the entire cost of a project, according to Dowd. "Yet most people involved fail to figure this additional cost into the time and cost projections for completed software. Assumptions are made that software will be completed with no errors and that testing will merely be a convenient way of showing this."

Dowd goes on to recognize that it is impossible to completely test a complex piece of software. We often aim instead to cover the limits of the program and assume that "middle ground" will be functionally correct also. Testing at discrete points representative of a variable's range is usually sufficient to fully characterize a well behaved algorithm or software program.

9.5 Data Variables

"The models we build usually include only a subset of the variables and interrelationships of the original system. Obviously the ability to build models by selecting the smallest subset of variables which adequately describe the real system is a very important and highly desirable quality of a good modeller." (Neelamkavil)

Coad claims that, "With a valid energy program, the calculated results can be assumed correct, adjusting, of course, for statistical versus actual weather conditions. Obviously, this also depends on all input factors being correct."

In a representative study reported by Alereza, the data from average weather years "used for the simulation were not for the same weather year as that of the utility bills [but] most of these values were within 10 percent of each other."

Weather data plays a subtle but critical role in valid simulations. Some jurisdictions specify the weather data that is to be used. The California Energy Commission, for example, recognizes official weather data for 16 California weather zones, based primarily on TMY hourly weather data format. (California Energy Commission [#2])

9.6 Software Validation Methodologies

The validation of building energy simulation software usually relies on some form of testing, increasingly supported by documentation of software design management and reliability engineering during the design phase. A related approach used by government agencies establishes compliance standards, which likewise typically depend on testing and documentation.

Most validation test methodologies establish a program of building energy simulations, the results of which are compared either with other simulations or with metered data from test buildings. Various methodologies for validating building energy simulation software appear in the annotated bibliography (Appendix A) or are described with the test findings below.

The most comprehensive example of compliance standards is found with the California Energy Commission (CEC). California Administrative Code, Titles 20 and 24, establishes requirements for building energy efficiency: building design, design procedures, component performance requirements, permits, certification, and enforcement. The Codes establish allowable calculation methods using computer programs, and define modeling input requirements. The Codes define performance and prescriptive compliance approaches, plus mandatory requirements for all buildings. (CEC #4)

Some computerized methods require successful completion of a standardized approval test that demonstrates substantial equivalence to a stipulated public domain computer program. DOE-2.1B is the comparison standard for second generation nonresidential standards in California (CEC #1): Certification tests include parametric runs on 21 measures. Test results are evaluated statistically; energy estimates for each of five end-use categories must be within 30% of reference method results: lighting, heating, cooling, HVAC auxiliaries, and other (CEC #2).

California's requirements are more extensive, however, than the tests alone. For approval, computation methods must provide specified capabilities, generate output reports with mandated information including end-use data, demonstrate acceptable accuracy by passing the certification tests, make available a Compliance Supplement to the user's manual, and have ongoing support from the supplier. Minimum modeling capabilities are specified and optional modeling capabilities are recognized. The procedures for obtaining approval include: application form and checklist, sample runs, compliance statement, computer data, statistical verification analysis, and weather data. (CEC #2)

9.7 Comparison Test Findings

Validation tests typically compare a test model with a reference model or building. Comparisons are made based on total building energy or some part of it, such as monthly increments, end-use data, or heating/cooling loads. The performance quality of the test model is judged by how closely it conforms to the reference model or building.

Metered building energy from a real building provides a primary comparison, while energy estimated from a model constructed with previously validate software such as DOE-2 or BLAST provides a secondary comparison.

Although the circumstances of the tests affect the quantitative results, sufficient testing has been accomplished to find overall patterns. Specifically, Wagner's efforts brought together the findings from two dozen validation test programs. "Differences between predictions and measurements in most of the studies compiled were within a ranges of +/- 20% on average for the monitoring period for simulations of individual occupied buildings or groups of occupied buildings." However, these figures were primarily for simulations where prior consumption data were available and models had been adjusted to conform. They also tend to be annualized figures for total building energy, which frequently hide offsetting component differences of greater magnitude. Further examination of detailed results suggest that comparisons are likely to be considerably more disparate when data are recorded under less controlled conditions, more like a typical energy audit.

Judkoff and Wortman [#3] found that input assumptions based on standard engineering references can cause prediction errors of approximately 60% even when using measured meteorological data. Accurate temperature prediction does not guarantee accurate load prediction, or accurate temperature prediction on the next building studied. There is evidence also of compensating errors giving a false sense of confidence. Even when most input inaccuracies are eliminated, prediction errors from 10% to 17% were still found. This can have a large impact on building and HVAC system design options.

The report from Arthur D. Little cited validation studies conducted by the International Energy Agency and the National Research Council of Canada. In the IEA tests, the range of annual energy estimates differed by a factor of more than two for both heating and cooling. In the Canadian study, annual energy results ranged from 0.5 to 2.0 of the average prediction.

In a further study by Judkoff and Wortman [#2], the base case yielded estimates 46% to 62% higher than measured loads, but when input values were changed to measured values, the resulting estimates were low by 11% to 33%. Differences between models were considerably less. The authors conjecture that the software programs are overpredicting both solar energy gains and conductive skin losses.

In a sample of CAP buildings drawn for analysis, weighted algebraic averages of differences ranged from 1.5% (lights) to 48.5% (hot water) and to 66% (miscellaneous); absolute differences were substantially more. However, some

of the differences were due to meter data channels that did not exactly coincide with the end-use categories modeled, or to other factors independent of the audit work. (Cambridge)

Even so, differences in excess of 50% were noted in elements of the CAP buildings that were analyzed: gross wall areas, 20%; lighting levels, 27%; rated total heating capacity of equipment, 24%; rating total cooling capacity of equipment, 24%; water heating, 13%. In individual buildings, still larger discrepancies were found between end-use energy estimates and metered end-use data; the report assigned this primarily to varying definitions used by each contractor and by the metering protocols, rather than to building types or locations. (Cambridge)

Differences between a test model and its comparison base were influenced greatly by modeling targets. Targets are typically established through the availability of utility billing histories for a building, or better yet by end- use metered data. The quality of base building models and simulated energy conservation measures was substantially improved when appropriate targets were used.

In a study reported by Alereza and Hovander in which target data were available from actual consumption data, models based on initial assumptions were of relatively poor definition. Discrepancies between modeled and actual consumption were identified and typical audit adjustments were made: "Inputs were reviewed for reasons to explain significant discrepancies when such discrepancies did exist. Accordingly, new runs were made until reasonable and justifiable results were obtained." After adjustment, the root mean square error of monthly energy consumption values in a office building was 16% of the mean energy use; 17% for a restaurant; and 7% for a retail store. The authors intimate that the models yielded predictions of (total) energy that were within 10% of actual usage.

In efforts reported by Spielvogel, estimates of energy consumption, for both heating and cooling, initially appeared to differ by as much as a factor of three during some months. "The probable reasons ... are the manner in which the various users interpreted the data ... and the manner in which the computer programs handled the heating and cooling loads." An effort was then made to eliminate the user interpretations, to the greatest extent possible: Further models were developed for a simple high-rise apartment house with four widely used energy analysis computer programs; the test case was sufficiently simple that all models produced very similar results.

Loads for two models studied by Akbari et al were compared with DOE-2; heating loads were within 20% and savings from conservation measures were within 10%, after adjustments were made to initial models. The comparisons were relatively more divergent for well insulated houses, mild climates, large thermal masses, and high infiltration. The authors rejected a third model, which understated heating loads and savings by as much as 50%.

After modeling adjustments were made by Cleary, new estimates of building energy consumption were 30% to 40% lower than the previous estimates, with comparable reductions in estimated savings potential.

Judkoff noted similar opportunities for improvement: "This analysis procedure revealed several input non-equivalencies [modeler effects] and several internal code bugs. The procedure also highlighted the sensitivity of several algorithmic differences between the codes. When those problems were corrected, the three American codes showed reasonable agreement." The adjusted models agreed within 6% to 13% for heating or cooling; except that in a Copenhagen environment where little cooling was simulated in any of the programs, DOE-2.1 predicted twice as much cooling as the other two programs.

Dispersions in results noted by Diamond were reported as standard deviations of monthly simulation estimates, which when averaged for the year for total energy ranged from 16% to 39% for uncontrolled input, but 12% to 18% for a more controlled "standard evaluation technique".

Well controlled studies often do show closer conformance between the test model and the comparison base than suggested by the preceding paragraphs.

Arthur D. Little reported base building simulations that placed total annual electrical energy for the test software models within 15% of DOE-2 and BLAST, while parametric runs for seven conservation measures showed typical differences between the two test models of about 15% (although ranging to a high of 80%).

Yuill reported BLAST simulation results for a standard house that were from 5% deficient to 11% excessive when monthly energy totals were compared, and from 1% to 15% excessive for an energy-efficient house; deviations were ascribed largely to input data difficulties. Overall agreement was taken as support for the BLAST predictions.

The CAP evaluation report concludes that CAP and ELCAP data were largely consistent on building definition and billings histories, providing mutual verification of the general accuracy of results. (Although, when building types were compared on an energy per square foot basis, results from the several contractors were pointedly different. Similarly, modelers' projections for cost and lifetime of recommended energy conservation measures differed significantly, affecting payback comparisons.) (Cambridge)

Investigators also considered a contrasting perspective, that less well controlled studies would be more representative of modeling performance under typical field conditions.

Because his results were limited to common parameters such as insulation, due to "vast differences in heat loss algorithms", Akbari projected that some other measures would have been still more divergent.

Building Energy Analysis Simulation (BEAS) codes "do indeed exhibit a broad range of calculated loads for the same sets of conditions. It is clear that caution must be exercised when using the absolute energy consumption calculated by a single BEAS. The practice of using results from a single BEAS to generate design guidelines or simplified tools or input for economic analyses, or to develop policy is questionable." (Wortman)

9.8 Modeler Effects

In complex models it is not always easy to identify the constituent elements that contribute to excessive differences between the results obtained from a test model and its comparative base. The potential certainly exists for contributions to be made from any or many of the possible sources, including modeler interpretations and errors, data errors, and software errors.

Neelamkavil asserts, "Skill in modelling depends also on experience, expertise, intuition, judgement, foresight, and imagination."

In the study reported by Diamond, dispersion in the results was attributed to modeler effects: user judgement and/or interpretation of data.

In the Canadian study reported by Arthur D. Little, the wide range of annual energy results (from 0.5 to 2.0 of the average prediction), showed "that the energy analyst can be a significant factor in the prediction of building energy consumption."

When Cambridge Systematics compared building types on an energy per square foot basis, results from the several CAP contractors were pointedly different; "one possible conclusion ... is that the methodology and judgment applied by the contractors has a significant influence on the end-use consumption estimates", but alternative reasoning was also proposed.

Spielvogel says "Results indicate that rather substantial differences can occur when several users make comparisons of the same building with different programs. "Several people using several programs on the same building will probably not get good agreement on the results of an energy analysis. The same person using several programs on the same building may or may not get good agreement depending upon the complexity of the building and its systems and the ability of the computer programs to handle the specific conditions in that building."

Spielvogel goes on to suggest "that the results to be obtained by using several computer programs on the same building will range from very good agreement to no agreement at all. The degree of agreement is dependent upon the interpretations made by the computer program user and by the ability of the computer programs to handle the building in question."

9.9 Overall Considerations

Conclusions from work reported in the literature should be drawn carefully. Substantially different circumstances need to be understood, and in some instances the results should be discounted. Some studies, for example, were conducted on residential structures for which envelope considerations usually dominate, rather than on commercial buildings where lighting and other interior loads often dominate. Nonetheless it is constructive to consider the thoughts expressed by the various investigators.

Findings by Cleary and Schuldt [#1] rest on a narrow statistical base: one example only of a building retrofit made for a reason other than a modeling conservation effort. There is concern about how representative this and some of the other studies may be.

Nonetheless, Cleary and Schuldt [#1] assert "The results ... emphasize the importance that should be placed upon collecting accurate audit data."

Among similar buildings, Hodge points out the Energy Utilization Index (EUI) provides an economical and effective way to estimate the potential for conservation measures in a building and in some instances to identify what the conservation opportunities are. It may be a useful tool to help determine where prescriptive path conservation approaches will be most effective.

Reiter notes that changes in schedule impact many of the estimates used in energy planning, and that suggests "the importance of using simulation models as the mechanism for weather normalization or revising estimates of building loads to reflect changes in schedules or occupancy patterns."

Reiter also concludes that schedules play a dominant role in determining the diurnal and seasonal shape of loads for the commercial sector as a whole.

Cleary and Schuldt (#1) found particular importance in the "increased accuracy of scheduling inputs resulting from end-use load data" when marginal benefits approach marginal costs. Standard analysis without end-use data resulted in more conservative estimates of savings than actually found from experience; presumably the reverse situation had equal potential for occurring: the uncertainty and risk of the estimates were higher without end-use data than they were with it. End-use load data provide potential improvements in conservation assessment.

Consistent end-use categories are recommended for all software. (Cambridge)

"No computer program as complex as BLAST can ever be completely validated by comparative studies of this kind." (Yuill)

"Modeling was seen to be most useful as a tool for the <u>comparison</u> of various energy conservation strategies - <u>not</u> for trying to predict the actual future load of a building. This is because many factors can affect the ability of a model to accurately predict future energy consumption levels, but when a model is used to <u>compare</u> prospective ECMs under the same conditions and assumptions, the most effective ECMs for a given application can often be determined." (ACEC)

The report from Brown and Caldwell (Bonneville [#1]) pertaining to evaluation of prescriptive path measures includes good descriptions of general modeling assumptions, applicable to most modeling.

"Considerable scatter in monthly results can be expected among expert users of building energy analysis computer programs such as DOE-2 when the input is uncontrolled. However, the most significant reduction in this scatter can be

obtained by having an independent observer check the input for errors and by eliminating gross ambiguities in the input." (Diamond)

The results to be obtained by using several computer programs on the same building will range from very good agreement to no agreement at all. The degree of agreement is dependent upon the interpretations made by the computer program user and by the ability of the computer programs to handle the building in question." (Spielvogel)

Agreement in simulation results is probably inverse to the complexity of the building. (Spielvogel)

"No 'perfect' program exists. What is required for reasonably useful analysis is that the user become very familiar with the tool selected and carefully apply it." (Arthur D. Little)

"Frequently it takes so much time and effort to become familiar and competent with just one of these programs, that consideration is not freely given to other programs that may or may not be better for the intended purpose." (Spielvogel)

Despite the difficulties and complexities, despite the large differences which sometimes occur between simulation models and reference buildings that should yield similar results, the need remains to provide estimates of building energy consumption and to make rational decisions about implementing energy conservation measures. Other estimation techniques are available, but they typically are associated with still further problems and greater uncertainty in their estimates.

Various authors concluded that building energy simulation analysis models are relatively effective and their use should continue. The literature points both to specific instances when software had to be corrected, and to broader opportunities for requiring vendors to document software reliability and verification programs as a condition for approving their products. The literature also points to significant impacts by modelers on model quality.

What the literature does not seem to address, and what appears to be needed, is cooperative efforts with modelers to standardize the approaches they use and to minimize the impacts that have contributed to diverse results.

CHAPTER 10: CONCLUSIONS AND INTERPRETATIONS OF RESULTS

A building energy simulation model combines the contributions of software capabilities, modeler decisions, and data describing the building and environment. The model's performance quality depends on the same factors.

The Evaluation of Software project shows that experienced modelers are able to construct representative building energy models from any competent software, although results and performance quality vary. Modeler variability is more significant, in general, than software variability. Modeler activities and decisions represent the single most important opportunity for controlling and improving modeling results.

The variability of energy estimates recorded during the study raises a question about how the savings from energy conservation programs should be extrapolated for planning purposes. Conservative treatment of the uncertainty suggests conservative energy saving projections.

Despite its weaknesses, building energy modeling remains an important, viable approach for making decisions in energy conservation programs. Nonetheless, action could be taken on opportunities to improve data acquisition, interpretation, and applications, modeler practices, and software features and performance.

10.1 Summary Conclusions: Overview

Building energy modeling/simulation is one way to analyze building energy requirements and energy conservation opportunities. Its end products are estimates of energy consumption and recommendations for energy conserving measures.

The modeling process can also be approached more circumspectly: How useful is it? How accurate is it? How cost effective is it? Can the modeling process be improved? Are there better ways to achieve the same goals?

Through study and analysis the Evaluation of Software project has sought to:

1. Conduct an evaluation of commercial building energy simulation software.
2. Analyze the impacts of software users on simulation results.
3. Estimate the absolute errors in simulation results.
4. Recommend simulation software programs for future BPA programs.

During the study more than 500 simulations were run on 25 models constructed by experienced modelers, using five software packages and four sample buildings. Upwards of 50,000 data points were transcribed and summarized on analysis spreadsheets.

The simulations permitted evaluation not only of software performance, but also of how those who use the software (the modelers) affect the results. The evaluations compared the simulated energy (both on an end-use basis and total building energy) against field-measured data of the energy actually used in each building.

The study and analysis show considerable differences between one model and another, between modeled energy estimates and metered consumption data, and between the ECM recommendations of the several modelers. The differences raise doubts about simulation modeling's ability to make consistent, accurate energy estimates and useful ECM determinations.

Are these differences critical? Are they due to the software or do they reflect modeler weaknesses? Do modelers need further criteria, standards, or training? Can the software be improved?

Simulation modeling is an integrated process: all of these factors affect the results; most errors are cumulative. Opportunities for improvement should be explored with respect to each factor.

A few major conclusions serve to highlight the study's findings:

1. All building energy software packages are imperfect: In varying degrees, all have defects.

2. For most purposes it doesn't make much difference which software is used to model a building as long as it's done well.

3. Overall, simulated building energy estimates miss the mark, often varying from the correct value by 20% or more, and occasionally by as much as 100% or more.

4. All modelers make mistakes. Their modeling efforts, more than any other factor, contribute to poor model performance.

The study also upsets a few pre-conceptions. Among these is a frequently heard premise, that simulated **changes** in building elements (ECMs) yield significantly closer energy estimates than results obtained for the underlying base building. Even if a base building simulation differs from the "real" building by a considerable margin, it is posited, the projected incremental (or percentage) saving for the ECM will be much closer and quite representative of what really happens.

Study results urge a contrary conclusion, however. As with most other differences calculations, simulated savings have the potential for showing dramatic shifts. On a percentage basis at least, differences recorded during ECM simulations were often greater than those associated with the respective base building models: in practice ECM results simulated with same-building models constructed from different software packages often showed considerably more variability than the difference between the base building models.

For example, the ECMs simulated for the small retail building during Cycle 3 were developed from base building models for which the annual energy estimates ranged from 0% to 16% more than the DOE-2.1 base building model. But the savings estimated for the ECMs ranged from 63% less to 100% more than the DOE-2.1 model (Appendix J).[1]

The real divergence probably is larger in energy auditing practice than reported in the study because by Cycle 3 the modelers had more modeling iterations behind them and more data (end-use) available to them than would typically be available during an energy audit.

In fact, by way of further example, consider the sensitivity study results for the small retail building. The simulations were developed from base building models for which the annual energy estimates ranged from 20% less to 12% more than the DOE-2.1 base building model. But the sensitivity measures there showed energy savings that ranged to 35 times as much as in the DOE-2.1 model. In fact, 18% of those sensitivity simulations showed savings reversals: savings that were negative in sign relative to the DOE-2.1 projections (showing a loss, for example, when DOE-2.1 showed net savings).

When the annual energy consumption of the Cycle 3 base building models is compared with ELCAP data (p5-46), the results show differences in the range of +11%/-20%. Similarly, Bonneville's Commercial Audit Program (CAP) showed 27 out of a 28-building sample to be within 20% of a metered consumption base (see page 2-4). Akbari (see page 2-3) found residential base buildings in the +/-20% range but held the ECM variance to +/- 10%.

One tentative conclusion might be that while control of base building estimates is similar, the variability of simulated ECMs tends to be more exaggerated in commercial buildings than what is experienced in residential buildings.

One of the questions posed at the onset (p2-3) addressed this tradeoff: Would the added sophistication of commercial-building software lead to improved modeling results, or would the added complexity of the commercial buildings outweigh this advantage? The apparent answer is that the added complexities are more important; greater variability is the consequence.

On the other hand, the average divergence measure developed in Chapter 5 suggests a somewhat more sophisticated answer. The best average monthly divergence for a building-set of models simulated during Cycle 3 was 7%, and that was for the most complex of the four buildings, the large office building (p5-46). However, some of the modelers had disproportionately great difficulty with this model, and indeed the average end-use divergence is not as favorable.

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1. Chapter and page references are to locations in this report unless otherwise noted.

Adding to the dichotomy, the most pronounced differences between simulations within one building group were those for the large office building. At Cycle 2 those models ranged from winter peaking to summer peaking, from distinct summer peaks to nearly "flat" consumption throughout the year. During Cycle 3 the models were noticeably improved (pp5-42..43 and p5-46).
The models for the large office building are capable of showing greater differences because the building is more complex, with more variables. Modelers reflected those demands and opportunities in their models.

These results suggest this further two-part conclusion:

a) Simulation variability in commercial buildings tends to be minimized when building requirements and model development take advantage of sufficient software features that they can be manipulated and balanced.

b) Simulation variability can be reduced when modelers devote additional efforts to model refinement.

Modeling results pose the least uncertainty when their variability is lowest, both in subjective acceptance and statistical evaluation. One benefit of good modeling and good software is that they reduce the uncertainty and risk through better estimates. But we cannot eliminate uncertainty altogether. Data reported here are believed to be representative of the existing standard of practice for performance quality and uncertainty in modeling commercial buildings.

The uncertainty that attaches to an individual building energy model and its simulations can have far-reaching ramifications. At very least it raises a question about making decisions to implement energy conservation measures.

When the projected payback of an ECM is close to the designated payback criterion, should the ECM be implemented or should the choice be biased to favor either type I or type II errors? Should a building owner/operator be advised that the savings and payback for this ECM are risky, with a certain probability of not being realized? On balance will this tend to reduce the number of ECMs that are implemented? Does this suppress the savings that can be projected for the sponsoring energy conservation program, and ultimately for regional conservation goals?

The programmetric and policy implications of modeling in the face of uncertainty warrant further analysis, beyond the scope of this study.

10.2 Study Methodology

Studies of complex systems necessitate practical tradeoffs.

To keep efforts and costs within realistic bounds any analysis of software performance must be less than comprehensive. Emphasis should be placed on how the software handles the most frequently encountered building types, equipments, and other features, and should test those component elements found in a large number of the cases examined.

The methodology adopted for the Evaluation of Software project was similar to what had been used by others in earlier investigations of building energy simulation software (Chapter 9).

Some studies have compared simulation results from two or more software packages. Other studies have used one well documented software program (e.g., DOE 2.1 or BLAST) as a standard of comparison. Still other studies have compared simulated energy with metered building energy consumption, in total (as in utility billings) or by end-use.

In varying degrees the Evaluation of Software project did all of these things.
The use of multiple approaches in the Evaluation of Software project was a new methodological perspective. The same can be said for the sensitivity analysis, and also for the attention given to modeling rather than simply to the software used in modeling. The broader view of modeling led to a look at modeler contributions, which had been noted previously but had gone largely unstudied (p9-12). Furthermore, some study procedures had previously been applied only to residential buildings, so their use with commercial buildings afforded an opportunity for new insights (p9-12). Overall the current project appears to have made important progress in methodology.

The Evaluation of Software project has also served to identify interests that warrant further investigation and where further improvements in methodology are needed. Likewise, the study has served to point out where additional analysis of data from the project itself would be desirable.

During the project, modelers were invited to share their observations in writing (pp5-58ff), but otherwise little was done to encourage communications or identify consensus on modeling techniques and practices. Perhaps the round robin study should have been structured to bring modelers together at the end of each Cycle to discuss their activities, insights, and opinions before distributing further data for the next Cycle. Opportunities could also have been created for discussing specific topics such as adjustments and targeting of utility billing histories, how to address discrepancies by adopting the most likely assumptions, and resolution of modeling difficulties and limitations.

The Evaluation of Software project's methodological contributions are founded on efforts to duplicate (or at least approximate) "real" modeling conditions - actual buildings, typical (experienced) software users/modelers, and metered energy consumption data. Departures from the real world are certain to affect

decisions about which Energy Conservation Measures (ECMs) should be implemented and how rapidly their investment can be recovered through energy cost savings (p9-11). Many studies in the literature report hypothetical buildings (MCS), overly simplified buildings, non-representative modelers, or information that would not be available during a typical energy audit. Studies that rely on non-real-world modeling appear to introduce a bias; for example in one study in the literature, simulations were repeated with improved schedule data (occupancy and lighting hours, etc.); predictably, the results improved when the schedules improved, but a real-world modeler would not have had sufficient information to make the improvements. The reported conformance was therefore better than would normally have been attained (p9-11).

On the other hand, some participants in the current project felt the building description files, in particular, were not truly representative of a normal engagement because the modelers were not able to visit the sites, talk with building owners/operators, or clarify items incompletely stated or altogether missing from the descriptive files supplied to them (p5-59). It would have been equally valid, however, to criticize the same descriptive files as superior to normal notes from a field audit, because the data was in fact compiled from three independent field audits of each building. It seems fair to conclude that these offsetting factors probably came close to balancing; and that the process therefore was fairly representative of a real engagement.

The Evaluation of Software project provides a broader base of experience than many of the other studies considered. In one of those studies, conclusions were drawn from a single example of how energy consumption shifted with a change in occupancy (p9-12). Other studies depended on larger but usually still limited samples. The Evaluation of Software project looked at five software packages, four buildings, the work of eleven modelers, with multiple years of data from the field. While it would have been salutary to have had still further data - for example from a food service building - the current project provides a better than average basis for evaluation and for avoiding unrecognized anomalies in the data.

The round robin simulations were an opportunity to compare estimates derived from several software packages. By including DOE 2.1 there was also an opportunity for comparisons to be made relative to an accepted "standard". Then again, problems were encountered with DOE 2.1 just as with other software (Chapters 5 and 6). Therefore, still another comparison was found by averaging the results - an established statistical method that, under certain circumstances, gives the best estimate of a parameter's actual value, in this instance the building energy. The Performance Index concept (Chapter 8) was later used to show that DOE 2.1 produces estimates which on the whole are closer to the group mean than any other software package evaluated (also see page 10-20).

When asked to match the consumption pattern reported by the electric utilities, modelers were given a little more than two years of electric bills (out of the six years obtained for this purpose), believing most of the

modelers would use data from only the most recent 12 months (p4-20). In fact, some modelers confirmed the expectation, but other modelers used most or all the data they received. Reasonable conclusions are a) overall, modelers probably would have taken advantage of even more utility data, had it been provided, as well as further ELCAP data beyond the 15 months supplied; b) modeling targets are improved when additional data on actual energy consumption is made available; and c) the resulting models yield better estimates of the real world (see pages 5-15, 5-45, and 9-10). The use of more extensive utility and/or metered end- use data results in better (and more consistent) energy estimates from study models developed from these data, and therefore is a preferred practice for future studies.

Many of the studies reported in the literature went no further than an analysis of base building model performance, but the Evaluation of Software project continued further with a comparative analysis of energy conservation measures, including 25 of them that were specified as sensitivity analysis measures. It is tempting to think of this as if there were 25 more base buildings to compare for each software package. However, each ECM is potentially interactive with its respective base building model. That is, the energy savings projected for an ECM depend not only on the measure and the change(s) in parameter values associated with it, but also on characteristics of the base building model. When experimental ECM results were compared (Chapter 5) and later when sensitivity results were compared (Chapter 6), variability in the results was often strikingly different from what had been seen in the base building models themselves. Therefore, including the ECM and sensitivity comparisons as separate analyses during the project was a positive contribution to the methodology.

Indeed, results from the simulation study may be significant not only to study modeling and methodology but may also be relevant in deciding which measures to emphasize in modeling decisions and prescriptive ECMs.

The sensitivity study, however, raised a question about methodology that is still unresolved. The discussion on pages 6-1 and 6-2 considered how best to structure the base building models for simulation analysis. Attempts to conform input parameters on the one hand, or energy levels estimated by the base building models on the other hand, each offer advantages and disadvantages. The Evaluation of Software project opted to conform input parameters, and as a result the several base building models yielded a sharply wider range of (output) energy estimates than those realized during the round robin simulations (p6-16). There is reason to believe the results would have shown less scatter if a larger set of input parameters had been adopted and if additional care had been taken to be sure modelers understood and correctly applied the input values that were specified. If the conformed input approach is used in future studies, more emphasis should be directed to the input parameters.

On the other hand, the final results obtained from a conformed-output approach might or might not have been all that different. It would be informative to compare the two methodologies in a further study; results would give insight not only into the best way to approach studies of this sort, but also into where emphasis can best be placed to improve base building models for real-life energy audits.

10.3 Input: Data Parameters

Building energy models are constructed to simulate the performance of specific buildings. Models are expressed through values assigned to defined parameters and entered as one or more input files for the computer program. Therefore, data parameters and values are determining factors in the performance quality of a simulation model.

Data for constructing a model typically come from multiple sources such as drawings and specifications, field visits, and utility records. Such data are of uneven quality. Some, more than others, contribute to the variability of the final simulation results.

The Evaluation of Software project opted to rely on an earlier study for evaluation of the differences introduced by field audits (p5-3), but took a closer look at variability in utility, weather, and metered end-use data in particular (Chapter 4). Errors introduced through these variables can be additive; accordingly, efforts to avoid even modest errors are important for each data element.

Weather

Weather data are delivered to a simulation model in a formatted weather file containing data representative of conditions at a specific site. For most software programs, weather files are available for a fairly limited number of sites, most frequently weather stations in larger cites, often recorded in atypical locations such as airports. A given weather file may be developed from data derived from one of several weather-series sources (p4-7), which report similar but nonetheless different sets of weather parameters and values.

Only infrequently are weather files interchangeable between software packages, because each program uses a unique file structure and data set (p4-7). Thus the simulation results developed with two different programs using parallel weather files for the same locality could be similar but will not be identical.

Software programs are nominally able to accept typical-year or real-year weather files, but in most instances real-year files for any selected year are not available. Most weather files are for "typical" years (p4-6). Typical year files should lead to estimates of "average" energy consumption.

When a model is being constructed for an existing building, an attempt will usually be made to match the simulated energy with the actual energy consumption recorded in utility billings during specific calendar years. Typical year files are obviously deficient for this purpose (p4-8). Where available, it would be better to build the model with a specific year weather file, and then shift to a typical year file to simulate average energy consumption.

It is conjectured that stoichastic weather models (or files) might be useful in simulating probable ranges of building energy consumption.

The type and extent of data recorded in a weather file varies from one program to another. The most obvious distinction is between files developed for bin or hourly types of simulations; but some files are also more comprehensive of data elements than others. Those programs and weather files that contain less than a full complement of data depend on approximations (unless the modeler is able to enter the data independently). Examples include: domestic water supply temperatures missing / value(s) assumed for water heating and boiler feedwater computations; elevation/pressure missing / sea level calculation assumed (significantly off for a community like mile-high Lakeview, Oregon); ground water temperature stated as a single value / constant temperature throughout the year assumed (could be seriously in error for ground water source heat pump calculations).

In many instances modelers do not know the scope, frequency, or values of the data elements in their weather files. In general the modeler is not told and is not able to inspect what data are provided and what data are missing. They therefore must accept the weather data as "given" and are unable to compensate for any errors, limitations, inconsistencies, or inapplicable aspects of that data.

Utility Data

Where records are available of energy consumption in an existing building, the data provide a target to which the simulation model should relate. Studies show that simulation results for existing buildings are substantially improved when modelers use the data for adapting their models (p5-15, p9-10).

Monthly utility billing records provide the most frequently available record of energy consumption. During the Evaluation of Software project, however, it was found that the records themselves can introduce problems in the form of irregular reading/reporting periods, gaps in the record, and outright reading and recording errors including inconsistent reading dates. Each one-day shift in a monthly billing period represents about 3% change in the energy charges; in the extreme case noted it totalled 43%. Incongruities also occurred between utility reading dates and the calendar months used in simulations models.

Billing data also show year-to-year variability, reflecting changes in weather, occupancy, equipment, maintenance, and so forth. Of 33 month-by-month raw data comparisons in one sample, 1987 data was within +/- 10% of the year earlier figure in 23 instances, with the remaining 30% as far apart as +31%, -23%. Another small sample showed changes of +38% to -26% from one year to the next.

The variability that can be introduced by these differences is significant (pp4-12..17); it therefore may be desirable to increase the attention given to the quality, interpretation, and consistent application of utility data.

Metered Data

Until a building energy model is able to simulate each component of energy use correctly within a reasonable range, the usefulness of the model is minimal.

Metered end-use data from buildings provide a more comprehensive set of modeling targets than total energy alone. End-use data targets permit the modeler to construct an enhanced model with superior performance in the form of more accurate energy predictions and ECM recommendations (p5-45, p9-13). Only rarely is end-use data available for an energy audit, but some practitioners now take spot readings that provide this information for a sample time period.

The Evaluation of Software project drew upon fifteen months of metered end-use data from Bonneville's ELCAP program data. Significant errors were found in data for two of the four buildings investigated, simply on the basis of internal consistency checks and comparisons with utility records (p4-27). On a total energy basis, the utility billing information was found to be more reliable than the data from ELCAP.

Metered data is potentially encumbered with the same problems as utility billing data - outright errors, variable reading intervals, incomplete records, inconsistencies between typical and actual weather, and date mismatches of specific readings. In addition, metered data is frequently grouped in different end-use categories than the simulated figures, making complete comparison impossible (p5-45, p9-13); moreover, categories vary by software package and even by modeler, suggesting an opportunity for standardization.

While this limited sample may not be representative of the overall quality of ELCAP data, it raises a flag of caution: Metered end-use data is as susceptible to error as any other data source; it should be welcomed as an extension of the information base, but it should be rejected as an absolute standard of comparison.

Modeling and Energy Targets

During the Evaluation of Software study participants were asked to prepare and adapt simulation models, given successively more information. Consistent with earlier studies, results improved when modelers were guided by month-by-month total energy targets (utility billing data), and improved still more when metered end-used data (ELCAP) were available.

Modelers used their models to interact with the consumption data and descriptive building information: each was used to test the others, and the conclusions were used to construct improved models. Most modelers indicated that, in a real field situation, they would use their simulation results to challenge field findings and to raise questions with the building owner/operator (p5-59).

Modelers were in fact able to conform their simulations fairly closely to what they assumed were the "correct" building energy consumption values. Some software packages were more capable in this task than others.

Nonetheless, there was considerable disagreement between modelers as to what the target base should be (pp4-17..23), inasmuch as building usage and utility billings both change from year to year. Potentially at least, modelers refer to multiple years of consumption data, consider weather impacts, look for irregular billing intervals, know how the building occupancy has changed, ask the building operator to explain abnormal peaks and valleys, and then use a dash of experience in developing the "most representative" data curve for the building being modeled.

In practice, however, none of the modelers stated their modeling targets, how they arrived at the goals, or how far they were willing to let their results stray from the target. In practice, the models demonstrated a wide range of simulation results, which by implication suggests a wide range of goals.

If modelers could agree on modeling goals, simulation estimates would be more comparable and consistent, leading to greater agreement on ECM recommendations and improving the basis for further analysis of software performance.

When building energy analysis is being performed for a real-world conservation opportunity, historical consumption data is usually available from utility billings if the analysis is for an existing building; but of course it is not available for a building still on the drawing board. If simulation models improve when modelers use target data, does this mean that pre-construction energy analysis is inherently less accurate?

In some respects, the "blind" simulations performed by the modelers during the Evaluation of Software project are akin to energy estimates on new building designs. While considerable information is typically available at this stage, uncertainties remain about differences between design and "as-built" construction, actual equipment performance, and how the buildings will be used and maintained.

In other respects, utility data matching is not a good example of modeling for a new building. The fundamental difference is that the design and construction entities working on a new building are able to specify and control the construction elements that represent input parameters for the model, while most often in an existing building values are given to those elements in the face of uncertainty.

On balance, the quality of a pre-construction energy analysis is less predictable than an analysis of an existing building, and its quality is certainly more difficult to assess unless a follow-up comparison is made after metered data have been collected.

On the other hand, using an energy consumption target is not the only way to improve the performance of a simulation model. It was observed during the study, as late as Cycle 3, that further iterations of the modeling cycle led modelers to discover their own errors as well as previously missed opportunities for improvement (p5-47). In short, more extensive and careful review is an important factor in modeling quality. This may even be an important reason why a consumption target is efficacious. The finding suggests an opportunity for improving modeling results by structuring the review process.

10.4 Input: Modeler Variables

Modelers engaged for the Evaluation of Software project were selected for their experience with energy conservation and software modeling tools. Despite this, they followed varied approaches and demonstrated a considerable range of results.

Simulations conducted for the project show that modelers are able to exercise control over their results, over a wide range. One modeler even adapted his small retail building model to the utility data for another building - mistakenly but successfully.

Modeler variables are arguably the single most important factor affecting modeling results and their quality, yet they have received relatively little attention in earlier studies and were almost an afterthought for the present study. But even when the desire is to concentrate on software performance, modeler effects are too pronounced to be ignored, as was further demonstrated during the sensitivity study (Chapter 6). Certainly, modeler influences should be more recognized as more important than software selection.

Because modelers strongly impact the results, it's reasonable to expect experienced, well qualified modelers to produce better results than modelers who are less well prepared. It follows that modeler qualifications and selection are important for achieving accurate, reliable, consistent simulation analyses. It's harder, however, to define what those qualifications should be. Indeed, there is an ongoing debate about the nature and extent of the qualifications mandated for modelers.

The Evaluation of Software study confirms the significance of good modeling, but the project can make only a limited contribution to the definition of a good modeler. Results suggest that model quality increases with a modeler's experience and familiarity with 1) the specific software used for modeling, 2) building energy systems in general, and 3) the specific parameters offered or considered for choice. The quality of the results also improves with the care exercised in modeling. A modeler's efficiency follows the same pattern.

Working from these observations, it seems reasonable to project that a modeler will enhance performance quality more by concentrating on one or several software modeling tools than by attempting to become marginally proficient in a large number of them. In an extension of the argument, a modeler's proficiency with his chosen software is more important to the quality of the simulation results than the software selected.

This does not refute a further observation, that some software packages are better suited to a particular modeling application than others (p7-11). Software selection therefore is a meaningful modeler variable. These circumstances may also suggest that particular modelers are best equipped to handle specific types of engagements.

It follows, moreover, that a modeler should have the option to select a familiar hourly modeling tool, if preferred to the bin-type software specified in some energy conservation program matrices.

Given the variety of data, circumstances, and options encountered in modeling, a modeler is confronted with the need to make subjective choices not only in software selections but also when selecting and applying modeling targets. Target selection, discussed in the previous subsection, is an important modeling variable.

Those who read energy audit results sometimes need to know what the modeling targets were and how they were determined; that information is rarely available unless the modelers state it. Modelers should therefore be expected to report their modeling targets and explain why or how they were selected.

No matter what a target is, a simulation model will never match it completely unless programmed conforming is used. Programmed conforming should be avoided for the reasons discussed on pages 5-57 and 5-58.

How closely should simulation results approximate the target? How accurately should the model be expected to simulate the real building's energy? Annual energy targets are easier to meet than monthly targets. Total energy targets are easier to meet than end-use targets. One investigator (C. M. Cleary) worked within 15% of the target value on a monthly (total energy) basis. A suggestion was advanced for the Evaluation of Software project that participants be asked to work within a 5% monthly limit, but the suggestion was discarded as untenable.

While it may be reasonable to expect modelers to be within 5% of a specified building energy total for the year, more generous allowances are needed in setting reasonable limits of work both on a month-by-month (monthly total) and end-use basis. During the study the modelers, without a specific mandate, averaged monthly average divergence figures (at Cycle 3) of from 7% to 24% for the four buildings modeled; the comparable divergence for end-use results was from 21% to 104% (p5-46).

Those overall results most certainly could have been better, but unless other types of improvements can be made, better results are purchased with higher costs from repeated simulations and more modeling efforts. Several suggestions for improvements do appear in Chapter 11. The best general advice is to observe good modeling standards, including thorough checking of input values by an associate of the primary modeler. Where additional modeling cost is warranted, usually on the largest buildings, it may be appropriate to run parallel simulations with a second modeling team and complementary software.

It would also be possible to adopt more advanced statistical measures of variability as acceptance criteria for base building modeling and for evidence of the confidence assigned to the range of ECM results.

When modelers make successive model adjustments to approximate their energy targets, they refer to the process as "tweaking". Model "tweaking" is

effective in reaching a total energy modeling target, but the changes may adversely affect end-use results.

During the Evaluation of Software project, modelers were able to adapt their simulations fairly closely to what they assumed was the "correct" building energy consumption data. Several modelers submitted after-the-fact Cycle 1 corrections. In two instances, data strongly suggested that modelers had attempted to match their simulations to the wrong utility billing data, noticed their mistakes, and then submitted the corrected simulations. It appears the modelers were successful in "matching" the wrong data before recognizing their errors. The energy differences on an annual basis were about 10% to 20% in both instances. A modeler's ability to manipulate the model is obvious.

Tweaking can be part of a careful review of input parameter values (to verify accuracy or explore probable ranges of uncertainty), or it can be a more heavy handed process (randomly "see what works", or use any available parameter to force the result). While the first approach usually improves the model's end-use performance as well, the second approach is equally likely to degrade it, leading to inappropriate or less capable ECM recommendations.

Modelers' ECM recommendations likewise may be highly susceptible to modeler choices as well as software idiosyncracies and the quality of the base building model. ECMs selected during Cycle 3 failed to show as much similarity from one modeler to the next as expected, although central tendencies were evident with lighting measures, somewhat less so with envelope measures, and still less with HVAC and other measures (p5-53). It is presumed that the ECM decisions made by the modelers impact the results strongly; additional investigations and analysis are needed.

Prescriptive path energy conservation analysis is sometimes specified by program matrices in place of simulation modeling. The concept is that, perhaps for designated building types, certain conservation measures will nearly always be cost effective and appropriate, and therefore can be prescribed without further modeling or analysis. Prescriptive path methods are most likely to be used for simple buildings that closely conform to a prototype for which careful analysis has already been completed; the prescriptive path is also likely to be used for smaller buildings, for which it is more difficult to justify the expense of complete simulation modeling.

Prescriptive measures are usually established by simulation modeling methods, and therefore are subject to all of the variability and uncertainty discussed in this report. With so much depending on them, prudence suggests that the results should be checked carefully by review and independent simulations. Marginal measures should be omitted.

Prescriptive approaches can also be used to point out or mandate certain energy conservation measures that should always be simulated during a modeled analysis. "Prescriptive methods for modeling" direct attention to where further analysis is likely to be most productive. This approach avoids one possible criticism of prescriptive methods, that interactive effects of other ECMs change the efficacy of prescribed measures.

10.5 Software Variables

The Evaluation of Software project is concerned with the accuracy of building energy simulations; software performance is an essential factor in addressing that interest.

An evaluation of software is a validation process. Validation should occur through the combined contributions of a software supplier's documented verification program, validation testing, and user's quality acceptance (p9-5..7).

A supplier's verification program should encompass organizational controls, design standards, testing, and documentation. In practice, verification of building energy simulation software is spotty. It has suffered from less than full participation and disclosure, perhaps for many of the following reasons:

- user indifference - failure to insist on it
- incomplete design
- incomplete supplier testing
- incomplete documentation
- proprietary interest - trade secrets
- simplicity - "protecting" the user from confusion

Formal quality assurance programs are rare in the design, development, and field use of engineering software. Quality is often the result both of informal checking by the software designer, and the extent to which problems encountered in the field are recognized, communicated, and acted on[2].

Only a few software users such as the Bonneville Power Administration would be large enough to implement formal quality acceptance programs with careful evaluation of each software feature. Several jurisdictions, notably the California Energy Commission, do require supplier certification (p9-8).

When validation tests are conducted, the focus is on the accuracy and consistency of simulated results. Testing methodologies include comparisons with existing standards, between software packages, between incremental inputs and incremental outputs, and under controlled conditions such as adiabatic barriers.

Even a comprehensive acceptance testing program can never provide complete assurance that all features are "correct". Any analysis of software performance must sample the most frequently encountered building types, equipments, and other features, along with elements found within a large number of the cases examined. The current project makes important contributions to validation testing and methodology, but does not supplant the need for an ongoing program of verification and validation.

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2. Several paragraphs have been abstracted from Appendix C.

All software packages have their own approximations, limitations, idiosyncrasies, demands upon operators, and even errors. The cumulative effect of these factors impacts the accuracy of the results obtained from simulations. Departures from the real world affect the decisions about which energy conservation measures (ECMs) should be implemented and how rapidly their investment can be recovered through energy cost savings. This project has determined a quantitative measure of how far simulation results from software models typically depart from "reality", based on the sampled building types and software.

The most important software variable is the extent to which the software, relating to the modeler variable, induces accurate modeling through -

- o user-friendly prompts
- o internal checks
- o adequate, informative outputs

A modeler's most common choice of software appears to be between bin and hourly modeling types (p4.-6), in both instances selecting software packages with which the modeler is already conversant. Bin models are generally viewed as less precise and therefore less accurate, but the Performance Index evaluations (Chapter 8) suggest that accuracy is more dependent on modeler quality and the specific software choice; some bin models rated better than some hourly models (p8-5). Bin type models require fewer computational cycles, and therefore "run faster". A wider selection of site-specific weather files is available for bin models. Some modelers believe bin models are easier to set up because minimal schedule information needs to be entered. Software selection may also depend on other aspects of availability, convenience, and program features.

Certain software may be selected for its ability to handle specific building features. But by an extension of the same reasoning, and by observations during the project, a software's built-in features and limitations also tend to bias which ECMs a modeler will select for evaluation.

Because bin type software reputedly requires less effort from the modeler, modeling fees are sometimes scaled accordingly, for example in Bonneville's Energy Smart Design program. However, most of the same information should be considered for each. The work to effect a DOE-2.1 hourly model unquestionably exceeds what it takes to set up a comparable TrakLoad bin model, but an ADM-2 hourly model requires about the same work as an ASEAM bin model. In fact it may take more work to model ECOs (ECMs) with ASEAM than it does with ADM-2. Definition of building envelope parameters is nearly identical with the two model types. And while entering schedule data (occupancy, lighting, equipment, etc.) takes less time with a bin model, a side evaluation of how to compromise several schedules into one may offset it.

Indeed, modeling complexity and effort depend primarily on building complexity, then on building size, specific software selections, and finally on the type of software selected. A modeler contributes to this relationship through his familarity with the software and his ability to move between one software package and another.

It's difficult therefore to say that any one software program is "best". Although the Performance Index results in Chapter 8 might encourage certain suppliers to claim superior performance, the differences in index ratings are relatively modest. Comparative features and modeler preferences will continue to determine which software programs are best suited to specific applications. Table 7.1 summarizes features of software evaluated during the project. Table 9.1 lists significant software features reported in the literature. Table 11.1 recommends features which may be appropriate for future software releases.

All software programs examined during the project are missing one or more features deemed important by the reviewer. Relative little of this pertains to building energy systems; most of the features enhance the interface between the software and its user, thus reducing modeler variability. Most software packages do not have:

- software utility for data analysis, averaging, curve fitting, etc.
- data entry checking, with modeler override
- graphics input
- graphics output
- performance curves for secondary/distribution equipment as well as primary equipment
- open software architecture for interface with vendor equipment data files

Although some of the foregoing features may require development of future capabilities, it should be noted that many are currently under review by ASHRAE committees.

The greatest disparity in features from one software package to the next was found in HVAC systems, which is also where the greatest variability in simulation results was recorded both for base building models and energy conservation measures (p6-17, p6-32). It is strongly suspected that software weaknesses and modeler practices both contribute to this condition; but the solutions to both factors may be most readily addressed in software improvements.

The time required to conduct a building energy simulation depends on specific models, the software selected, and the hardware on which the software is installed. Run time is important because it is a modeling cost and because it can become an inhibiting factor in model development and ECM analysis: The longer the run time, the more likely a modeler is to forego further analysis including intensive development of a base building model and extensive examination of "what if" conservation options.

Model size and complexity, frequently tied to the number of zones, contribute to a model's run time. In the Evaluation of Software study, most of the buildings warranted 6 or less zones; only in the large office building, where the DOE-2.1 model used 27 zones compared to 8 (maximum) for the other models, was the number of zones an apparent factor in performance (p5-12).

As noted earlier, bin models run faster than hourly models, but other important software differences include coprocessor capabilities and coding efficiency.

Typical (profiled) day models may warrant more study and use; they potentially capture the better features of other hourly models (such as schedule flexibility and improved accuracy) while offering more rapid simulations. Hourly type modeling software could be structured to achieve similar flexibility by permitting analysis/simulations at user-defined time sampling - that is, to conduct an approximate analysis by skipping hours or days during the simulation; this practice should be preferable, more accurate, more consistent, and more efficient of modeler time than using a bin model for preliminary evaluation and then switching to an hourly model for final analysis.

Faster hardware may eventually eliminate the concern for more speed.

10.6 Implementation and Interpretation

Consistent with the variables recognized in Chapter 4, this section offers conclusions about implementation and interpretation variables.

Implementation Variables

The interest here focuses on how a modeler and the modeling process influence the implementation of energy conservation measures.

Physical implementation of a recommended ECM obviously depends on a recommendation being issued in the first place. With building energy simulation, the recommendation will be offered only with the right combination of a base building model, a modeler's desire to analyze the ECM, an ability to evaluate the ECM, favorable energy savings from it, favorable economics, and the modeler's favorable interpretation and communication of the conclusion. Interactive effects with other ECMs may also affect the conclusions.

It is noted that a modeler will only analyze energy conservation opportunities of which he is aware and for which he anticipates favorable paybacks. The modeler's scope of experience with building energy systems and ECMs will influence the scope of ECM analyses he will attempt. "Prescriptive path modeling", previously suggested, could direct modelers (especially those with less experience) to ECM opportunities which have significant potential for favorable payback and which therefore should be analyzed.

Likewise, it has been suggested that a modeler's ECM evaluation is likely to be influenced by the availability in the chosen software of specific ECM routines: They prompt the modeler, facilitate analysis, and provide reporting consistent with other software-modeled ECMs. To avoid this potential bias, modelers may need a periodic reminder.

The economic factors that affect ECM analysis are initial ECM cost, ECM lifetime, energy cost or rate, and incentives (if any). The cost of money/ interest rate may be a further factor. In large part the Evaluation of Software study sidestepped economic factors by referring to the CAP evaluation report (Cambridge Systematics). A few remarks are in order at this time, however.

The CAP evaluation report offered scant opportunity to address why certain decisions were made or their ultimate validity. For example, it was established that most of the CAP contractors referred to ASHRAE findings (McRae et al) in selecting values for ECM service life, and yet the values chosen frequently disagreed with ASHRAE. Actually, the discrepancy was more overt than real. Even when the CAP inputs were markedly different than the ASHRAE mean, they were usually within ASHRAE's range. Nonetheless, a service life range of 2 to 20 years (for example) leaves wide discretion to the modeler, with obvious effect on the payback period reported to the building owner.

Similar observations and conclusions could be made about modelers' inconsistent estimates of ECM first cost. Estimates occupy a wide range of values.

Relatively little has been said about coordinating ECM service life with conditions in an existing building. The life of an economizer section added to an existing HVAC equipment unit will be limited by the life of the base equipment. On the other hand, the initial cost assignable to an ECM that calls for replacing a piece of equipment may be low or even zero if the equipment is about to be replaced anyway. But if an existing roof or equipment unit does have a remaining service life, when is the optimal time to replace it, what cost should be ascribed to the ECM, and what follow-up processes should be used to encourage implementation of the ECM when the time arrives? Modelers and energy auditors could benefit from help in answering these questions.

Finally, in a policy focus, differences are noted in the energy cost rates used in various conservation programs. Higher rates make feasible a larger range of energy conservation measures; incremental incentives further increase the scope. Therefore an ECM recommended under one program might be rejected under another; or an ECM recommended in one utility district might be rejected in another. From a regional perspective, however, the energy saved by a given ECM in a particular building should have the same value no matter where it is located. The value probably should reflect avoided costs rather than historical system costs; otherwise, fewer ECMs will be recommended and implemented than would be consistent with the region's desire to capture conservation opportunities before they are lost.

Likewise, energy demand plays an important role in energy conservation, beyond what little recognition most conservation programs may give it. From a building owner's perspective, demand charges are part of the economic decisions they make when accepting or rejecting a recommended ECM. From a supply perspective, conservation should include the demands of consumer loads on system capacity, and on generating and transmission resources. The Evaluation of Software study was focused on energy rather than power: modeling and software evaluations compared kilowatt-hour figures rather than kilowatts. But both affect the ECMs recommendations. Simulated demand at Cycle 2 deviated -85%,+240 from utility data. Software and models used in building energy analysis apparently do a better job of simulating energy consumption than demand; therefore further analysis of demand simulation would be constructive.

The investigators believe the ECM decisions made by the modelers impact the modeling results and implementation so strongly that additional investigations and analyses of these activities are needed.

Interpretation Variables

The same types of interpretation variables which affect the acceptance of modeling results and ECM recommendations also apply to the Evaluation of Software study. The interpretations and conclusions presented to the reader reflect the reviewer's experience and perspectives. Acceptance of the interpretations and conclusions depends in part on how successful this report has been in communicating the study's findings and salient insights.

The understanding of some study features may be improved with a few comments:

- The project gathered considerable data, creating extensive opportunities for analysis, only a part of which has been attempted or completed.

- Further in-depth analysis is warranted. So is demand analysis.

- More generally, the project described what was found from the study activities but considerably less about why the results would have been what they were.

- The project identified new questions, as well as answering many that had been posed at the beginning. Some questions may warrant further attention.

- The sensitivity study showed greater variability than had been anticipated. Isolating variables and reducing variability are desirable goals, but the study did not directly address them.

- Area graphs were used for energy end-use profiles. Similar presentations in other studies have used bar charts because the bars reflect total energy consumed during an interval of time. The area graphs, however, emphasize the continuity of the process through the use of continuous lines and ramp functions, rather than stepped increments.

Some of these conclusions point to opportunities for further study. Study recommendations have been included in Chapter 11.

Performance Index

The Performance Index developed in Chapter 8 quantifies modeling performance with respect to accuracy and consistency. It does much the same for the software used in the modeling, when allowance is made for potential modeler influences.

- Similar values of Performance Index were found for all the software packages evaluated. Some of the software may be better than others but all are similar, all have problems, and yet all are probably suitable for the intended application.

- No matter what the Performance Index value, all software should be selected and used carefully, with good modeler discretion, background knowledge, and skills.

- The Performance Index does not include descriptive data. Would it be constructive to place cost, convenience, accuracy, run time, and a multitude of other variables into a single index number?

The Performance Index approach could be useful not only in evaluation studies such as this but also for ongoing software evaluation and selection, and in the evaluation of modelers, modeling techniques, programs, and methodologies.

If the Performance Index approach is deemed to have future utility, efforts should be made to improve, standardize, and then consciously implement the process. Once the Index is in use, its utility will depend partly on how widely it is adopted and recognized as an evaluative standard.

Indexing procedures used in Chapter 8 were troublesome in their application to future software samples. When the mean value is used as the comparison base, an index value for the additional software package can be computed without changing the rankings represented in the original software set. The index value for the new software is determined relative to the rankings assigned to the original five packages by interpolating its simulated energy against theirs.

10.7 Supplemental Comments

Interest in software quality is widespread:

SERI (Solar Energy Research Institute) has an ongoing program for investigation and validation of building energy software.

In the literature reviewed, Kerth notes, "The IEEE Computer Society has put a great deal of work into establishing software engineering standards. Contact George D. Tice, Jr., Tektronix, Wilsonville." (Institute of Electrical and Electronics Engineers)

ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) has given particular attention to building energy simulations through separate committees on Computer Applications and Energy Calculations. Interests being explored include field audit standards and graphics interfacing.

ASHRAE recently established a new Standard Project Committee 140P, "Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs". Mr. Corson, senior author of this "Evaluation of Software" report, serves on the ASHRAE committee. The Bonneville Power Administration is also supporting and should benefit from the group's work.

Cooperative efforts of groups such as these parallel the advances of the Evaluation of Software project. Their continuing progress should be monitored and supported.

CHAPTER 11: RECOMMENDATIONS

The Evaluation of Software project provides comparative information about specific software, lends insight to the energy modeling process, and suggests opportunities for further advances. The extent to which energy conservation decisions are influenced by this project depends considerably on how widely the information becomes known and is acted on, and the extent to which it stimulates further efforts to understand and improve the process.

This chapter identifies opportunities to communicate the project results, to use the information in new ways, and to investigate further the factors that lead to good modeling results and reliable energy conservation decisions.

11.1 Learning and Sharing

11.1.1 Bonneville programs: Bonneville Power Administration has an ongoing interest in determining the best way to facilitate energy conservation efforts; the interest is evidenced in part by support for studies such as this. Findings from the Evaluation of Software project can contribute to other studies. The following current activities are identified in the report and are recommended to receive copies of this report:

a. CREUS (Computer Related End Use Study). CREUS uses metered data from the ELCAP program to monitor end-use energy consumption in selected buildings before and after the installation of Energy Conservation Measures, and to compare the results with building energy simulations modeled with ASEAM software (p4-30).

b. Prescriptive path manual for the Energy Smart Design program. The study uses simulation modeling with DOE 2.1 to establish generic recommendations for prescriptive energy conservation measures that can be applied in commercial buildings (p9-13).

11.1.2 Publications and workshops: Results of the Evaluation of Software project can be made known through workshops/seminars, technical journals, and other publications. A generic modeling handbook or manual for modelers would encourage consistency and reduce modeler variability. A structured workshop with interactive input from participants would be an opportunity to:

1) share ideas,
2) find solutions for dealing with problems,
3) discard less acceptable alternatives, and
4) record the most effective suggestions.

Offering one or more workshops is a potential way to emphasize the modeling recommendations in subsection 11.2 of this report; a workshop would promote consensus on modeling practices and techniques.

Electronic publishing through the Electric Ideas Clearinghouse bulletin board system provides a further opportunity to share findings, post new software offerings, features, and Performance Index ratings; and encourage good modeling practices.

11.1.3 Weather file exchange: Weather data files for simulating building energy are not always readily available for specified locations, or may entail considerable outlay in money or labor. New weather files created by modelers for this purpose are of uneven quality (two ostensibly equal files in the Evaluation of Software project led to distinctly different energy estimates) (p10-8 and 9).

Bonneville should consider establishing an exchange program and repository for non-proprietary weather files, with program standards and incentives to encourage submission and use of carefully prepared, well documented weather data files for additional locations.

11.1.4 Utilities billing data: Simulation results for existing buildings are substantially improved when modelers use utility billing data for adapting their models, but the data is not always of uniform quality and records supplied to energy audits have not always spanned enough years to identify anomalies and trends (p10-9). Utilities can be encouraged to cooperate in supplying billing histories for energy audits of existing buildings:

1) Strive for accuracy and consistent monthly reading dates
2) Report actual reading dates
3) Make three or more years of data available for energy audits.

11.2 Changes in Modeling Practices

11.2.1 Policy decisions affecting modeling: Conservation programs either implicitly or explicitly deal with the influences of policy decisions on modeling: regional goals, avoided costs, energy rates, demand, payback period, fuel switching, and equalizing subsidies or incentives. Program management can be supported by a practice of dealing with these issues overtly and making consistent determinations (p10-19).

Consider the possibility of evaluation and reporting ECMs for energy audits according to a common energy cost standard that reflects regional, rather than local, interests and rates.

Restrict ECM recommendations to those which model with good paybacks; discard ECMs with marginal paybacks, or subject them to further analysis.

Project size and potential savings should be the primary determinants in deciding how much additional analysis is warranted. Additional analysis could include a "second opinion" consisting of parallel recommendations from another modeler working independently on the same or alternative software.

11.2.2 Criteria and standards for modelers: The Evaluation of Software project showed that modeler choices play a major role in the variability, and hence quality, of the simulation models and their results. Knowledgeable, well trained, experienced modelers will generally deliver better simulation results than modelers who are less well prepared, for any software package. It follows that modeler qualifications will improve energy estimates and decisions about Energy Conservation Measures (p10-12).

As in the past, modelers should be selected for energy conservation programs according to qualifications. Modelers should be well prepared and experience in building energy systems and energy conservation measures. They should be familiar with the specific building energy simulation software that will be used in the engagement.

11.2.3 Criteria and standards for modeling practices: Likewise, the Evaluation of Software project showed that modeling practices play a major role in the variability and quality of the simulation models and their results. Modeling standards will lead to greater consistency, improve energy estimates, and enhance decisions about Energy Conservation Measures (p10-13ff).

a. Recommendations for immediate implementation:
The following recommended modeling practices could be publicized and implemented without further development:

1. Software selection
   - o Maintain familiarity with modeling software developments.
   - o Concentrate on expert skills with a few software packages, rather than attempting to master them all.
   - o Know the capabilities and limitations of the software you use.
   - o Determine weather file availability and characteristics
   - o Select software for the modeling requirements of the job.
   - o Concentrate on software overall, rather than bin/hour choice.

2. Data/input selection
   - o Obtain and compare at least three years of utility billing data for existing buildings.
   - o Review input data and make corrections as needed: billing intervals and offsets, anomalies, trends.
   - o Adjust for weather.
   - o Know how the building occupancy has changed.
   - o Ask building operator to explain atypical peaks and valleys.
   - o Obtain end-use consumption data when available.
   - o Cross check data for consistency.
   - o Avoid default values in input for final analysis.

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   - o Ask building operator to explain atypical peaks and valleys.
   - o Obtain end-use consumption data when available.
   - o Cross check data for consistency.
   - o Avoid default values in input for final analysis.

3. Modeling targets
   - o Select and develop the "most representative" data for input.
   - o Limit ranges.
   - o Set acceptance limits for differences with modeled values.
   - o Use experience and professional judgement to reconcile data.
   - o Use combined data and averaging to set modeling target.

4. Modeling practices
   - o Check input values carefully with an associate.
   - o On large buildings consider parallel modeling and simulations, second modeling team, complementary software; cross modeling.
   - o Use area graph energy end-use profiles for analysis.

5. Documentation
   - o Annotated input data sheet: criteria for base building data.
   - o Save and maintain data files on disk for future modeling.
   - o Include in audit report: type of model, source and ultimate source of weather file, weather file data characteristics.
   - o Include in audit report: modeling targets and how determined: annual, monthly, total, end-use, averaging, ranges, percents.
   - o Include in audit report: advice to building owners/operators about uncertainty of results and recommendations.

b. Recommendations for further development:
A cooperative effort should be initiated to develop further specific recommendations for modeling practices and standards. Participants should include expert representatives from interest groups: utilities, independent modeling firms, and Bonneville. Further recommendations for modeling practices are also likely to arise from subsequent studies. Potential recommendations include:

1. Software selection
   - o Encourage improved software capabilities and be alert to them (see subsection 11.3).

2. Data/input selection
   - o Observe standard field audit report and input standards (ASHRAE)
   - o Use graphics inputs
   - o Use software tools for anomalies analysis, trending, weather adjustments, billing interval adjustments, range limits, averaging.

3. Modeling targets
   - o Establish consensus among modelers on practices for setting modeling targets from utility billing histories.
   - o Use procedural standard for setting modeling targets, for audits of existing buildings

4. Modeling practices
   - o Adopt and use consensus standard for end-use energy categories.
   - o Use software that embodies cross checking and end-use data comparison capabilities.
   - o Use software that provides graphics for analysis of results, including end-use energy profiling.
   - o Establish prescriptive measures for modeling, using simulation modeling, independent simulations, and careful review; omit marginal measures.
   - o Establish statistical measures as acceptance criteria for base building modeling and ECM confidence range.
   - o Utilize software capabilities for analysis/simulation under multi-level speed/comprehensiveness options.
   - o Adopt and use further standards for recommendation of ECMs analyzed as having marginal payback.
   - o Establish recommendations for timing and cost of replacing existing building components with ECM items.

5. Documentation
   - o Adopt recommendations for use of graphics, including end-use energy graphs, in energy audit reporting.
   - o Establish addition recommendations of energy audit reporting.
   - o Establish a repository at Bonneville for master database logging - a place to store disk records of input files.

11.2.4 Modeler instruction, training, and development: Having established that knowledgeable, well trained, experienced modelers will generally deliver better, more consistent simulation results than modelers who are less well prepared, it also follows that modeler training will improve the energy estimates and decisions about Energy Conservation Measures (p10-12). This suggests, in addition to subsection 11.1, value will be found in:

a. Instruction/training manual for modelers, suggesting uniform approaches for dealing with weather variability, irregular utility billing periods, software limitations, and other factors which modelers treat at their option.

b. Seminars/colloquia for modelers, structured both for training and to encourage the sharing of experiences between experienced modelers.

c. Topical scope encompassing these and other interests:

modeling processes	modeler development
software selection	weather files
data acquisition	data selection and adjustment
target selection	interactive effects of ECMs
ECM selection	documentation

11.3 Software Selection and Improvement

11.3.1 Performance Index / register and applications: The Performance Index benchmarking concept developed in the Evaluation of Software project is designed to be applied to software beyond those packages tested during the project. Findings from the present study, however, are tenuous at several points, so the Performance Index model needs further work, strengthening, and validation. It can then be used with greater confidence. Once the Index is in use, its usefulness will depend in part on how widely and extensively it is adopted and recognized as an evaluative standard (p10-20..21). The following approaches are suggested to improve, standardize, and implement the process:

a. Further development of the Performance Index concept. Further work on the concept is needed, both to review the data already established and in conjunction with the other efforts recommended in this chapter (most notably, the sensitivity studies). Development should consider the building descriptive file definition, the size of the comparison base, and which software entities are included in the base. Development should also include ideas developed in an interactive group setting of modelers and others. Adopt a standard Performance Index procedure.

b. Validation. Development of the Performance Index was based on five software packages, with the intent of applying the result to other software. Applicability should be verified with a sixth software package, by running the index and repeating the simulation studies for the same buildings.

c. Performance Index values. Figures of merit should be established for other software packages using the Performance Index procedure, without need for further cross-simulation comparisons.

d. Performance Index register. Establish and make public a register of Performance Index ratings.

11.3.2 Criteria and standards for simulation software:

The Evaluation of Software project has been more successful in identifying features and performance limitations to be considered in selecting building energy simulation software, than it has been is recommending specific software programs for use. Software selection remains a subjective process that relates software price and availability, supplier support, modeler experience, building and occupancy features, and programmatic requirements (p10-15..16).

Building energy simulation software will continue to evolve with new features and improvements as long as there is a market for the product. When suppliers provide the features which their customers demand, it encourages an ongoing market and still further software development. Software updates provide an opportunity for establishing and implementing software standards; they lead to gradual replacement of less satisfactory modeling tools. Recommendations are in Table 11.1 and below:

a. Software selection - ratings. Specific features that contribute to rating one software package over another appear in the Conclusions chapter of this report. Further considerations include how program development is funded, how long the program has been available, when the most recent update was, and how extensively it is used and by whom. The following rank order is suggested for overall suitability of the five software programs evaluated, beginning with the most favorable; however, the ranking is neither an endorsement or recommendation of any product nor an indication of unacceptable quality:

	DOE 2.1		
ADM-2	SEA	TrakLoad	(tie)
	VCACS		

b. Software performance standards. Bonneville can influence the future capabilities of the software used in its energy conservation programs by specifying the desired features and performance standards. Mandatory and optional standards should be developed for software, including supportive data (such as weather files and documentation), presumably distinguishing between hourly and bin type models, present requirements and future improvements, and stand-alone simulation software compared to independent software used to facilitate or improve the energy estimates and their presentation (e.g., graphics).

c. Validation and quality control standards for software. Mandatory verification and quality control standards for suppliers should be developed and software should be certified for conformance. Suppliers should schedule periodic software updates; software not upgraded should be decertified. Bonneville and other purchasers determine their own quality acceptance testing and criteria. Just as Bonneville can influence the performance features, it is also able to influence the standards for quality control, validation, and documentation that make the software acceptable for energy conservation programs.

11.3.3 Supplemental software development: The Evaluation of Software project showed that some variables introduce cumulative errors into the simulation process; but variability, errors, and error tolerances can be reduced. Improvement is likely to come through changes in the software packages that eliminate software errors, avoid or compensate for modeler errors, and provide further software tools for improved convenience and performance (p10-16..18). It may be advantageous to encourage development the items listed in Table 11.1 and below:

a. Input data interface. More sophisticated data entry checking, with user-friendly prompts and modeler override. Graphics input for dimensional data; interface with CAD programs. Program facilitation for mouse input.

Table 11.1

RECOMMENDATIONS FOR SOFTWARE SELECTION AND DEVELOPMENT

Summary

The criteria for building energy software selection and development presented in this table are recommended to software purchasers, modelers, and energy conservation program managers. The recommendations focus primarily on features which are likely to promote accuracy in modeling and the model building process: integrity, repeatability, error avoidance, comprehensive analysis and ECM investigation, adoption of best-fit modeling targets, and consistency in key software design elements for the modelers who use more than one software package.

The recommendations are also intended to encourage ongoing development and improvement of software by guiding software purchasers and motivating software developers.

Some of the recommendations pertain to the software itself; because that is the vehicle through which building energy models are constructed and simulated. The remaining recommendations pertain to manuals and other documentation that support the software, because documentation is an overwhelming factor in determining how effectively the software can be applied and used: Good documentation can cover a multitude of software sins.

Some features are important enough that the recommendations treat them as "required". The rest of the recommendations are also important but merely "desired". Few, if any, existing software packages offer all features. However, people selecting software are urged to obtain as many of the features as possible. With continued development it is expected that many, if not most, of the features will become available in the future.

Existing software packages offer many features beyond those listed in the table. There is, for example, considerable variety in the way building energy systems are simulated. People who are selecting software will want to weigh those options as well.

Still further features will undoubtedly be added as development of the software continues.

Table 11.1

RECOMMENDATIONS FOR SOFTWARE SELECTION AND DEVELOPMENT

Documentation/Manual Features:

Required	Desired	
x		Program name, release date, and supplier/source name and address
x		Software design standards followed, including performance standards
x		Quality assurance standards used in design, development, and release of software and supporting data
x		Validation testing; general results; published study citations
	x	Recommendations for further validation
	x	Policy regarding continued support of software after a new version release
	x	Policy on software upgrades, including notices to registered users and upgrade purchase options.
x		Policy on user access to technical assistance
x		Recommendations of the most appropriate applications for the software
	x	Software flow diagram
x		Modeling methodologies, assumptions, approximations/simplifications, and computational algorithms
x		Software features, errors/problems, deficiencies, weaknesses, approximations, and limitations
	x	Ways to avoid or compensate for difficulties noted
x		User guide/manual documentation in hardcopy and/or ASCII disk format
x		Table of contents and/or index
x		Printed copies of input screens
x		List of input parameters together with their engineering units, definitions, descriptions, default input values, and assumed performance values (e.g., equipment efficiencies, values of partial load curves)
x		Summary of weather file contents by parameter, frequency, and bin ranges
x		One-to-one correspondence between parameter types and engineering units used on input screen, input data echo, and manual
	x	One-to-one correspondence between order in which parameters are displayed on input screen, input data echo, and manual
x		Description of system types modeled, their applicability and control; possible adaptations for system variations
	x	Narrative of how each system and plant parameter affects performance, and what problems may be encountered in using particular ranges of values (such as low air supply volumes)
	x	Description of spreadsheet transportability and graphics procedures
	x	Proposed future improvements and features; anticipated availability

RECOMMENDATIONS FOR SOFTWARE SELECTION AND DEVELOPMENT

Software Features:

Required	Desired	
x		Internal identification: program name, version, release date, and source
	x	Efficient use of hard disk file space; minimize small files
	x	Coprocessor or equal compatibility
x		Common mnemonic identifier for all input data files for a given building
x		Not more than six input data files per building
	x	Display/retrieval of existing data files, by category
x		Input data saved to disk only on command from user; prompt on exit
	x	Terminate processing any time during data entry or computational run
	x	Software checking of data entry, with modeler override
	x	Screen programmed to mask, skip, or challenge inapplicable input values
x		Display engineering units on input or help screen
	x	Display context-sensitive default values, ranges, and help messages
	x	Modeler override of input defaults, including pre-assigned ECM values
	x	Sufficient precision in input parameters to meet modeler preferences
x		Screen and hardcopy echo of input data direct from data file
x		User identification of model's zones (ASCII text in input file)
	x	Zone add/delete after initial entry
x		Building orientation by degree/azimuth
	x	Wall orientations in addition to orthogonal
	x	More than 4 walls per zone
x		Heat transfer through interior partition/wall
	x	Dynamic differential temperature computation for interior partition/wall
	x	Interface w/ vendor equipment files; primary/secondary performance curves
	x	Optional autosizing lockout or lockdown of autosized values as input data
	x	Display autosized values
x		User-input utility history file, with graphic display
	x	Billing interval adjustment of utility data to exact monthly intervals
	x	Shift dates of simulation to coincide with monthly utility billing dates
	x	Adjust utility data for weather variability: approximate std. weather year
	x	Internal identification of weather file (site name in ASCII text)
	x	Formatted display of entire weather file contents
	x	Ability for user to create or modify weather files
	x	Help select month-by-month target consumption based on utility billing history; allow user to adjust specific data points and/or targets
	x	Model-to-model comparisons: Facilitate analyses and display ECM results
	x	Graphic display of standardized end-use energy profile
x		Display graphics directly or through commercial data base program, including full documentation and any macros or other necessary support
	x	User options for calculation shortcuts/approximations to speed run times, e.g., skip-hour and skip-day options using internal multipliers
x		Calculate applicable energy and demand charges from user-input rate schedules and computer-simulated energy and demand
x		Economic analysis of base building and ECM models, including initial ECM cost input and simple payback calculation
	x	ECM life cycle cost analysis
	x	Audit report text
	x	Windowing capability for using spreadsheet, graphics, and word processing

Table 11.1

RECOMMENDATIONS FOR SOFTWARE SELECTION AND DEVELOPMENT

Weather File Parameters

Latitude		Time zone
Longitude		Elevation/pressure
Ambient Air Temperatures:	average	Dry bulb temperatures
	maximum	Wet bulb temperatures
	minimum	Heating degree days
	range	Cooling degree days
	design %	
Insolation/Cloud Cover		
solar angle or algorithm		direct/indirect
local megashading		normal
ground and/or water reflectance		horizontal by compass direction
Wind velocity		Wind direction
Ground water temperatures		Domestic water supply temperatures
Ground temperatures		Soil diffusivity, density, permeability

Potential weather file data elements are listed above. Not all elements are provided or needed in each weather file. Other data or other forms of the same data elements may be included. Frequency varies with the element; some may be represented once, while others may appear monthly, hourly, or at some other interval.

b. Weather files. Compilation of weather data into standardized files for distinctive Pacific Northwest locations, for the most frequently used simulation software.

c. Weather adjustments. Software able to "normalize" utility billing data, to account for weather variability.

d. Billing interval adjustments. Software able to adjust monthly utility billings for irregular billing intervals.

e. Calendar adjustments. Software able to adjust utility billing data to regular calendar months.

f. Data smoothing and averaging. Software able to facilitate selection of monthly targets that best represent the typical building energy consumption, using multi-year utility billing data.

g. Analysis tools. Consistent end-use energy categories. Area graphs for end-use energy profiles; other graphics outputs including optional graphic display as primary output to avoid print time. Specific advanced modeling features such as daylighting, solar water heating, etc.

h. ECM facilitation. Other convenience features that will encourage evaluation of all appropriate "what if" ECM options.

i. HVAC system capabilities. Additional HVAC system/plant options. Performance response curves and staging for primary and secondary systems/equipment including pumps and fans by fan type; modeler override of default response curves; open software architecture for introducing vendor data by designated equipment model; prompt messages to facilitate correct use of controls and software switches.

j. Statistics. Statistical analysis tools to encourage self-evaluation of model performance.

k. Execution speed. Skip-hour and skip-day options for multi-level speed/comprehensiveness options allowing quick, approximate answers. Faster hardware; compatibility with parallel processing computers. Faster execution - improved software coding, coprocessor compatibility.

11.4 Further Investigations and Analyses

During the Evaluation of Software study, the project goals were addressed, extensive data were collected, and many questions were answered. It is unlikely however that the solutions and answers are unique, optimal, or final. On the contrary, the project has accumulated information that begs for further analysis, raised new questions, and suggested further investigations and evaluations. Some of those opportunities may warrant ongoing attention (p10-5..7).

The project's investigators are especially intrigued by the extent of differences found between building energy simulation models during the sensitivity study. Are these due to fundamental differences in the software or do they reflect modeler weaknesses? Would the results and conclusions be the same if the study were repeated, perhaps from a different perspective? Should the study be repeated? Should there be another evaluation project with an improved or different methodology?

Recommendations have been advanced in this chapter for better software and higher standards for modeling. Some could be effected immediately, others over the course of months or several years. If any suggestions are implemented the effect should be realized in more consistent simulation results. How much improvement will be achieved? Will improved precision foster improved accuracy? Will it reduce the "noise level" sufficiently that investigators will be able to do a better job of sorting out the other variables? Should the changes be followed with a further evaluation study?

The study options and suggested methodologies which follow should be considered in the even further study is anticipated, desired, or attempted.

11.4.1 Coordinated development with other Bonneville programs: Bonneville's energy conservation programs provide many opportunities for learning still more about the quality and effectiveness of computer based building energy modeling. Additional efforts can be applied to cross comparisons and correlations. In each instance, part of the work is already complete or under way, which allows the rest of the work to be completed with minimal commitment.

a. Prescriptive measures project. Compare and analyze the findings reported in "Modeling of Prescriptive Measures" in light of the findings and recommendations from the Evaluation of Software project. Run building energy simulations paralleling those performed by Brown and Caldwell, using one or more software packages from other suppliers. Compare the results and analyze the differences. Potential benefits accrue both in increasing the confidence afforded to the prescriptive measures, and in furthering the software/process studies of the Evaluation of Software project.

b. CREUS program. For each of the buildings used in the Evaluation of Software project, copy or recreate the ASEAM models used in the CREUS program. Compare results and analyze differences in the same manner as analyzed in the current project. The goal is to extend the cross comparison of simulations performed in the Evaluation of Software project to include one more software package; it would establish a link for comparing the post-ECM results of the CREUS program with a larger sample of simulations and software.

c. Commercial Audit Program (CAP). The CAP files offer a large data base for comparative analyses, including data on the same buildings analyzed in the Evaluation of Software project. Although the CAP

c. Software packages. Increase the number of simulation software packages evaluated. Five programs were used in the Evaluation of Software project. Other high visibility programs, such as ASEAM and HAP, could be subjected to the same simulation and comparison procedures.

d. Energy conservation measures. Repeat the ECM segment of Cycle 3 with several changes in the modeling and reporting ground rules, primarily to test the hypothesis that tighter controls on modeling procedures will produce more consistent results. It is posited that the ECM decisions made by the modelers impact the results so strongly that additional investigations and analysis presumably are warranted.

e. Demand. Further simulations in which modelers are asked to control for demand could be used to extend the analysis of existing demand data, as previously suggested.

f. Analysis. Insofar as possible, analysis of results from the studies suggested above would be accomplished in the context of improved approaches - for example, modelers' advance agreement on modeling targets to achieve more comparability, and using a common set of end-use categories both for software and analysis. Further simulations might be structured to bring modelers together to discuss their activities, insights, and opinions before final simulations are made.

11.4.6 Extension of sensitivity simulations: For some measures, the sensitivity studies performed during the Evaluation of Software project showed markedly different results from software package to the next. Much of the difference was attributable to differences in end-use composition between the several models tested (p10-7). Are these fundamental differences in the software as assumed, or do they actually reflect modeler choices? Four approaches are available help to answer this question and clarify the comparative performance of the software:

a. Repeat the sensitivity runs using the Cycle 3 base building models without adaptation; that is, without conforming their input parameters to common values. Results offer insight not only into the best way to approach studies of this sort, but also into where emphasis can best be placed to improve base building models for real-life energy audits.

b. Repeat the sensitivity study with the remaining building files; that is, only 10 of the 26 available building models were used in the simulation studies and therefore some or all of the remaining 16 models could be used for comparative runs.

c. Identify additional parameters (and sensitivity measures) for sensitivity comparisons. Particular attention should be given to controls and to comparisons of additional plant and system types.

d. Search for patterns within the existing input data used for the simulation study, to see if variations in modeling approaches can account for the variant sensitivity results.

11.4.7 Application of Performance Index findings: The Performance Index approach may be useful not only for ongoing software evaluation and selection, but also in the evaluation of modelers, modeling techniques, programs, and methodologies (p10-21). Further investigation of this approach should be initiated once the Performance Index concept has been developed into a standard (section 11.3.1).

11.4.8 Cooperation with technical societies and others: Bonneville should support continued cooperation with groups such as ASHRAE and IEEE, monitor work pertaining to building energy modeling, and benefit from the results (p10-22).

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APPENDIX A: ANNOTATED BIBLIOGRAPHY AND REFERENCES

ACEC Research & Management Foundation. "The Energy Edge Building Design Process". Report to the Bonneville Power Administration, ACEC/3-21-88, March 1988.

Report of experiences with Energy Edge. First time participants in energy conservation modeling approaches were positive toward the experience, felt that additional cost effective savings were achieved, would re-use successful energy conservation measures in future design projects, and would utilizes similar design approaches in the future.

Akbari, Conner, and Usibelli. "Residential Energy Simulations in the Pacific Northwest: A Comparison of Four Widely Used Models". ASHRAE Preprint No. 2985 (Transactions 1986, V.92, Pt.2). Work supported in part under BPA contract DE-AI79-85BP2327.

Residential energy simulation models were constructed with three building energy software programs using an MCS prototype house and weather files for five Pacific Northwest locations. Results from base building and parametric runs were compared with a similar DOE-2 model. Multiple runs permitted construction of several response curves. Heating loads for two of the models were within 20% and savings from conservation measures were within 10% of DOE-2; the comparisons were more divergent for well insulated houses, mild climates, large thermal masses, and high infiltration. The third model understated heating loads and savings by as much as 50%.

Alereza and Hovander [ADM Associates]. "A Micro Evaluation" ASHRAE Journal, December 1985.

Description of ADM-2 and report of comparisons between simulated energy and actual consumption in 36 commercial buildings in California, Idaho, and Oregon, with results presented in tables and scatter diagrams. Where discrepancies between modeled and actual consumption were identified, typical audit adjustments were made. "Inputs were reviewed for reasons to explain significant discrepancies when such discrepancies did exist. Accordingly, new runs were made until reasonable and justifiable results were obtained." After adjustment, the root mean square error of monthly energy consumption values in a office building was 16% of the mean energy use; 17% for a restaurant; and 7% for a retail store. The authors intimate that the models yielded predictions of (total) energy that were within 10% of actual usage.

Arthur D. Little, Inc. Evaluation of Microcomputer Programs for Commercial Building Energy Analysis. Electric Power Research Institute, EPRI CU-6457, October 1989.

Evaluation of microcomputer-based software for commercial building energy analysis, using hourly calculations, directed to multiple fuel applications and ease of use by utility customer service representatives. Preliminary screening identified 11 programs (compared descriptively in the report), from which ADM-2 and Micro-AXCESS (Syska & Hennessy) were selected for further testing. In addition, ESAS

(Meriwether Energy System Analysis Series) and MICRO-DOE passed all screening criteria except "ease of use"; Tests of program accuracy accessed two test office buildings and five climate regions; results were compared with mainframe modeling by BLAST-3 and DOE 2.1. Base building simulations placed total annual electrical energy for the test software models within 15% of DOE-2 and BLAST, while parametric runs for seven conservation measures showed typical differences between the two test models of about 15% but ranging to 80%. Specific improvements were recommended for the selected programs and suggestions were directed to users.

ASHRAE Journal's HVAC & R Software Directory. ASHRAE, 1990.

An inventory of available software for heating, ventilating, air conditioning and refrigeration. The inventory contains annotated abstracts about software intended for various computer hosts, including a section devoted to energy analysis simulation programs. Other sections of the inventory are devoted to equipment sizing/selection, heat transfer analysis, heating/ cooling load calculations, lighting design and analysis, weather data analysis, and other interests related to building energy simulations.

ASHRAE Task Group on Energy Requirements for Heating and Cooling of Buildings. Energy Calculations 1 - Procedures for Determining Heating and Cooling Loads for Computerized Energy Calculations. ASHRAE, 1976.

Compendium of algorithms (with explanatory descriptions) for computing heating and cooling loads that determine building energy requirements, with emphasis on building envelope considerations. These algorithms provide the foundation for most building energy simulation programs.

ASHRAE Task Group on Energy Requirements for Heating and Cooling of Buildings; W. F. Stoecker, Ed. Energy Calculations 2 - Procedures for Simulating the Performance of Components and Systems for Energy Calculations. ASHRAE, 1976.

Compendium of algorithms (with explanatory descriptions) for computing the performance of fundamental HVAC systems, controls, and plant and other components, given information about them and the building loads they serve. These algorithms provide the foundation for most building energy simulation programs.

Bonneville Power Administration [#1]. Modeling of Prescriptive Measures. (Brown & Caldwell) draft report, December 1988.

Analysis of energy conservation measures expected to be cost-effective when applied to small commercial buildings; if effective these measures may be recommended and prescribed as generic measures for energy conservation without further site-specific analysis. DOE 2.1C was used to model four types of commercial structures (using models of hypothetical MCS office, movie theater, retail, and church buildings of several sizes) under climates typical of the Pacific Northwest. Base building modeling runs were followed by a series of runs for energy conservation measures, both individually and interactively (descriptions in the report of interactive effects are particularly helpful where the

effectiveness of one measure is enhanced by others). Estimated initial costs of energy conservation measures were compared with energy cost savings and with a specified economic criterion for initial cost of $0.35 per kWh/yr. Measures that met the criterion were recommended as prescriptive measures.

Bonneville Power Administration [#2]. "Standard Heat Loss Methodology". October 1985.

Bonneville Power Administration [#3]. The Commercial Audit Database, A Descriptive Data Summary - Volumes 1 and 2. March 1989.
Compilations and summaries of data reported for 3714 of the 3800 energy audits performed under Bonneville's Commercial Audit Program. Volume 1 discusses the methodologies used to capture the database electronically, methods to correct certain problems, and methods to reduce the number of variables reported in the results. Volume 2 presents the database collection instruments, a concordance of reports available from the database, summary graphics of information in the dataset, and listings of energy conservation measures used in the audits.

California Energy Commission [#1]. Compliance Options Approval Manual for the Building Energy Efficiency Standards. March 1988.
Administrative procedures for obtaining approval of compliance options (computer programs and other calculation methods) for the Building Energy Efficiency Standards, under first and second generation residential and nonresidential standards. Some computerized methods require successful completion of a standardized approval test that demonstrates substantial equivalence to a stipulated public domain computer program, which for second generation nonresidential standards is DOE-2.1B. Technical approval requirements are referenced to the two volume Alternative Calculation Methods Approval Manual. The appendices include building descriptions and DOE-2 input data for base case conditions used to test software conformance for low-rise office, high-rise office, and retail/wholesale store buildings.

California Energy Commission [#2]. Alternative Calculation Methods Approval Manual for the Nonresidential Building Energy Efficiency Standards. June 1988.
Requirements for approval of calculations and software used in the design of nonresidential structures. It encompasses Alternative Calculation Methods (ACMs) used to demonstrate compliance with the performance approach to the second generation nonresidential Building Energy Efficiency Standards, and procedures for obtaining approval of the methods including: application form and checklist, sample runs, compliance statement, computer data, statistical verification analysis, and weather data. Appendices include building descriptions and DOE-2.1C input data for testing software conformance.

California Energy Commission [#3]. Alternative Calculation Methods Approval Manual for the Low-Rise Residential Building Energy Efficiency Standards. June 1988.

Requirements for approval of calculations and software used in the design of low-rise residence structures including multiple family dwellings to three stories high. The general form of compliance is the same as specified for nonresidential buildings.

California Energy Commission [#4]. Building Energy Efficiency Standards, 1987 Edition. P400-88-001, December 1987.

California Administrative Code, Titles 20 and 24, covering requirements for building energy efficiency: building design, design procedures, component performance requirements, permits, certification, and enforcement. The Codes establish allowable calculation methods using computer programs, and define modeling input requirements by reference to the Commission's Energy Conservation Manual. The Codes define performance and prescriptive compliance approaches, plus mandatory requirements for all buildings,

California Energy Commission [#5]. "Building Energy Efficiency Standards, Approved Computer Programs". November 1989; March 1990.

A listing of energy analysis computer programs approved by the Commission according to Titles 20 and 24 of the California Administrative Code covering building energy efficiency. Separate categories of approved programs are provided for Residential Buildings, Second Generation; Nonresidential Buildings, Second Generation; and Nonresidential Buildings, First Generation. The March 22 list cites approvals through December 31, 1990.

Cambridge Systematics, Inc. and others. Evaluation of the Commercial Audit Program, Final Report with appendices. Bonneville Power Administration, December 1988.

This is an overview and analysis of Bonneville's Commercial Audit Program, which accounted for 3800 energy audits of existing commercial buildings by 15 contractors during 1984-87. The evaluation reviewed audit results, interviewed contractors/modelers, compared preliminary findings of ELCAP data for 33 of the same buildings, and considered reasons for successful marketing of the program and implementation of energy conservation measures. The report concludes that CAP and ELCAP data were largely consistent on building definition and billings histories, providing mutual verification of the general accuracy of results. But when building types were compared on an energy per square foot basis, results from the several contractors were pointedly different. Similarly, modelers' projections for cost and lifetime of recommended energy conservation measures differed significantly (just as construction bids for the same work will often show considerable spread).

Cleary, C. M. "Preliminary Analysis of Conservation Potential in Office Buildings". ASHRAE Paper PO-86-07, No. 3 (for Transactions 1986, V.92, Pt.2).

Comparative study of energy consumption in eight existing buildings within the service area of Seattle City Light: two each office, grocery, retail, and restaurant buildings. Each building was modeled with DOE 2 until the base building model results agreed with 1984 utility billing data within 15% on a monthly basis. The models were used to determine the energy conservation measures best suited to each building. Results were compared with earlier estimates of conservation potential within the service area, based on hypothetical buildings. The new estimates of building energy consumption were 30% to 40% lower than the previous estimates, with similar reductions in estimated savings potential. Following installation of the recommended ECMs, building energy end-use data monitoring was instituted, but data were not reported in the paper.

Cleary and Schuldt [#1]. "A Beneficial Application of End-Use Loads Data in Commercial Building Simulations." Thermal Performance of Exterior Envelopes of Buildings III - Proceedings of the ASHRAE/DOE Conference, December 1985, pp 329-335. ASHRAE, 1986.

A study using DOE 2.1A, compared "standard audit" with modeling, and compared both to metered data. The study used 2 each existing office, restaurant, food store, and retail buildings. Engineering consulting firms conducted audits and simulated each building with DOE 2.1A, adjusted interactively to agree with utility billings (and end-use data of 6 of the 8 buildings) "within an acceptable range". Life cycle cost modeling analyzed benefit/cost of measures, individually and combined. Recommended improvements were installed and monitored (metered). Standard analysis without end-use data resulted in more conservative estimates of savings than actually found from experience; presumably the reverse situation had equal potential for occurring: the uncertainty and risk of the estimates were higher without end-use data than they were with it.

Cleary and Schuldt [#2]. "Measured End-Use Savings Versus Predicted Savings of a Commercial Lighting Conservation Retrofit". Conservation and Solar Division, [Seattle] City Light Department, August 1986.

Coad, William J. "The Computer as a Tool for Energy Analysis", Handbook of Energy Conservation for Mechanical Systems in buildings, Robert W. Roose, Ed., pp 61-67. Van Nostrand Reinhold Company, 1978.

Concepts and significance of building energy modeling; procedures for modeling and identifying viable energy conservation measures.

Diamond, Hunn, and Cappiello, "The DOE-2 Validation". ASHRAE Journal, November 1985 (Vol 27, No 11).

Round robin testing of the DOE-2 building energy analysis computer program, in which six experienced contractors constructed models of four existing buildings (single story office, multi-story office, retail, and restaurant) and conducted round robin simulations with three levels of increasingly refined input data. Levels of input control provided for a) uncontrolled input (description comparable to normal field audit), b)

refined input (refined descriptive data plus instructions to review specific input elements), and c) standard evaluation technique (fixed parameters for weather data, building operating conditions, and selected fixed-data input values). Despite the paper's title, the tests were not designed to validate the software, but to determine the effects of software users. Dispersion was reported for each building as the standard deviation of the monthly simulation estimates, which when averaged for the year for total energy ranged from 16% to 39% for uncontrolled input, to 12% to 18% for the standard evaluation technique. Dispersion in the results was attributed to modeler effects: user judgement and/or interpretation of data.

Dowd, Stephen. "Software Analysis and Design Methods", Northcon Professional Program "Software Development Methodology in an Engineering Environment". Session Record, Seattle, 1984.

Testing is an important, and sometimes overlooked, part of the software engineering environment. Testing should be implemented at the start of any software lifecycle. The goal of software testing is the elimination of errors. By planning to test the different parts of the final system, actual testing will be performed with fewer problems. The developers of the test plans and test procedures should be from a different organization than the software developers or designers, for reasons of objectivity and fresh perspective. The testing or quality assurance activity should be part of each phase of the software lifecycle; requirements, specifications, design, test case design, implementation or integration, configuration management, and maintenance. Definition of testing requirements and procedures and results should be documented at each stage of the lifecycle, including documentation of the analysis and design processes themselves.

Evans, Rex. "Guidelines for the Selection of Analysis Software", Mechanical Engineering, March 1987.

Guidance for users of analysis software: how to select software suppliers and software. The first step in choosing an analysis program is to make a list of needs; put as many items as possible in a future category: "if a program does not offer continuing development, it probably has not been a success." The vendor should supply quality assurance problems that test the program's capacity, along with solutions obtained by a third party with which comparisons can be made. "A vendor should ... produce a list of the quality assurance tests that have been run and describe how the solutions were evaluated; the solutions should be checked."

Hamilton, Margaret H. "Zero-defect Software: the Elusive Goal". IEEE Spectrum, March 1986.

Computerized software development tools can be used to manage the software development process and minimize the errors in new programs.

Hodge, Steele, and King. "A Simplified Energy Audit Technique for Generic Buildings". ASHRAE Preprint No. 2983 (Transactions 1986, V.92, Pt.2).

Among similar buildings, the Energy Utilization Index (EUI) provides an economical and effective way to estimate the potential for conservation measures in a building and in some instances to identify what the conservation opportunities are. It may be a useful tool to help determine where prescriptive path conservation approaches will be most effective.

Howel and Sauer. Bibliography on Available Computer Programs in the General Area of Heating, Refrigeration, Air Conditioning and Ventilating. ASHRAE Special Project 22 Task 7, 1980. [Also revised in 1986]

An inventory of available software for heating, ventilating, air conditioning and refrigeration. The publication, following an 1986 revision, has since been released (1990) as ASHRAE Journal's HVAC & R Software Directory (q.v.).

Judkoff, R. D. "International Energy Agency Building Simulation Comparison and Validation Study" (SERI).

Comparative study of BLAST-3.0, DOE-2.1A, and SERIRES-1.0 building energy simulation software, based on a monitored, unoccupied test building in Ottawa, Canada, and extrapolated to simulations with weather data for Denver and Copenhagen. The analysis was targeted to investigate large differences noted in annual heating and cooling energy predicted by the three programs. The procedure also highlighted the sensitivity of several algorithmic differences between the codes. After adjustments were made, the three codes agreed within 6% to 13% for heating or cooling; except in the Copenhagen environment where little cooling was simulated in any of the programs, DOE- 2.1 predicted twice as much cooling as the other two programs.

Judkoff, Wortman and Burch [#1]. "Empirical Validation of Building Analysis Simulation Programs: A Status Report". Solar Energy Research Institute, WPA No 304, September 1982.

Judkoff, Wortman and Burch [#2]. "Empirical Validation Using Data from the SERI Class-A Validation House". Solar Energy Research Institute, WPA No. 304- 82, April 1983.

A study on a residential test building in Golden, Colorado compared measured energy performance data with energy estimates from simulation models constructed on DOE-2.1A, BLAST-3.0, and SERIRES. The base case models used handbook or assumed values, which were successively replaced with measured values for eight test cases (including infiltration, ground temperature, set point, and wall/roof conductance). The base case yielded estimates 46% to 62% higher than measured loads, but when input values were changed to measured values, the estimates were low by 11% to 33%. Differences between models were considerably less. The authors conjecture that the software programs are overpredicting both solar energy gains and conductive skin losses.

Judkoff, Wortman and Burch [#3]. "Measured Versus Predicted Performance of the SERI Test House: A Validation Study". Solar Energy Research Institute, WPA No. 304, May 1983.

Comparison tests based on two test residential buildings and three software programs (including DOE-2.1A) led the authors to these conclusions: Input assumptions based on standard engineering references can cause prediction errors of approximately 60% even when using measured meteorological data. Accurate temperature prediction does not guarantee accurate load prediction, or accurate temperature prediction on the next building studied; there is evidence of compensating errors giving a false sense of confidence. Even when most input inaccuracies are eliminated, prediction errors from 10% to 17% have still be found; this can have a large impact on building and HVAC system design options.

Judkoff, Wortman, O'Doherty, and Burch. A Methodology for Validating Building Energy Analysis Simulations. Solar Energy Research Institute, SERI/TR-254-1508 August 1983.

Kert, Norman L. "Success by Managing a Software Program as if it was a Hardware Project", Northcon Professional Program "Software Development Methodology in an Engineering Environment". Session Record, Seattle, 1984.

Software development needs to be well managed to achieve reliable, quality performance software in a cost effective, timely manner. One approach is to take advantage of parallels noted between software development and the development of a hardware product.

Lawrence Berkeley Laboratory. DOE-2 Reference Manual, Report LBL-8706, Rev. 3, 1981

Liddament and Allen. "The Validation and Comparison of Mathematical Models of Air Infiltration". AIC Technical Note 11, September 1983.

Mazzucchi, R. P. "The Project on Restaurant Energy Performance End-Use Monitoring and Analysis". ASHRAE Paper PO-86-07, No. 4 (for Transactions 1986, V.92, Pt.2).

Summary and analysis of data archived from monitoring end-use data in seven restaurants in the Pennsylvania, Virginia, and New Jersey.

McRae, Rufo, Guddat, and Baylon. "Service Life of Energy Conservation Measures", ASHRAE Journal, December 1988.

Estimates of the average service life of 51 energy conservation measures under typical field conditions in the Pacific Northwest, based on an iterative Delphi survey of 53 expert architects, engineers, energy consultants, quality assurance engineers from equipment manufacturers, service/repair firms, and facility managers. The range, median, mean, and modal values of estimated services lives were reported. Maintenance was he factor cited by most panelists as having the greatest influence on HVAC equipment life, while installation was important for envelope measures and thermal storage systems, and installation and obsolescence were important for energy management control systems.

Meckler, Milton. "Flexible Approach to Computerized HVAC System Analysis", Handbook of Energy Conservation for Mechanical Systems in Buildings, Robert W. Roose, Ed., pp 66-76. Van Nostrand Reinhold Company, 1978.

The use of building analysis software for energy conservation and system design.

Mixon, W.R. "Protocols to Guide Building Energy Monitoring Projects". ASHRAE Journal, June 1989, p.38.

Development of procedures and methodologies for monitoring building energy. Specific programs are cited including ELCAP.

Musa, John D. "Tools for Measuring Software Reliability". IEEE Spectrum, February 1989, p.39.

Reliability engineering tools are being developed to monitor the evolving reliability of software programs under development. Software reliability is a measure of how closely user requirements are met by a computer program in actual operation. Users are likely to demand that software developers prove their products meet maximum failure intensity limits.

Neelamkavil, Francis. Computer Simulation and Modeling. John Wiley & Sons, 1988.

General introduction to modeling and simulation, with emphasis on computer applications. Covers types of systems, models, model validation, discrete and continuous system simulation, simulation languages, and simulation experiments in practice with attention to sources of errors, error detection and control, variance reduction, and validation of results. Validation can be achieved by collecting evidence to support the validity of concepts, methodology, data, results, and inference; this may be demonstrated from retrospective, predictive, and structural perspectives. Verification refers to the correctness, consistency, and completeness of model implementation with respect to the design specifications, whereas validation is concerned with the correctness and consistency of a model with respect to the real- world system under study [other authors use the terms more interchangeably].

Ohadi, Meyer and Pollington. "The Applicability and Limitations of a Simplified Building Energy Analysis Model (ASEAM2.1) - A Comparison Study". ASHRAE Transactions, 1989, V.95.

Examination of the applicability and limitations of ASEAM2.1; detailed testing of algorithms based on hand calculations and comparisons with four commercial-domain software programs, and a hypothetical movie theater in Minneapolis. Heating loads simulated by the four commercial programs were within 7% of the hand calculated base case, but ASEAM2.1 was 62% lower due to its treatment of infiltration. Comparable results for cooling were below the base case by 38% and 4%.

Peters, Lawrence. "Software Analysis and Design Methods", Northcon Professional Program "Software Development Methodology in an Engineering Environment". Session Record, Seattle, 1984.

Software development is a process in logic that has been viewed as a progression of analysis, design, and coding; but in fact "most software

either starts out without any blueprint or is quickly modified without updating the blueprints. Each new development such as higher level or macro oriented languages ... aggravate the problems...." The development of structured analysis, structured requirements definition, structured analysis and design technique, and other methods respond to this analysis need. The comparable design responses are found in structured design, structured systems development, and Jackson's design method.

Rees and Shedd. "Energy Models: Exploring the Mini-and Microcomputers Applications". Newcomb and Boyd Consulting Engineers.

Reiter, P. D. "Early Results from Commercial ELCAP Buildings: Schedules as a Primary Determinant of Load Shapes in the Commercial Sector". ASHRAE Transactions, 1986, V.92.

Concepts of schedule and temperature-determined end-use loads were empirically examined using two buildings from the ELCAP metering project together with overall load data from PURPA and utility sources. Hourly end-uses were compared to the archetypes. The conclusion drawn is that schedules play a dominant role in determining the diurnal and seasonal shape of loads for the commercial sector as a whole.

Richter, Horst P. "Verifying the Reliability of Engineering Software", Computers in Mechanical Engineering, January 1984.

"The performance of any software is judged by its productivity and its reliability. The process of establishing the reliability of a computer program is called verification. Government agencies, technical societies, and companies are active in the production of guidelines and standards for verification." "Many standards stress procedures that require a test plan for development of a program and emphasize the specification of acceptance criteria and expected results for tests, [but] users in industry must rely [primarily] on results-oriented documentation and verification." Reliability is measured by comparing the accuracy of the results from the program with results from another source. Recommendations are presented for the contents of a verification report.

Ruegg and Petersen. Comprehensive Guide for Least-Cost Energy Decisions. U.S. Department of Commerce, NBS Special Publication 709, January 1987.

Estimating long-run economic performance of energy-related building components, using engineering and economic data. The publication assists "by guiding the decision maker to ask the right economic questions, by showing how to evaluate the cost effectiveness of energy conservation and renewable energy investments, by providing computational aids, and by supplying data needed to make the evaluations."

Shohl-Wagner, B. "Verifications of Building Energy Use Models: A Compilation and Review". ACEEE Summer Study on Energy Efficiency in Buildings, August 1984.

Spielvogel, L. G. "Comparisons of Energy Analysis Computer Programs". ASHRAE Journal, Vol. 20, No. 1, January 1978.

Comparative simulations of a 20-story office building in Washington, DC were conducted by five modelers and unnamed software programs, as the result of a Symposium on Energy Analysis Computer Programs. Although units to quantify comparisons were intentionally omitted, the heating and cooling energy consumptions appear to differ by as much as a factor of three during some months. "The probable reasons ... are the manner in which the various users interpreted the data ... and the manner in which the computer programs handled the heating and cooling loads." An effort was then made to eliminate the user interpretations, to the greatest extent possible: Further models were developed for a high-rise apartment house with four widely used energy analysis computer programs; the test case was sufficiently simple that all models produced very similar results. Agreement in simulation results is probably inverse to the complexity of the building.

Tishman Research Corporation. "DOE-2: Comparison with Measured Data", U.S. Department of Energy, March 1984.

Wagner, B. S. "Comparisons of Predicted and Measured Energy Use in Occupied Buildings" ASHRAE Transactions, Vol. 90, Pt. 2B, 1984.

Compiled results of two dozen verification studies on building energy simulation modeling, spanning a wide range of model complexity, quality of input and consumption data, modeler capabilities, and type of verification. "Differences between predictions and measurements in most of the studies compiled were within a ranges of +/- 20% on average for the monitoring period for simulations of individual occupied buildings or groups of occupied buildings." However, these figures were primarily for simulations where prior consumption data was available and models had been adjusted to conform. The author concluded that energy analysis models are effective.

Walton. Thermal Analysis Research Program. NBSIR 83-2655, National Bureau of Standards, March 1983.

Wortman, O'Doherty and Judkoff. "An Overview of Validation Procedures for Building Energy Analysis Simulation Codes". Solar Energy Research Institute, Task 1053.00, March 1981.

Validation depends on the control exercised over possible sources of error: weather, occupant behavior, modeler error, handbook error - which are external error types; and on modeling algorithm discrepancies, numerical solution inaccuracies, and coding errors - which are internal error types. SERI's work in validating building energy analysis simulations has resulted in a methodology that uses three kinds of tests: analytical verification, empirical validation, and code-to-code comparisons.

Yuill, Grenville K. "The BLAST Verification", ASHRAE Journal, January 1986.
A study of the BLAST computer program, complementing earlier verification efforts. The current study compares actual energy consumption and simulation estimates for two houses in Edmonton, Alberta. Simulation results for a standard house were from 5% deficient to 11% excessive when monthly energy totals were compared, but 1% to 15% excessive for an energy-efficient house; deviations were ascribed largely to input data difficulties. Overall agreement was taken as support for the BLAST predictions.

APPENDIX B MODELER QUALIFICATIONS

The Project Team

The Evaluation of Software project was performed cooperatively by a team comprised of a prime contractor, six subcontractors, and two members of the Bonneville Power Administration staff. Team members were selected for their experience and capabilities in modeling energy consumption in commercial buildings.

The prime contractor was Gale C. Corson Engineering. Mr. Corson, the firm's owner and principal, was responsible for project management and for coordinating the work of other contractors. The primary subcontractor was Solarchitecture Planning, P.C.. The project was initially proposed as a joint venture between the two, and it was carried out in that spirit.

Five other subcontractors were selected for the project:

- Applied Energy Management Techniques (AEMT)
- CADD Management Services
- Portland Energy Conservation, Inc. (PECI)
- Utility Systems & Applications, Inc. (US&A)
- VBB Pacific

The two Bonneville staff members were Tom Osborn (Snake River District office) and Tim Steele (Portland main office). Both have worked on Bonneville's building energy conservation programs and are experienced building energy modelers. For this project they not only offered recommendations and guidance but also constructed building energy models and participated in the simulation studies. Mr. Osborn was the Contracting Officer's Technical Representative (COTR) for the project.

Common experiences were the basis for the interest and close cooperation between Corson and Solarchitecture on the present project. Both firms have a long history in the use of building energy simulation software for modeling, and are well equipped with appropriate software and computational hardware.

In 1984-85 Mr. Corson supported the Solarchitecture team working on two Commercial Audit Program (CAP) contracts from the Bonneville Power Administration. Later the two firms served independently as consultants for the Energy Edge Program. Corson and Smith came to realize that users of simulation software, from various suppliers, are generally hampered by limitations and problems. Sophisticated users/modelers have found ways to get around the limitations and to improve results through input data which may be nominally incorrect but give superior results. However, there has been little or no organized effort to determine the extent of the limitations or the validity of the methods used to circumvent them.

This project was a way for the two firms to explore such questions, express their common interests, and advance the practice of building energy modeling.

Project Participants

Key persons contributing to the Evaluation of Software project through planning, simulations, and evaluations are show below.

Gale C. Corson Engineering
594 S.E. Craven Road
Bend, OR 97702
Gale Corson
Shirley DeMaris

Solarchitecture Planning, P.C.
19028 65th Ave NE
Seattle, WA 98155
Larry Smith
Dennis Oberto

In addition to the management team, the following firms and individuals participated in elements of the Evaluation of Software project, including building energy modeling.

Applied Energy Management Techniques
508 SW Jefferson
Corvallis, OR 97333

Cadd Management Services
723 The Parkway
P.O.Box 283
Richland, WA 99352

Portland Energy Conservation, Inc.
921 SW Washington, Ste 840
Portland, OR 97205

Utility Systems & Applications, Inc.
4160 SE International Way, D-107
Milwaukee, OR 97222

VBB Pacific
5901 S.W. Macadam Ave, St 135
Portland, OR 97201-3620

Tom Osborn - WCB [COTR]
Bonneville Power Administration
101 W. Poplar
Walla Walla, WA 99362

Timothy R. Steele / RMCC
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97211

Specific Experience - Gale C. Corson Engineering

Gale C. Corson Engineering offers an established practice in energy management, conservation, control; energy resources; energy systems for building facilities, and feasibility analyses of power production facilities and systems. The firm and its predecessor (Center 4 Engineering) have dealt with projects for building energy systems and energy conservation since 1977.

The firm has extensive experience with commercial building energy audits, including building energy simulations, work on two CAP contracts, and participation in other BPA commercial energy conservation programs. The firm is experienced in building energy system designs for new and renovation construction.

Contributions in energy conservation programs include IBP, CAP, Energy Edge, Energy Smart, and Energy Smart Design; programming of building energy software; and earlier studies concerned with energy conservation and the use of energy and energy resources. Among the projects completed are:

BPA Commercial Audit Program. Field work and engineering analyses for energy audits of approximately 150 commercial and institutional buildings in Portland suburbs.

BPA Energy Smart Program. Computer simulations, engineering evaluation, and design recommendations for energy conservation in the design and construction of new commercial buildings.

BPA Energy Edge Program. Engineering evaluation and design recommendations for building energy conservation; demonstration program encouraged designers to surpass the energy efficiency of the Model Conservation Standards.

Software for Computer Assisted Design. Design, development, and coding of software for a computer based numerical simulation package used in the design and evaluation of ground source heat pumps.

Energy Management and Control Reporting System. Data processing for Veterans Administration national energy conservation analysis and reporting.

Energy Study - Conservation Through HVAC Controls. Study for the Navy of HVAC control technologies for energy conservation, resulting in a guideline manual for design, operation, and maintenance.

Electrical and mechanical design of lighting, electrical, HVAC and plumbing systems in new construction and rehabilitation projects for commercial, institutional, and multiple family housing facilities.

Gale Corson, the firm's owner, served the Evaluation of Software project as Project Manager and Principal Investigator. He applies more than 30 years of experience in engineering and management responsibilities to the projects he leads.

Corson holds engineering and MBA management degrees, is a registered Professional Engineer and a member of engineering and professional societies, and is currently serving on ASHRAE Standard Project Committee 140P, "Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs."

He previously was Chief Engineer for Nissen Corporation (Nissen Universal), and before that served in business management, finance, and other engineering capacities. He was appointment by the Oregon Public Utility Commission to a select committee studying PURPA, and by the Governor of Oregon to the governing Board of the Citizens Utility Board of Oregon. Corson's written work, primarily on energy topics, has appeared in several journals and government publications as well as private monographs.

During the CAP efforts with Solarchitecture, extensive use was made of building energy simulation software. When software errors and limitations were encountered, Corson prompted the supplier to make corrections; he also programmed new support software to improve data input, analysis, and reporting.

As an experienced energy auditor, Mr. Corson performed some of the building energy modeling for this project. He assigned Shirley H. DeMaris, an electrical engineer, to assist with modeling and analysis, especially electrical engineering concerns. DeMaris has supported energy analysis projects and Technical Assistance Studies for the firm, as well as engineering design work for the firm's engagements on commercial, institutional, and multiple-dwelling unit buildings.

Solarchitecture Planning, P.C.

Solarchitecture Planning is an architectural planning and design firm with particular interest in building energy efficiency. Until recently the firm operated from offices in Portland, Oregon, but is now active in a new location in Seattle, Washington.

Solarchitecture's owner, Lauren A. "Larry" Smith, formed the firm in 1976 and concentrated much of his work on building energy conservation.

Mr. Smith has extensive experience directing projects in architecture, planning, and energy analysis/conservation. His contract experience includes two energy audit contracts under the Commercial Audit Program. More recently he supported BPA's Purchase of Energy Savings Field Test (PES) program. In earlier employment he contributed to the work of architect/planner firms in Oregon and on the east coast. He is a Registered Architect, holds degrees in architecture and planning, and is a member of professional groups including the American Association of Architects.

Mr. Smith is an experienced energy auditor who performed building energy modeling for this project as appropriate. He also assigned Dennis Oberto to the project as a key participant. Mr. Oberto is an energy auditor who served on Solarchitecture Planning's team for the two Commercial Audit Program contracts; his further credits include extensive residential energy audits.

VBB Pacific

VBB Pacific is a Portland, Oregon affiliate of an international mechanical engineering company. The local firm specializes in commercial and institutional building energy performance and comparative energy systems analysis.

VBB's engineers have experience in computer software development as well as technical support of energy analysis programs.

The firm's computer modeling is used by design teams to optimize building energy systems and architectural features; by owners/ developers for comparative system analysis and conservation measures; and by facility managers and utilities for monitoring and evaluation building operations.

VBB Pacific's engineers have modeled several hundred commercial and institutional buildings throughout the Pacific Northwest and nationally, including participation in conservation programs such as Design Advantage and Smart Design. Representative modeling clients include the Washington State Energy Office, Pacific Power & Light Company, U.S. General Services Administration, Pacific Gas & Electric Company, Portland Energy Conservation Inc., and the Oregon Department of Energy.

Applied Energy Management Techniques, Inc.

Applied Energy Management Techniques, Inc. (AEMT) is an incorporated division of Gordon and Associates (Corvallis, Oregon) established to perform services relating to energy analysis. AEMT performs energy prequalification analyses, energy audits and monitoring of the effectiveness of energy conservation measures, including all calculations for shared energy savings agreements.

Gordon and Associates, Inc. is an engineering consulting firm, established in 1971. The staff is comprised of multi-disciplinary talents representing mechanical/electrical/ industrial engineering, energy analysis ad data processing services.

Applied Energy Management Techniques has developed an automated approach to analysis of energy consumption in commercial facilities. The approach involves an integration of actual utility consumption, an inventory of specific building equipment, hours of operation and building envelope information which is used as input to the appropriate computer simulation model. In addition to energy analysis performed for over 200 commercial clients relating to specific buildings, the following are government programs that provided substantial energy analysis experience:

Commercial Audit Program (CAP): Over 400 Level 2 buildings were analyzed by AEMT under this program. The building locations were primarily in the Kennewick/Pasco area of Washington and in Central and Western Oregon. All energy simulations were modeled using either the Simplified Energy Analysis SEA program or the Elite building energy analysis program.

Energy Edge Program: Four major projects have been accomplished by AEMT under this program, using PC-DOE, MICRO-DOE, and DOE2.1C.

Purchase of Energy Savings Program (PES): Three analyses projects have been completed under the PES program, using PC-DOE and SEA.

Commercial Incentives Pilot Program (CIPP): Five projects were investigated and carried through the analysis phase, using MICRO-DOE and SEA.

Simulation Modeler - Lewis J. Ebner, Member of Technical Staff

M.S., Physics; A.S., Energy Technology, Linn Benton Community College.

Conducts energy use analyses, energy audits, computer system designs, programming, implementation and operation. Performed over 200 energy audits and analyses for the Commercial Audit Program (CAP), the Energy Edge Program and the Purchase of Energy Savings (PES) program and the Commercial Incentive Pilot Program (CIPP) using the SEA, PC-DOE and MICRO-DOE and ELITE simulation programs.

CADD Management Services, Inc.

CADD Management Services, Inc. is experienced in building energy modeling for existing and new buildings. Their work includes more than 30 buildings and 600 models with ADM-2, and more than 20 buildings and 300 models with TrakLoad.

CADD Management specializes in computer aided design and drafting. The firm offers computer expertise to produce high quality analysis and documentation. It has seven full time employees and a wealth of computer equipment, software, and design and drafting expertise.

Dallas B. Noyes, P.E., the firm's principal engineer, performed the computer modeling and analysis for the current project. Over the past eight years Mr. Noyes has acquired extensive experience in energy audits and energy conservation measure design. He has worked with a wide variety of energy modeling software including DOE2, BLAST, TRACE, SOLCOST, ADM2, and TrakLoad. His solar, geothermal, and other renewable energy source experience provides additional depth of support.

The major projects which Mr. Noyes has managed and completed include:

Alternative service provider for the BPA Energy Smart program in regions administered through the Walla Walla and Spokane offices.

Energy Smart Design Assistance through the BPA Spokane office.

Services to the City of Richland for two years under the CIPP program. Audit review and support services for CIPP.

Ten level III buildings in Benton County under the BPA Commercial Audit Program. Modeling was with ADM2.

Energy conservation management services to other architects/engineers under the Washington State Energy Office Energy Edge program. Four Energy Edge studies were completed under this contract. All studies resulted in more than 20% reduction in the Base Case energy consumption.

Led the team which completed energy audits for schools in the Pasco School District, under the WSEO Institutional Buildings Program.

Walk-through audits for nine Washington State National Guard armories in Eastern Washington. No modeling was required.

Life cycle cost analysis for a new elementary school for the Pasco School District and for the remodeling of the junior high school. Extensive modeling and analysis were completed for decisions relative to the life cycle cost of the building. TrakLoad was used for the computer modeling.

Alternate energy source design and evaluation, including geothermal, biomass, hydrothermal, solar, ethanol and industrial heat recovery.

Portland Energy Conservation, Inc.

Portland Energy Conservation, Inc. (PECI) has been implementing energy conservation programs in the commercial sector since 1981. Under the direction of PECI, over 800 existing commercial facilities have been analyzed using either hand calculations or XENCAP, a computer-based audit program.

In the last four years, PECI has used both TrakLoad and DOE2.1C to model commercial buildings for Bonneville Power Administration with Energy Edge and Smart Design, the Conservation Law Foundation of New England, and BC Hydro. In the last year, small office and retail facilities have been simulated using TrakLoad to analyze energy savings in prototypical buildings for three different utilities in New England, and in British Columbia for BC Hydro.

PECI's first experience with computer simulation programs was as a sponsor of Energy Edge in analyzing the potential savings of new commercial buildings. As applicants submitted their preliminary designs for consideration, PECI staff used TrakLoad to simulate the buildings. Once buildings were selected for the final round of consideration, an engineer modeled the buildings with DOE2.1C.

Will Miller, Technical Director, directs the modeling efforts. Mike Kaplan, consulting engineer, provides the design expertise to make sure that reliable models are built. Rick Jones, a recent addition to PECI's staff, had three years experience modeling for Puget Energy Services, using ASEAM and TrakLoad.

Mr. Miller directs technical aspects of the new commercial designs and programs which PECI is developing for sixteen utilities in the United States and Canada. He researches baseline parameters for commercial buildings; develops modeling criteria and formats; identifies energy-efficient design options, including resulting energy savings, costs, and expected life; and determines appropriate incentive levels for utility programs.

Mr. Miller provides technical consultation on design and implementation of commercial retrofit programs for twelve northeast utilities, and advises Pacific Power on appropriate strategies for commercial energy conservation in its six-state service territory.

Miller designed PECI's plan for implementing Energy Edge, a Bonneville Power Administration program for new commercial buildings that achieves a 30 percent savings over regional model conservation standards. He conceived the

Industrial Lighting Incentive Program, funded by Bonneville and operated by PECI, that improved lighting systems in industrial facilities. He developed and supervised a commercial audit program for Clark Public Utility district, that provided 540 commercial audits in Clark County, Washington. He directed the commercial/industrial audit program for Portland, Oregon, saving electricity and fossil fuels for 440 Portland businesses.

Utility Systems & Applications

Utility Systems & Applications (US&A) has demonstrated its ability to successfully manage diverse energy-related technical services. Since 1980, US&A has offered services to utilities, corporations, and public agencies throughout the Pacific Northwest. Those services include:

- Energy audits and technical services;
- Electricity use recording and translation; and
- Design, acquisition and installation of electricity metering and submetering.

US&A has extensive experience conducting energy audits. The firm performed over 600 audits as part of Bonneville Power Administration's Commercial Audit Program. Commercial audits were also conducted on behalf of the City of Portland's energy savings center and for the University of Oregon.

Electricity user recording and translation services have been provided to industries and utilities in four states. US&A performed detailed end-use surveys required to document loads and determine survey points in both residential and commercial applications.

US&A has tested and calibrated meters or performed comprehensive audits on major accounts for Northwest utilities. It has installed load survey equipment for US Navy commissaries, metering for federal HUD housing, and submetering and calibration capabilities for commercial and industrial accounts.

Lynn Frank, President, served nearly eight years as director of the Oregon Department of Energy. He managed an array of energy conservation programs - Residential audits for oil-heated homes; commercial tax credit applications for energy conservation projects; project review for loans under the Small Scale Energy Loan Program; implementation of MCS; administration of Energy Edge and Energy Smart; administration of the Schools and Hospitals Programs; and numerous other conservation programs.

Hussein Hassoun, Executive V.P., is skilled in spreadsheets and graphics for tracking, status, and other purposes; and has demonstrated experience in data entry and calculations. While with the Oregon Department of Energy, he was responsible for long-range energy demand forecasting, studies of energy resource alternatives, and cost/benefit analysis of energy incentive programs. His division performed energy use survey and audits on residential, commercial and industrial facilities.

Jack Callahan has over six years experience in energy analysis and mechanical systems design for commercial and industrial facilities. He has contributed as a consulting engineer, and by administering public sector energy conservation programs for the Oregon Department of Energy. Callahan has extensive modeling experience including hourly, typical day, and bin models using DOE-2.1, PC DOE;, ASEAM-2, SEA, TrakLoad, and Elite Building Energy Analysis Programs. He has performed audits, modeling, and design assistance under BPA's IBP, ITP, Energy Edge, Technical Assistance, and Energy Smart Design programs, including detailed energy analysis on over 50 commercial and industrial buildings.

Bonneville Power Administration

Bonneville Power Administration (Bonneville) performs energy simulations of all new substation buildings. DOE-2.1 is the energy simulation program commonly used. Energy modeling is used to justify building and HVAC construction features and to establish an estimate of building energy use. Bonneville uses commercial building prototypes in load forecasting, in energy conservation studies and as the basis for the energy conservation supply curves.

Two Bonneville engineers gave direct support to the Evaluation of Software project - Tom Osborn and Tim Steele. Marilyn Brown, another BPA engineer and manager of an allied energy conservation project, contributed helpful insights. Jeff Jansen operated the laser printer to be sure quality graphics would be available for the report.

Tom Osborn earned his Bachelor of Science in Mechanical Engineering from Gonzaga University, Spokane, Washington in 1986. He has worked with BPA since 1985 and has been involved in the Walla Walla Area Office operation of Irrigation, Residential, Industrial and Commercial programs. In the past year, Tom has modeled over 20 different buildings using ASEAM-2, ADM-2 and TrakLoad. He constructed several building energy simulation models for the Evaluation of Software project, and served as the capacity of COTR.

Tim Steele was responsible for the development of Bonneville modeling requirements and use in energy conservation projects. He has performed studies at Bonneville using DOE-2.1D and A Simplified Energy Analysis (ASEAM) software. He also has spent time as a consulting engineer during which he performed energy audits and new construction design studies using Simplified Energy Analysis (SEA).

APPENDIX C

VARIABLES IN ENERGY CONSERVATION MODELING

The world in which we live is irregular, and evidences variability. It is known to us imperfectly and is subject to interpretation.

The same attributes reflect in building energy modeling and simulations, first in how a simulation model is constructed and ultimately in our understanding of the simulation results. Thus the energy consumption of a given building is itself subject to variability as are estimates of the consumption, even before considering differences between the various software packages that could be used in the simulation. Moreover, the conclusions that are drawn depend on perspectives as well as data.

The building energy estimate derived from any given simulation model will fall within a range which depends both on the software and construction of the building-specific model. Measures of performance such as spread in the likely range of estimates willl depend on the parameters of the building being modeled as well as the way the simulation software was designed.

The preceding paragraphs recognize variabilithy both within the simulation process and the "real world" it seeks to mimic. Variability is linked to variables. The number of variables associated with a building is large, both in the real world and in models used to simulate its energy. Indeed, it is the extensive number of variables and how they interrelate that leads to the use of computerized simulations for energy consumption estimates, rather than relying on manual calculations.

Simulation models are useful tools, in part, because they encompass a large number of often comlex relationships and consistently compute the results of a large number of calculations. When energy conservation measures (ECMs) are considered, a number of alternatives can be evaluated quickly, easily, and economically.

The complexity of the world being simulated, however, is also the reason for compromises in the calculations; and the complexity of the models helps explain why they may embody incorrect calculations. The quality of simulation models depends on the care exercised both by the respective software houses and by the people who construct and exercise the final building-specific models.

The same profusion of variables adds to the difficulty of conducting meaningful investigations and anayses of modeling techniques, software quality, and simulation results. It follows that variabliilty is a significant aspect of the Evaluation of Software project.

It is helpful to examine the variables that affect building energy simulations. The variables recognized and classified in Chapter 4 are further detailed in the summary chart and narrative which follow.

Factors Affecting Energy Simulations

Input Variables

Available data
- unrecorded building changes
- occupancy changes and variability
- energy delivery, meter, and reading variability
- energy consumption variability
- energy consumption records
- weather variability
- weather records
- conduct of field audits

Model definition
- modeler interpretation of field audit and other data
- modeler decisions on model input data
- modeler's conformal choice on use of actual energy data
- modeler's adaptations to simulation model
- construction of basic model

Data entry errors

Software Variables

Software design
- conceptual design - methodology (hourly, bin, etc)
- software scope, limitations, and applications
- design compromises
- extent of building system types simulated
- algorithm selection
- weather file structure and adequacy
- other internal data files
- input parameters
- design and coding errors
- ECM options

Software implementation
- documentation, other information, supplier support
- ease and clarity of data input
- availability of data for weather parameters
- availability of weather files
- hardware compatibility
- running times and running time choices
- interactive effects, order of runs, etc.

Factors Affecting the Interpretation of Energy Simulations

Implementation Variables

Interpretation and application of simulation results
- end results evaluation and conclusions
- local variables - utility rates and availability
- ECM cost, service life, and payback; ECM selection
- communication of results

Building construction deviations and variables
- owner and construction contractor choices; base building changes
- ECMs not implemented

Output Variables

Building end-user variability; changes in:
- occupancy type; hours of operation; numbers of occupants
- heating/cooling set-points
- ventilation, especially operable windows
- envelope, shading
- lighting and lighting hours
- etc.

Weather encountered
- differences from "simulation weather" data: temperatures, cloud cover, humidity, wind

Other "real-world" variables, including undefined random processes

Data quality
- extent and quality of monitoring
- end-user data
- energy delivery and reading variability
- energy consumption variability and records
- weather variability and records

Interpretation Variables

Study plan
- sampling plan
- specific simulations

Interpretations and conclusions
- reviewer experience, perspectives/bias
- communications

1. Variations in Input Variables

Input variables occur in the information used to construct a simulation model (or other energy analysis). Input variations may arise in utility, field, or weather data, or from choices made manifest by the data input to the simulation model.

Data used to construct a buildign energy simulation model determine what the model will be, how it will behave, and therefore what results it will produce. Some input data is determined from sources which are largely beyond a modeler's control, or otherwise provide "raw data" for the modeler to consider. "data variables" arise from such data itself. By way of contrast, "modeler variables" derive from a modeler's selection, modification, and adaptation of the raw data.

For analysis purposes it is helpful to distinguish between the availability and collection of data defining a building, and the interpretation and entry of that data into a simulation model. The former derives from a field audit, while the latter is the work of the engineer/technician who serves as the modeler. There are fundamental differences between input variables resulting from modeler choices and those due to other input factors.

The CAP evaluation report provides a reasonable analysis of what is typically encountered when field data is collected, and the probable errors associated with it. This step of an energy analysis can introduce considerable differences in the work and results reported by several modelers. The Evaluation of Software project did not attempt to test those findings and conclusions further. Efforts to help modelers acheive greater consistency might appropriately embrace this step, however.

Chapters 4 and 5 of this report include considerable information about the collection and vagaries of data variables pertaining to buildings and building energy analysis. The examples there are for the buildings selected for the Evaluation of Software project, but the examples are representative of other buildings as well. Further comments are noted below.

Much remains to be understood about how the interpretation and entry of data into a simulation model affects the simulation results. Note can be made of variables such as thermal conductivity and shading coefficients. A modeler will interpret these variables in ways that affect the value entered for a specific software algorithm. Accordingly, if the input value is made larger or smaller the algorithm will compute a larger/smaller result. The significance of these variables and interpretive effects can be determined through a sensitivity analysis in which changing output values are observed in response to changing values of input parameters.

On the other hand, some interpretive variables represent choices between several algorithms. Examples are the selection of a heating system type, a decision to ignore certain shading features, failure to specify setback controls or optimization, and approximations of a seasonal plant vacation

the simulation software does not support directly. For these variables there is no simple relationship between input and output increments. Instead there may be massive shifts in energy consumption estimates.

In both instances, specific patterns of modeler interpretation can be observed, but not always predicted. To understand the frequency and significance of interpretive variations, it is therefore necessary to observe and record the behavior of an appropriate number of representative modelers.

However, no process has yet been found to obtain complete, accurate data for all parameters that affect a buildling's energy performance. Drawings, specifications, and field audits are used, with varying degrees of success.

How a modeler interacts with the data and the osftware afects model performance. It follows that the modeler's ability is a variable of interest. Modeler ability has most frequently been judged by speciifc qualifications including education and training, general experience, modeling experience, and experience with specific modeling tools (software programs). There is, however, a notable lack of agreement about these qualifications and how stringent they should be. It seems reasonable to suggest that modeler qualifications should be related to the frequency and magnitude of overall effects ascribed to modeler variables - the greater the variability the more emphasis that should be placed on the qualifications.

Return now to the instance in which an input delta-change produces an output delta-change. An example is the change in a wall "U" value that produces a change in simulated energy consumption according to algorithms linking them. A modeler's decisions about input variables may be of this type, which we will call type a). Modeler decisions may also be of at least three other types: b) choices (valid or not) between algorithms, c) modeling compromises and compensations, and d) shaping/leveling choices. Type b) may be illustrated by a multizone HVAC system modeled with or without reset; type c) may be illustrated by forcing wall orientations of a six-sided building into a four-wall simulation model; type d) may be illustrated through use of a modeling feature that allows average simulated energy to be set to a specified level (for example, to agree with utility billings).

Modeler choices of the latter three types are not subject to sensitivity analysis and need to be analyzed through simulation experience. Type b) may be significant in degrading model performance by modelers who have insufficient engineering training. Type c) includes attempts by experienced modelers to improve a model, although results are likely to be inconsistent when the work of two modelers is compared.

Type a choices seem to have received the most attention in the literature, perhaps because they are the easiest to study and explain. The same emphasis is noted in this study, but at least a start has been made in investigating the more subjective decisions affecting input variables.

At the same time, there seems to be an ongoing opportunity to reduce the variability associated with type a) decisions, which is pointed out by the sections in this report that deal with utility billing data and weather data.

Weather is an important environmental variable. The data in a weather file introduces variability because it is only an approximation of real weather.

Furthermore, many software suppliers ask the modeler-user to accept weather data on faith: weather data may be available only in a coded (unreadable) file and only from the supplier, of unspecified contents, and used in the software in unspecified ways. Often there is no way the modeler can test or confirm the data, much less correct it or adapt it to his individual needs.

To compare simulated and actual results meaningfully, it is necessary to adjust for the differences in weather data - by changing either the simulation process or the results of the simulation to account for the specific weather conditions, or by normalizing the "actual" weather data to yield average building energy.

One way to adjust simulated building energy for specific weather data is to alter the computer-based weather file used in the simulation. For adjustment purposes, some files can be modified fairly easily, others less so. Many commercial building energy software packages use ASCII-format weather files with numerical values related to physical measures such as temperature, humidity, and cloud cover. In a few instances, actual-year weather files are already available. In theory therefore, a building energy simulation can be repeated with the new weather file to yield an estimate on a basis comparable to the energy "actuals" for the period represented by that weather data. Two caveats are in order. This method introduces some uncertainty because a modified weather file will be less well authenticated than the one it replaces. Furthermore, while the work required to establish a new weather file may be acceptable for a few analyses, it would be excessive for routine energy simulations. As a practical matter, there may be instances in which the weather file is not amenable to this kind of manipulation.

An alternative is to multiply the simulated heating/cooling energy (month by month) by the ratio of actual and normal heating/cooling degree days or some similar parameter. Alternatively, the same procedure can be applied to energy "actuals" to normalize them for comparison with "typical year" weather. This procedure provides only an approximation of the desired adjustment, but the reduced accuracy is in the adjustment rather than the base calculation. The usual objections to degree-day methods apply therefore only to the relatively small portion of the total represented in the adjustment. The result will be a substantial improvement over unadjusted data.

In the real world, desired weather data is not always available. Further approximations become a necessity. The need is increased to examine the data carefully and adjust it as appropriate.

Weather variability shows up in the bills rendered by utility companies. It takes more energy to maintain building comfort when the weather is increasingly cold or increasingly hot, or for that matter other extreme conditions such as high winds and excess humidity. Utility billings provide an important source of information both about the environment and about the characteristics of the building being investigated.

However, utility billings introduce variability of their own. Meter errors, meter reading errors, meter reading dates, and accounting lags, approximations, and errors can all take their toll.

Likewise, the specially metered energy data available from the ELCAP/CREUS program - is not without its own problems - despite safeguards to maintain its integrity. Simple tests and comparisons flagged three instances, affecting two buildings, where the ELCAP data originally provided could not be correct. Corrections were obtained from the data source for two of the errors, while the third remained without resolution.

Building data was yet another source of uncertainty and variability for the project. The project was premised on the use of a few real buildings as a sample of what can occur, and as a basis against which the study simulations and other activities could be compared. The four buildings that formed the comparative base for the Evaluation of Software project are real, existing buildings, each with a history of occupancy and energy use. Each building had been studied three, four, or more times in a succession of investigative programs sponsored by the Bonneville Power Administration. Files from those programs offered a wealth of information about the buildings, and those files were made available for the Evaluation of Software project.

Furthermore, the CAP evaluation report had previously made an investigation of the variables and errors which can and do occur when building data is gathered from the field, interpreted, and utilized in building energy modeling. It was decided that those variables need not be explored further for the Evaluation of Software project. Thus, the file data already available on the four buildings was the accepted data base adopted for the current project.

Even so, modelers complained that the parameters were not fully defined. By implication they were critical of the demand forced upon them to extrapolate appropriate input values for modeling based on the partial information given them. They were concerned about the uncertainty and variability introduced by this process.

No process has yet been found to obtain complete, accurate data for all parameters that affect a building's energy performance. Drawings, specifications, and field audits are used, with varying degrees of success. There is considerable agreement about the correct applicability of this data as long as it is complete. There is considerably less agreement about how the data should be extrapolated and interpreted, when those needs arise.

2. Variations in Building Energy Simulation Software

Software differences stem from differences in algorithms, the number and variety of input parameters, differing ECM options, the structure and choice of weather data files, and conceptual differences of models utilizing typical buildings, typical weather days, bin methods, or hourly simulation.

Determining comparative quality and differences between building energy simulation software packages was the primary analysis goal for the Evaluation of Software project.

Some comparisons, such as hardware compatibility or the extent of documentation, can be made fairly easily and reported descriptively. A determination of a program's technical features - for simulating certain building energy systems, components, or controls - is somewhat more sophisticated yet still quite easily accomplished, at least superficially. Most of the studies reported in the literature, however, and most of the efforts in the Evaluation of Software project focused on the more difficult demands for software testing and validation.

The difficulty stems from the need to analyze the software through the intermediary of building-specific models that have relied on the software for their development and calculation. In the analysis, the software is treated as a complex "black box"; how it functions - or at least how well it functions - is deduced by comparing its output with a "standard" output obtained from another blck box or a real-world building. Occasionally the output may also be evaluated on an input/response basis, but unless a very simple building model is used the output response is too complex to anticipate through manual calculation processes.

The Evaluation of Software project relied on macroscopic comparisons between models but omitted procedural steps for determining and anayzing the sources of the differences. Compared to the large number of variables, the sample size was small. Therefore, while the software design variables listed on page C-2 are recognized, the results were not sufficient to isolate their individual contributions to overall program performance.

uated to see if they are suitable for this study: the probable magnitude of errors may need to be estimated.

As a general statement, all of the software packages introduce their own approximations, limitations, idiosyncrasies, demands upon operators, and even errors. The cumulative effect of these features impacts the accuracy of the results obtained from the simulations. Departures from the real world are certain to affect decisions about which Energy Conservation Measures (ECMs) should be implemented and how rapidly their investment can be recovered through energy cost savings. The Evaluation of Software project encountered these various limitations, with the result that less conformith between the several base building models was realized than had been expected, but the effort was still successful in determining quantitative measures of how far the simulation results depart from each other and "reality".

Because the choice of software for a specific modeling project is a strong determinant of the results that will be obtained from the simulation, the choosing process itself should be recognized as introducing variability. However, software selection is made by the modeler, and therefore is classified as a modeler variable.

3. Variations in Implementation Variables

Two types of implementation variables are recognized, those that arise during the evaluation process and those representing differences between what is projected for a building (new) or building modification (renovation or ECM), and what in fact is constructed.

Variability arising during the evaluation process is reflected in recommendations for building design features and ECMs, rather than discrepancies in building energy consumption. Modeler choices and economic factors influence the selection of recommended building features and ECMs, even if energy projections remain constant. When energy savings and installed cost are held constant, the economic feasibility of an ECM is a function of the utility rate at which the energy savings are priced. However, an ECM will never be considered if the modeler does not include it in his analysis, and the building owner will not select it for implementation if a recommended results is not communicated effectively.

ECM determinations are strongly influenced by the input values assigned by the modeler. The inputs are not only for technical parameters (setback temperatures, changes in lighting efficiency, economizer action, etc) but also for economic parameters (cost, rates, and economic service life of the ECMs). Equally important, the modeler does not make simulation runs for all possible ECMs and combinations of ECMS; he chooses which analysis runs to make, usually because he anticipates a positive payback based on prior experience in the field and with the simulation program. The modeler may choose to observe cutoff points (for example, ignore ECMs that cost more than $X or have a payback longer than Y years), and the modeler controls the ordering and packaging of ECMs (which often interact to affect the estimated payback of other ECMs).

Variability arising from how a building is constructed, on the other hand, is likely to be reflected in building energy performance that differs from the simulated model projections. Quite simply, the model anticipated and simulated something other than what was eventually built. Such differences may arise from discrepancies or changes in site conditions, regulatory requirements, further improvements sought by the design team, omitted ECMs. owner choices and decisions (including financing limitations and capital investment tradeoffs), availability and variances of materials of supply and equipment, and the work performed by construction contractors.

Implementation variables therefore arise both from model-user decisions about what energy conservation measures should be modeled and recommended, and from decisions the building owner/user and others make about what would be built. The CAP evaluation report considered most of the topics in the previous paragraphs; Section 3 and 4 addressed the modeling decisions, while Section 4 considered factors affecting the as-built decisions. The CAP evaluation report recognized that decisions made by modelers impact the results, and contractor and owner decision are driven by cost and payback considerations.

4. Variations in Output and Real-World Variables

Implementation variables arise from the data obtained from a finished project. Building end-use consumption varies with end-user impacts (occupancy, leaving windows open or lights on, thermostat set-points, etc.), quality and sufficiency of data monitoring, and weather variables. Output variables also include unspecified random processes.

The "real world" energy consumption of a building is significant in the evaluation of simulation software when it is used as a comparative base: the suitability of the software is judged by how closely it approximates "reality".

A building's actual energy consumption depends not only on how it was constructed (implementation) but also on what environmental variables it encounters, such as weather and how its occupants use it.

The factors affecting weather variability as identical to those considered for input data. In general, future weather will never agree with the weather file used for simulation, although compensating adjustments may be possible; in addition, no two buildings will experience the same weather, although buildings in the same neighborhood will usually be affected by similar weather during concurrent data logging. When weather variables are significant to the results, as they usually are, either the simulation or the field data (or both) need to be normalize to a common base.

When comparisons are made between projected and actual building energy consumption, the tendency is to accept verbatim the data taken in the monitored building. The situation arises frequently when some but not all measures have been installed from a package of recommended ECMs' If the building occupancy has changed, the weather was atypical, or the buidling was equipped or constructed in a manner other than the predictive simulation, then a notation may be entered as to why the model gave a poor prediction; but this is only partially informative at best, and may at times be misleading, because the energy bases are no longer comparable. In such instances the evaluation of simulation software performance should compare metered data with a revised simulation.

The quality of metered data is a further concern. Imprecision in the instruments can usually be ignored relative to the larger variables, but human errors in placing equipment, separating circuits, and recording multiplies can introduce significant data errors.

Futhermore, many aspects of the real world are irregular, even when we fail to identify the variables or find them important only in the aggregate. The probable range of variability introduced from this source can be estimated only imprecisely; fortunately such unknowns appear to contribute only a small part of the total variability.

5. Variations in Interpretation Variables

Interpretation variables are encountered during analysis and communication of the study results. Findings from a study of building energy simulation modeling depend on the study plan adopted, the specific simulations made, and the perspectives of the reviewer. These could lead to differences in the conclusions reported by two different researchers.

Interpretation variables are encountered when people attempt to analyze and interpret differences between two sets of simulation estimates, or between simulated energy and energy consumption data collected from real buildings. Such variables reflect specific samples, sample sizes, simulations, the need to fill in for missing data, and the prior experience ("bias") of the reviewers.

Related factors, such as differences in end-use categories between two data sets, add to the difficulty of presenting applicable, unbiased conclusions.

These variables therefore are factors in what is ostensibly "determined" by a particular study. Such variables are inherent in any study, but their magnitude can be limited through peer review and their impacts (on the reader of a report for example) can be further reduced simply through recognition and disclosure.

It may be helpful to remember that things are not always what they seem to be.

APPENDIX D: BUILDING DESCRIPTION FILES

Modelers were asked to construct building files for simulation studies, using progressively more complete data. For Cycle 1 they received only descriptive information about the buildings, in the form of written "Building Description Files".

By way of example the text from one of the Building Description Files is reproduced in this appendix: the file for the large office building. Further information, although not reproduced here, was provided in the form of sketches, schedules, and copies of selected information from the CREUS project files. For one building a nearly complete, though reduced and hard to read, set of architectural and engineering drawings was located and made available.

Modelers were asked to work from the descriptions, and avoid visits to the building sites, but they were encouraged to direct questions to the prime contractor if additional information was needed. In some instances it was possible to answer those questions, in the form of written supplements sent to all modelers. A composite example appears on the next page of this appendix.

SUPPLEMENTAL BUILDING DESCRIPTION FILE
(a composite of several issued)

BUILDING #1 - Small Retail Building, Eugene

1. **General -**
2. **Envelope -** The common wall on the east side of the building is actually a double wall (see photo).
3. **HVAC -**
4. **Lighting -**
5. **DHW -**
6. **Occupancy -**
7. **Other Loads -**
8. **Weather -** See attached
9. **Cut-off date -** The presumed date of the field audit is January 1, 1987.

BUILDING #2 - Large Retail Building, Richland

1. **General -**
2. **Envelope -** The main entryway is covered by a canopy (see photo). Exterior concrete walls have aggregate finish on the outside (see photo).
3. **HVAC -**
4. **Lighting -** The (transverse array of) fixtures in the "mall" area are marked on the lighting sketch by "3"s in rectangles: Each rectangle identifies three fixtures end-to-end, each with four 4' H.O. lamps.
5. **DHW -**
6. **Occupancy -**
7. **Other Loads -**
8. **Weather -** See attached
9. **Dates -** The presumed date of the field audit is January 1, 1987. Billing dates shown each month: date read, date billed, date paid.

BUILDING #3 - Small Office Building, Eugene

1. **General -** Some of the sketches are marked "NRW", indicating a former building occupant.
2. **Envelope -**
3. **HVAC -** Night setback is manual.

   One panel schedule shows exhaust fans:

lunch room	180 cfm	50W	HVAC control
restrooms, ea	100 cfm	30W	light switch
conference	180 cfm	50W	room switched
ship/receive	? cfm	50W	unknown control

   Shipping/receiving was augmented by 8' baseboard heater, 2000W
4. **Lighting -** 7 of the 4' fixtures had only 2 lamps when audited (delamped)
   Ballast was probably still in place.
5. **DHW -**

6. **Occupancy -** The occupant apparently occupied building first in April of 1987, and their "computer center" business gradually grew (they outgrew the building in 1989). By August 1988 they had 45 computers, 8 printers. The prior tenant also used computers, but more as an adjunct to their office work.
7. **Other Loads -** microwave, dishwasher, Saran wrap heater
8. **Weather -** See attached
9. **Dates -** The presumed date of the field audit is January 1, 1987.

BUILDING DESCRIPTION FILE

Large Office Building
Richland, Washington

BUILDING ABSTRACT:

1. **General** - The building is a four-story office building currently occupied by the owner and tenants; a portion of the building is vacant. A penthouse provides space for a cooling tower and mechanical equipment. Total conditioned area of building, including basement, is approximately 50,500 square feet. The drive-in banking facility is shown in the photos.

The building was constructed in 1978; except for additional air conditioning for computers in 1982 and an Energy Management and Control unit added in 1984, no major modifications have been made since then. The building is in good condition with an estimated remaining life in excess of 30 years.

Energy audit file references to a separate drive-up booth (for the credit union's banking operations) do not show up on the building drawings.

The building is all electric. Two meters have been noted, one with demand metering.

2. **Envelope** - The building is of concrete wall construction. Walls and roof are insulated. Construction details are shown on the building drawings.

The architect/engineer drawings show the 3rd and 4th floors ready for "build out" to meet tenant requirements. Additional interior walls and partitions have in fact been provided to meet tenant requirements. See attached sketches, and comments below under "Occupancy".

3. **HVAC** - The HVAC system is composed of three primary systems:

. The basement is heated by two electric furnaces with minimum outside air.

. Two air-handling units with hydronic heating and cooling coils, filters, and economizers serve the credit union's high-ceiling areas on the first floor.

. The rest of the building is served by two and four pipe fan coil units.

Hot water is supplied by an electric boiler located in the basement; chilled water is supply by two chillers located in the roof penthouse. Heat is rejected via a closed loop cooling tower. Most of perimeter fan coil units (McQuay SCB-081A and SCB-121A) have cooling capacity only; interior units have both heating and cooling capacity. Fan coil units shut down at night, but night cycle below 60F. Lack of peripheral heating capacity has led to winter temperature control problems; "temperature control problems and thermostat 'fighting'" result.

Outside air for the areas served by the fan coil units is provided by two makeup air units per floor. These units are electric furnaces which draw in 100% outside air, temper it in winter, and discharge it into a ceiling plenum where it mixes with return air from the space before entering the fan coil unit. A later modification was to connect the makeup units to the peripheral fan coil units, to provide a type of economizer performance. Return air enters the ceiling plenum through the luminaries.

A packaged terminal air-conditioning unit serves the separate drive-up booth with both heating and cooling.

A split system heat pump stands ready 24 hours a day - in the event of outage or overload of the main equipment - to provide cooling for the main computer on the first floor. The outdoor section condenser unit is at the SW corner of the building, shown in one of the photographs,

Building cooling is provided by two Carrier (30HR 100 B600) hermetic reciprocating compression chillers and a Baltimore air coil cooling tower (#VNT-100DA). When sampled, temperatures of the water to the tower were 90.5F in and 87.0F out. The chilled water pump is interlocked with the chillers, and the condenser water pump is interlocked with the cooling tower. Chilled water temperature is monitored by the EMCS.

The primary heat source for the building is an electric boiler (1 126 000 BTUh). Boiler temperature is monitored by the EMCS and is reset based on outside air temperature ("boiler temp reset by O.A. temp to 80F by EMCS"). The heating hot water pump is shut down based on outside air temperature. Additional heating is provided at the electric furnaces in the basement and at the makeup air units above grade.

The building has a pneumatic temperature control system. It was originally equipped with time clocks for the equipment serving the credit union spaces on the first and second floors, and separately for the rest of the tenant spaces; the system provided for temperature setup/setback during unoccupied periods. An Energy Management Control System, installed in 1984, now provides optimum start/stop control for the fan coil units and air-conditioning units (credit union public spaces), night cycle control for the fan coil units when space temperatures drop below 60F, setup/setback of space temperature, chiller start/stop, boiler temperature reset based on outside air temperature, and chilled water temperature control. Due to the schedule of the real estate office on the first floor, the units serving this area have been essentially disconnected from the EMCS and are operated continuously in the day mode (i.e., the fans run continuously).

The building nominal set point temperature of 70F is maintained from 7 a.m. until 7 p.m., Monday through Friday. Each fan coil unit, air-conditioning unit, and furnace has its own thermostat.

During a late-September field audit, temperatures in occupied spaces ranged from 70F to 84F; most of them were 72F to 78F.

The HVAC systems are generally well-maintained including filter replacement, duct and piping insulation, fan belts, and damper controls.

4. **Lighting** - Lighting shown on the building drawings has since been supplemented during build-out to meet tenant requirements. See attached sketches for supplemental information.

Lighting is primarily fluorescent. Basement fixtures are surface mounted, 4-ft, 2-lamp fixtures with prismatic lenses, while the office areas are mainly recessed 2 ft by 4 ft, 2- and 4-lamp fixtures with prismatic lenses and return air vents. The corridors and the high ceiling area on the first floor is lit according to the "base bid" design area using 75-W mercury vapor lamps with recessed fixtures. With the exception of one financial tenant and the owner's second floor offices, which have separate lighting switches for individual office and work areas, the lighting control is in large groups from a single switch.

Outdoor lighting was inventoried as:

Pole lights	qty 17	each 400W	low pressure sodium
Entrance lights	2	30W	
Sign	1	unknown	
Patio lights (3rd Fl)	4	40W	fluorescent

5. **DHW** - Recirculating system, continuously pumped. One electric water heater tank; see connected load sheet. Tank thermostat setting 140 F. No time clock.

6. **Occupancy** - Space allocations (square feet) by occupancy are approximately:

	Bsmnt	Fl 1	Fl 2	Fl 3	Fl 4
Financial #1	4 420	9 810	2 700		
Real estate		1 620			
Financial #2			945		
Law office			635		
Research*					5 910
Vacant			3 260	8 650	2 740
Common**	2 500	2 200	2 160	1 290	1 290
Total	6 920	13 630	9 700	9 940	9 940

* primarily paper studies

** including circulation and utility areas

Quarters are occupied approximately as follows:

		avg:peak employees	avg:peak customers
Financial #1	9am - 6pm M-F	42:50	
public hours	10am - 6pm M-F		2200:2800
Real estate	8am - 6pm * 7day/wk	13:15	12:25
Financial #2	9am - 5:30pm M-F	3:3	100:200
Law office	8:30am - 5pm M-F	4:4	10:20
Research	8am - 5pm M-F	15:20	1:5

* hours a little less on weekends

The basement is used for storage.

Drive-in banking service is provided 9:30 - 5:30 M-F, and 9:30 - 2:00 Sa.

By January 1, 1987, occupancy had reached approximately 90%. The primary increase is attributed to "Research".

7. **Other Loads** - See connected load sheets.

8. **Weather** - See attached

9. **Dates** - The presumed date of the field audit is January 1, 1987. Billing dates for each month are: date read, date billed, date paid.

10. **Drawings** - Drawings for Building #4 were distributed as the initial release of the building description. Some notations are difficult or even impossible to read. The master copy is slightly more legible; therefore if you need to have critical entries confirmed, please call.

APPENDIX E - METERED ELECTRICAL CONSUMPTION DATA

SMALL RETAIL : EUGENE

	YEAR	ANNUAL KWH	JAN	FEB	MAR	APR	MAY	JUN
EWEB	1984	74580	11400	8940	6240	5880	4260	2640
	1985	90720	17340	13260	9000	4800	3000	3060
	1986	75060	11640	10260	5940	6420	4060	3540
	1987	85500	13060	9540	7680	3780	4860	4920
	1988	89580	13020	10920	8160	6180	5460	4620
	*1989	83520	12660	14880	6720	3780	3780	4560
	86-87 AVG	80280	12360	9900	6810	5100	4470	4230
	84-89 MAX	105300	17340	14880	9000	6420	5460	4920
	84-89 MIN	65160	11400	8940	5940	3780	3000	2640
ELCAP	1987	85563	12963	9096	7246	4212	4647	5503
(CREUS)	*1988	128128	13281	9630	9121			

LARGE RETAIL : RICHLAND

	YEAR	ANNUAL KWH	JAN	FEB	MAR	APR	MAY	JUN
CITY OF	1984	1371600	158640	128400	84960	95760	96480	105120
RICHLAND	1985	1186800	121200	135840	82080	66960	66000	84720
	1986	1140720	144240	119280	87120	73680	61440	96240
	1987	1321200	144480	125280	102960	107520	103440	96240
	1988	1245840	123120	120480	96720	79200	78000	90720
	*1989	1306240	121920	153600	87120	76320	89280	102000
	86-87 AVG	1228440	144360	122280	95040	90600	82440	96240
	84-89 MAX	1504080	158640	153600	102960	107520	103440	105120
	84-89 MIN	1074240	121200	119280	82080	66960	61440	84720
ELCAP	1987	1313313	142318	102940	108734	108652	98828	103201
(CREUS)	*1988	1303844	125146	106424	94391			

SMALL OFFICE : EUGENE

	YEAR	ANNUAL KWH	JAN	FEB	MAR	APR	MAY	JUN
EWEB	1984	211800	20640	18360	16920	16920	15120	15360
	1985	210120	25440	21600	18600	13800	14520	15840
	1986	146060	12840	12240	12960	13440	11520	9000
	1987	177280	20040	19560	12720	6720	11800	12360
	1988	196600	23880	17160	17640	15960	13080	14280
	*1989	194160	27480	20400	12840	12960	12360	11040
	86-87 AVG	162680	16440	15900	12840	10080	11660	10680
	84-89 MAX	234600	27480	21600	18600	16920	15120	15840
	84-89 MIN	137520	12840	12240	12720	6720	11520	9000
ELCAP	*1987	156272	20346	17980	14423	7907	11410	12642
(CREUS)	*1988							

LARGE OFFICE : RICHLAND

	YEAR	ANNUAL KWH	JAN	FEB	MAR	APR	MAY	JUN
CITY OF	1984	1597760	203840	170400	135680	121440	113920	108800
RICHLAND	1985	1519680	202400	181440	123520	104000	103520	92320
	1986	1623200	171360	160320	120800	97760	119360	122560
	1987	1767320	189400	183360	136640	146080	136960	126880
	1988	1789120	185120	166400	154880	139200	134080	131680
	*1989	1852320	172320	210560	153120	152960	148960	132480
	86-87 AVG	1695280	180380	171840	128720	121920	128160	124720
	84-89 MAX	1916960	203840	210560	154880	152960	148960	132480
	84-89 MIN	1415040	171360	160320	120800	97760	103520	92320
ELCAP	1987	1766071	199880	154379	149641	139830	137770	129111
(CREUS)	*1988	1965676	164505	156799	155115			

(UTILITY AND ELCAP) APPENDIX E

JUL	AUG	SEP	OCT	NOV	DEC
2940	3720	2640	4140	6100	13680
5040	3480	2520	3540	7920	17760
3840	5460	3360	2760	5520	12240
5880	5160	5520	4140	8220	12720
5880	5700	4920	4200	7860	12660
4740	4560				
4860	5310	4440	3450	6870	12480
5880	5700	5520	4200	8220	17760
2940	3480	2520	2760	5520	12240
5613	5593	5319	3601	7614	13756

JUL	AUG	SEP	OCT	NOV	DEC
130560	139440	133200	82560	92160	124320
105360	120000	94560	70560	79920	159600
93840	99600	97680	80880	82320	104400
103200	95280	152880	95040	85440	109440
118800	128480	116880	98160	89760	107520
115440	128480				
98520	97440	125280	87960	83880	104400
130560	139440	152880	98160	92160	159600
93840	95280	94560	70560	79920	104400
104186	124976	117813	89674	86624	125167

JUL	AUG	SEP	OCT	NOV	DEC
13440	13920	15240	17520	21120	27240
13560	12360	12600	15840	28560	17400
9960	9480	10200	10440	15000	21000
10800	11520	12480	13680	18240	27360
16200	14160	11760	14400	19800	20280
10380	10500	11340	12060	16620	24180
16200	14160	15240	17520	28560	27360
9960	9480	10200	10440	15000	17400
10693	10192	11611			

JUL	AUG	SEP	OCT	NOV	DEC
106960	106480	111040	104320	135040	175840
83920	100480	95520	97920	123360	201280
118560	127200	121600	138720	158560	168400
130560	134880	130720	120640	158560	172640
130560	133440	140160	130240	165600	157760
127520	136960				
124560	131040	126160	129680	158560	169520
130560	136960	140160	138720	165600	201280
83920	100480	95520	97920	123360	157760
132705	134480	123338	140545	158469	185723

APPENDIX F

METERED END-USE ELECTRICAL CONSUMPTION DATA

SMALL RETAIL BUILDING : EUGENE

	END USE DATA	ANNUAL KWH	JAN 87	FEB 87	MAR 87	APR 87	MAY 87
ELCAP	TOTAL 1987	85529	12950	9094	7246	4216	4646
1987-88	Heating	29126	9100	5257	3362	257	139
	Mixed HVAC	19141	1115	891	565	451	1222
	Interior Lighting	33080	2333	2601	2971	3163	2955
	Exterior Lighting	141	28	27	0	0	0
	Water Heating	1508	156	127	123	122	121
	Receptacles	2533	220	191	225	223	209

LARGE RETAIL BUILDING : RICHLAND

	END USE DATA	ANNUAL KWH	JAN 87	FEB 87	MAR 87	APR 87	MAY 87
ELCAP	TOTAL 1987	1313313	142318	102940	108734	108652	96828
1987-88	Interior Lighting	718831	75219	67837	75428	68342	53906
	Mixed HVAC	502795	58409	27691	25469	33139	37517
	General Mixed	91687	8690	7412	7837	7171	7405

SMALL OFFICE BUILDING : EUGENE

	END USE DATA	ANNUAL KWH	JAN 87	FEB 87	MAR 87	APR 87	MAY 87
ELCAP	TOTAL (9 months)	117192	20325	17989	14409	7906	11410
1987	Heating	22054	6694	4639	5796	2048	1095
	Mixed HVAC	47763	6694	7893	4284	1834	4199
	Ventilation	1251	0	54	0	8	183
	Interior Lighting	23651	1729	1115	1889	2910	3994
	Exterior Lighting	3025	488	378	361	285	262
	Other (sum)	19448	4720	3920	2077	823	1677
	Water Heating	2353	183	162	216	198	217
	Other	17095	4537	3758	1861	625	1460

LARGE OFFICE BUILDING : RICHLAND

	END USE DATA	ANNUAL KWH	JAN 87	FEB 87	MAR 87	APR 87	MAY 87
ELCAP	TOTAL 1987	1786071	199680	154379	149841	139830	137770
1987-88	Heating	465660	103035	68074	46197	30933	20666
	Cooling	270770	10184	11424	16799	23375	29207
	Auxiliaries	362730	27156	23620	27448	29534	31963
	Ventilation	5046	599	309	450	420	413
	Interior Lighting	388273	31949	29332	33148	30793	32376
	Other (sum)	293592	26957	23620	25799	24775	23145
	Specialty 1	27226	2396	2007	2400	2240	2342
	Other	266366	24561	21613	23399	22535	20803

(ELCAP)

JUN 87	JUL 87	AUG 87	SEP 87	OCT 87	NOV 87	DEC 87	JAN 88	FEB 88	MAR 88
5505	5808	5599	5292	3596	7822	13755	13281	9630	9121
17	1064	1214	1250	241	2782	4443	3971	3258	3183
2273	1471	1499	1048	367	2008	6231	6898	3576	3019
2895	2930	2573	2875	2661	2751	2572	2263	2381	2536
0	0	0	0	0	47	41	27	29	18
116	122	117	133	122	125	124	122	145	119
204	221	196	186	205	109	344	0	241	246

JUN 87	JUL 87	AUG 87	SEP 87	OCT 87	NOV 87	DEC 87	JAN 88	FEB 88	MAR 88
103201	104186	124976	117813	89874	86624	125167	125146	106424	94391
51239	50530	61174	64797	50329	48336	51694	52489	47406	49227
44008	44696	56546	46536	31636	31185	65963	63888	50496	37605
7954	8960	7256	6480	7909	7103	7510	8769	8522	7559

JUN 87	JUL 87	AUG 87	SEP 87	OCT 87	NOV 87	DEC 87	JAN 88	FEB 88	MAR 88
12941	10665	10192	11623						
632	0	428	720						
6207	6589	5196	4865						
88	310	306	302						
3729	1925	2691	3669						
228	385	336	302						
1757	1476	1233	1765						
215	770	183	209						
1542	706	1050	1556						

JUN 87	JUL 87	AUG 87	SEP 87	OCT 87	NOV 87	DEC 87	JAN 88	FEB 88	MAR 88
129111	132705	134480	123338	140545	158469	185723	184505	156799	155115
8909	7173	6724	4805	32076	54092	84976	84688	58231	47000
30341	36132	36175	29079	20822	16856	10576	9225	10630	13860
31503	34405	34158	31913	31654	29505	29871	29521	29665	31333
387	399	403	370	422	317	557	369	314	310
33440	32545	33486	33514	32358	32877	32855	32857	31705	35211
24631	22051	23534	23657	23213	25222	27068	28045	26054	27301
2195	2258	2286	2218	2251	2221	2412	2399	2197	2327
22336	19793	21248	21439	20962	23001	24676	25646	23857	24974

Heat strips
Heat pump
Interior lighting
Exterior lighting
Water heating
Receptacles

Interior lighting
Heating/cooling units and fans
Exterior lighting, receptacles, garbage compactor

Heating - heat strips
Mixed HVAC [cooling]
Ventilation - air handler
Interior Lighting
Exterior Lighting
Other - Water Heating + Sanitation + General Mixed + Specialty
(...including plug lights, receptacles, copier machine)

Heating - heat units, ceiling heaters, boiler
Cooling - A/C units
Auxiliaries - cooling tower fans, chillers
Ventilation - air handlers
Interior Lighting
Other, including:
emergency battery
exterior lighting, water heating, receptacles,
elevators, and data processing/computers

APPENDIX F

EVALUATION OF SOFTWARE PROJECT

SUMMARY OF INPUT DATA
COMPARATIVE SIMULATION STUDIES

SMALL RETAIL: EUGENE

SOFTWARE	MODELER	SIMULATED ENERGY base bldg annual kWh cycle 1	cycle 2	cycle 3		WEATHER FILE location cycle 1	cycle 2	source cycle 1,2	ZONES # of zones cycle 1	cycle 2
ELCAP 1987				85563						
ADM2	A *	89236	71998	82953			Salem	supplier		2
SEA	B	107105	76700	88954			Portland	supplier		2
	J	71883	84591	81249			Eugene	supplier		3
TRAKLOAD	D	68179	85803	85500			Eugene	supplier		2
	E	91588	83333	93999			Eugene	supplier		2
VCACS	D	87594	85136	85500			Portland	supplier		2
	K	98620	82409	84153			Eugene	supplier		3
DOE 2.1	F	126277	90622	81097			Salem			2
ASEAM-2.1	(n.i.o.)			88084	(Run #11)					1

* added for sensitivity study

LARGE RETAIL: RICHLAND

SOFTWARE	MODELER	SIMULATED ENERGY base bldg annual kWh cycle 1	cycle 2	cycle 3	WEATHER FILE location cycle 1	cycle 2	source cycle 1,2	ZONES # of zones cycle 1	cycle 2
ELCAP 1987				1313313					
ADM2	A	1506399	1442557	1388126		Richland	supplier		4
	H	1080448	1266240	1266239		Richland	supplier		2
SEA	C	1369550	1288088	1288089	Moses Lake	Pendleton	b)		4
	J	2334861	1323009	1442372	Spokane	Walla Walla	supplier		7
TRAKLOAD	E	1084561	1084562	1184966		Walla Walla	q)		5
VCACS	none								
DOE 2.1	F	1529639	1227976	1219656	Yakima	Hanford	TRY		3
ASEAM-2.1	(n.i.o.)								

SMALL OFFICE: EUGENE

SOFTWARE	MODELER	SIMULATED ENERGY base bldg annual kWh cycle 1	cycle 2	cycle 3	WEATHER FILE location cycle 1	cycle 2	source cycle 1,2	ZONES # of zones cycle 1	cycle 2
UTILITY 1987			177280						
ADM2	H	174243	173454	173454		Richland	supplier		1
SEA	B	225545	160765	160765		Portland	supplier		2
	G	128801	185769	185769		Eugene	a)		2
TRAKLOAD	D	208672	142805	142000		Portland	supplier		3
	I	209695	170257	197161		Eugene	supplier		c) 4
VCACS	none								
DOE 2.1	F	116741	168278	145016		Salem		2	5
ASEAM-2.1	(n.i.o.)								

LARGE RETAIL: RICHLAND

SOFTWARE	MODELER	SIMULATED ENERGY base bldg annual kWh cycle 1	cycle 2	cycle 3	WEATHER FILE location cycle 1	cycle 2	source cycle 1,2	ZONES # of zones cycle 1	cycle 2
ELCAP 1987				1766071					
ADM2	A	2126476	2157149	1761791		Richland	supplier		8
SEA	A	969483	766720	1776891		Spokane	supplier		8
TRAKLOAD	I	1670195	1732105	1755029		Pendleton			5
VCACS	D	1069262	1764319	1764320		Pendleton	supplier		6
	K	647906	1722237	1759874		Richland	b)		6
DOE 2.1	F	966363	1692104	1497993	Yakima	Hanford	TRY		27
ASEAM-2.1	(n.i.o.)								

FLOOR conditioned sqft cycle 1	FLOOR conditioned sqft cycle 2	FLOOR loss type cycle 1,2	FLOOR loss Btu/hF cycle 1	FLOOR loss Btu/hF cycle 2	ROOF roof/attic R cycle 1	ROOF roof/attic R cycle 2	N walls sqft cycle 1	N walls sqft cycle 2	E walls sqft cycle 1	E walls sqft cycle 2
	5305	area		163		12.00		800	700	0
	5305	perim		8		12.00		800	700	0
	5339	perim		400		11.57		860	0	770
4680	5080	area		104	12.50	14.90	1017	578		0
	5330	area		179		11.63		1032		0
	5082	area				11.00	895	578	769	0
	5320	area				9.00		793		16
	5089	g) area		611	6.17	11.76		790		36
	5088			0		12.50		800		35

FLOOR conditioned sqft cycle 1	FLOOR conditioned sqft cycle 2	FLOOR loss type cycle 1,2	FLOOR loss Btu/hF cycle 1	FLOOR loss Btu/hF cycle 2	ROOF roof/attic R cycle 1	ROOF roof/attic R cycle 2	N walls sqft cycle 1	N walls sqft cycle 2	E walls sqft cycle 1	E walls sqft cycle 2
	69976	area	9171	1878	14.75	16.57		5287		6595
	69985	area		24		15.60		5201		8800
	69290	perim		744		20.00		2156		4574
	70755	perim		28	4.71	15.87		3823		6145
	63350	area		703		18.52		6179		6817
	72100	g) area	16230	834		16.13		5617		6960

FLOOR conditioned sqft cycle 1	FLOOR conditioned sqft cycle 2	FLOOR loss type cycle 1,2	FLOOR loss Btu/hF cycle 1	FLOOR loss Btu/hF cycle 2	ROOF roof/attic R cycle 1	ROOF roof/attic R cycle 2	N walls sqft cycle 1	N walls sqft cycle 2	E walls sqft cycle 1	E walls sqft cycle 2
	6336	area		24		16.00		976		913
	6263	perim		181		16.10		1433		843
	6121	perim		5080		18.18		1232		640
	6380	area		35		17.90		1600		1770
	6370	area		25		27.00		1239		
6500	7020	g) area		48		16.95	1272	1024	704	864

FLOOR conditioned sqft cycle 1	FLOOR conditioned sqft cycle 2	FLOOR loss type cycle 1,2	FLOOR loss Btu/hF cycle 1	FLOOR loss Btu/hF cycle 2	ROOF roof/attic R cycle 1	ROOF roof/attic R cycle 2	N walls sqft cycle 1	N walls sqft cycle 2	E walls sqft cycle 1	E walls sqft cycle 2
	53297	area		1780		8.60		5198		5517
	53297	area		100		8.60		5198		5517
	57680	area		28		10.00		2252		2792
	61091	area		0		11.00		2034		1981
	52630	area		0		13.00		4948		2552
57800	l) 47800	g) area		l) 2064		10.20		3320		3960

WALLS (GROSS)							WINDOWS			
S walls sqft		W walls sqft		exterior wall R		partition	window sqft		window U	window SC.
cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1,2	cycle 1,2
	940		702		1.40	yes	91	350	1.10	0.90
	940		702		1.39	yes	91	350	1.10	0.50
	948		661		2.57	no		245	1.23	0.50
928	884	266	620	3.88	2.00	no	347	348	1.10	0.95
	960		924	1.86	2.50	no		322	0.87	0.75
644	884	994	578		2.00	no		285	1.02	0.93
	940		724		1.00	no		246	1.02	0.93
	873		720		1.86	no		362	1.02	0.94
	928		718	2.65	1.81	no		352	1.04	0.94

WALLS (GROSS)							WINDOWS			
S walls sqft		W walls sqft		exterior wall R		partition	window sqft		window U	window SC.
cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1,2	cycle 1,2
	5184		3187	2.60	2.30	yes		778	0.50	0.94
	5592		4228		2.40	yes		386	0.95	1.00
	5203		2620		1.51	no		982	0.54	0.58
	4893		3015	1.32	1.50	no		387	1.20	0.80
	5359		2547		1.49	no		784	1.10	0.95
	4737		3250		3.28	yes	4568	1200	1.02	0.94

WALLS (GROSS)							WINDOWS			
S walls sqft		W walls sqft		exterior wall R		partition	window sqft		window U	window SC.
cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1,2	cycle 1,2
	1970		874		14.00	no		785	0.95	1.00
	1117		849		14.90	yes	32	453	1.10	0.80
	1024		672		15.00	yes		498	1.10	0.30
	1540		1770	14.00	15.60			560	1.10	0.95
	1466		794		14.90	no		507	0.85	0.82
	1232	272	864	15.63	9.01	yes		430	1.02	0.64

WALLS (GROSS)							WINDOWS			
S walls sqft		W walls sqft		exterior wall R		partition	window sqft		window U	window SC.
cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1,2	cycle 1,2
	4729		5708		14.20	yes		10264	0.50	0.36
	4729		5708		14.08	yes		10264	0.50	0.36
	2252		2792		13.00	no		10088	0.53	0.83
	2247		2122		11.00			10334	0.65	0.75
	2225		2546		12.00	no		10942	0.65	0.75
	3200		3980		4.02	yes		11760	0.59	0.62

EVALUATION OF SOFTWARE PROJECT

SUMMARY OF INPUT DATA
COMPARATIVE SIMULATION STUDIES

SMALL RETAIL: EUGENE

SOFTWARE	MODELER	PEAK LIGHTING CHARACTERISTICS interior kW cycle 1	interior kW cycle 2	exterior kW cycle 1,2	OCCUPANCY max people cycle 1	max people cycle 2	WATER HEATING gallons cycle 1,2	Temp F cycle 1,2	gal/day cycle 1
ADM2	A *		8.84	0.30		21	40	120	
SEA	B	0.09	s) 8.83	na		21	r)	r)	
	J		7.22	na		22	r)	r)	
TRAKLOAD	D	7.98	7.98	0.30		21	40	120	30
	E		7.85	0.60		21	30	125	
VCACS	D	8.27	8.34	1.00		23	40	120	
	K		8.12	0.50		21	40	120	
DOE 2.1	F		7.86	0.30		21	e)		
ASEAM-2.1	(n.i.c.)	8.94	7.74	0.00		18	e)	120	

* added for sensitivity study

LARGE RETAIL: RICHLAND

SOFTWARE	MODELER	PEAK LIGHTING CHARACTERISTICS interior kW cycle 1	interior kW cycle 2	exterior kW cycle 1,2	OCCUPANCY max people cycle 1	max people cycle 2	WATER HEATING gallons cycle 1,2	Temp F cycle 1,2	gal/day cycle 1
ADM2	A	157.62	151.32	8.00	237	226	105	140	168
	H		238.82	7.95		108	100	140	
SEA	C		d) 86.02			p) 250			
	J		d) 110.57			569			
TRAKLOAD	E	d) 123.97	d) 134.39	3.00		205	104	140	
VCACS	none								
DOE 2.1	F		d) 131.34	3.60	2145	255	205		
ASEAM-2.1	(n.i.c.)								

SMALL OFFICE: EUGENE

SOFTWARE	MODELER	PEAK LIGHTING CHARACTERISTICS interior kW cycle 1	interior kW cycle 2	exterior kW cycle 1,2	OCCUPANCY max people cycle 1	max people cycle 2	WATER HEATING gallons cycle 1,2	Temp F cycle 1,2	gal/day cycle 1
ADM2	H		12.80	0.90		34	52	150	
SEA	B		11.00			36			
	G		12.50	na		34			
TRAKLOAD	D	8.99	8.99			34			
	I		13.20			34	52	150	
VCACS	none								
DOE 2.1	F		11.96	0.71		32			
ASEAM-2.1	(n.i.c.)								

LARGE OFFICE: RICHLAND

SOFTWARE	MODELER	PEAK LIGHTING CHARACTERISTICS interior kW cycle 1	interior kW cycle 2	exterior kW cycle 1,2	OCCUPANCY max people cycle 1	max people cycle 2	WATER HEATING gallons cycle 1,2	Temp F cycle 1,2	gal/day cycle 1
ADM2	A		123.02	8.62		180	125	140	
SEA	A		123.02	8.62	640	180			
TRAKLOAD	I	69.90	76.50			1800	142	140	
VCACS	D	73.00	69.71	8.00		483	140	140	
	K		108.23	4.00	179	249	120	12684	
DOE 2.1	F	97.89	97.93	10.00	119	139		(120)	
ASEAM-2.1	(n.i.c.)								

	OTHER INTERNAL LOADS max kW		SETPOINTS F heating		setback		cooling		setup	
cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2
20		1.50	71	72	60	55	78	75		80
n) 112		1.50		72	60	55	78	75		r)
n)		9.50		72		55	78	74		r)
20	0.10	0.89		70		61		75		r)
15		8.00		69		62		72		
20		h) 2.00		70		65		75		85
40		1.60		72		62		76		80
e) 112		0.60	72	70	64	60		74		90
20		1.50		70		60	78	76		-

	OTHER INTERNAL LOADS max kW		SETPOINTS F heating		setback		cooling		setup	
cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2
119		6.00	65	68		45	75	76		100
65		16.00	65	71	65	71		78		76
		l) 50.00	65	63	50	45		75		
		10.00		68	60	55		75		
52		15.84		65		60		75		80
847		13.48		65		60		75		90

	OTHER INTERNAL LOADS max kW		SETPOINTS F heating		setback		cooling		setup	
cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2
90		19.00	70	74	70	74	72	76		76
	18.80	25.00	74	72		60	74	75		
	13.60	16.50		74		74		74		
	33.10	16.40	74	74	69	59	74	74		89
10	17.80	11.60	74	76	69	70	74	77		83
51	5.20	5.04		72	62	68		74	90	80

	OTHER INTERNAL LOADS max kW		SETPOINTS F heating		setback		cooling		setup	
cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1	cycle 2
74		32.00		70		60		74		84
28		32.00		70		60		74		
2200	64.70	14.40	70	78	60	73	70	78		83
165	97.00	78.00	70	72		60	70	75		65
m) 392	25.40	41.00		70	60	70		72	90	72

AIR DISTRIBUTION CFM

supply v)		night fans w)	outside air v)		infiltration w)		economizer
cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2
6400	e) 6641	cycling	1320	584	914	183	no
6400	e) 6641		k)	583	k) 914	183	no
	3933	cycling		393		528	
10000	10000		1000	1200			no
	7500			395			no
	10000	auto	1000	1300		877	no
	8000	not auto		800		224	no
e) 5950	e) 4630		595	463		315	no
	e)	cycling		10%		254	no

AIR DISTRIBUTION CFM

supply v)		night fans w)	outside air v)		infiltration w)		economizer
cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2
74300	68900	cycling	3115	2905		1394	no
	49900	cycling		3493		0	no
71678	70298	cycling	6727	6638	8877	8897	no
98252	77454	cycling	9825	0	5339	2617	no
	59200			3105			no
88050	52237	cycling	4009	2386		2738	no

AIR DISTRIBUTION CFM

supply v)		night fans w)	outside air v)		infiltration w)		economizer
cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2
	4600	on	336	980	0	100	no
	7669			669	167	835	no
681	9468			1019	0	1020	no
	7200			1440			no
	6900			690			
	5610	cycle/on	1122	1170	550	558	no

AIR DISTRIBUTION CFM

supply v)		night fans w)	outside air v)		infiltration w)		economizer
cycle 1	cycle 2	cycle 1,2	cycle 1	cycle 2	cycle 1	cycle 2	cycle 1,2
	57917	cycling		9105		765	yes
	22970			2756			
	129323			12932		8145	yes
	61850			15400			
45610	71520	on/cycling	4258	10458			no

SUMMARY OF INPUT DATA
COMPARATIVE SIMULATION STUDIES

SMALL RETAIL: EUGENE

SOFTWARE	MODELER	SYSTEM/PLANT TYPES distribution cycle 1,2	heat cycle 1,2	cool cycle 1,2	HEATING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2
ADM2	A *	pkg single zone	electric res	DX		123000		1.00
SEA	B	pkg term sys	electric res	DX	c) 243688	a) 202050		1.00
	J	central	electric res	chiller				1.00
TRAKLOAD	D	central/rooftop	electric res	DX air cool		500000		1.00
	E	central/rooftop	electric res	DX air cool		198000		1.00
VCACS	D	rooftop pkg	rooftop/elec	rooftop/elec		501711	1.00	0.95
	K	rooftop pkg	rooftop/elec	rooftop/elec	258000	210000	1.00	1.00
DOE 2.1	F	pkg single zone	electric res	DX	e) 380810	e) 290533		f) 1.00
ASEAM-2.1	(n.i.c.)	single zn reheat	electric res	DX		e)		1.00

* added for sensitivity study

LARGE RETAIL: RICHLAND

SOFTWARE	MODELER	SYSTEM/PLANT TYPES distribution cycle 1,2	heat cycle 1,2	cool cycle 1,2	HEATING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2
ADM2	A	pkg single zone	electric res	DX		1874600	0.99	1.00
	H	pkg single zone	electric res	DX air		1670000		1.00
SEA	C	pkg terminal	electric res	?	e) 1450100	e) 1279500		(1.00)
	J	central AH/const	electric res	chiller				1.00
TRAKLOAD	E	central/roof top	electric res	DX air cool		1516000		
VCACS	none							
DOE 2.1	F	pkg single zone	electric res	(DX)	e) 5253157	e) 3082619		g) 1.00
ASEAM-2.1	(n.i.c.)							

SMALL OFFICE: EUGENE

SOFTWARE	MODELER	SYSTEM/PLANT TYPES distribution cycle 1,2	heat cycle 1,2	cool cycle 1,2	HEATING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2
ADM2	H	pkg single zone	electric res	DX		102360	2.70	1.00
SEA	B	pkg term sys-dx	elec. res	dx				na
	G	pkg terml sys-DX	electric res	DX				
TRAKLOAD	D	central	electric res		234000	202000		
	I	central	electric res	DX		238000		
VCACS	none							
DOE 2.1	F	pkg single zone	electric res	(DX)	e) 349011	e) 352364		f) 1.00
ASEAM-2.1	(n.i.c.)							

LARGE OFFICE: RICHLAND

SOFTWARE	MODELER	SYSTEM/PLANT TYPES distribution cycle 1,2	heat cycle 1,2	cool cycle 1,2	HEATING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2
ADM2	A	air,water 2-pipe	electric	chiller,twr		1943487		
SEA	A	air,water 4-pipe	electric	chillers,twr		637207		1.00
TRAKLOAD	I							
VCACS	D				1676670	614200		
	K							
DOE 2.1	F	2&4-pipe;unitary	elec boilr,+	chillers,twr	e) 1791000	e) 1527000		(1.00)
ASEAM-2.1	(n.i.c.)							

COOLING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2	OTHER CHANGES in Input Data during cycle 2	OTHER CHANGES in Input Data during cycle 3
	192000		1.90		see note t)
o) 49468	e) 68601		1.90		see note u)
120000	180000		2.80		
	180000		2.20		
	139200		2.20		
	204000		2.50		
	192000		2.30		
e) 163258	e) 129213	2.05	1.75		
	e)		2.40		

COOLING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2	OTHER CHANGES in Input Data during cycle 2	OTHER CHANGES in Input Data during cycle 3
	2152000		2.30	reduced lighting hours	
	1860000		2.70		
e) 529684	e) 641456	2.30	1.91		
e) 2496000	e) 1980000		2.80		
	1165200				
e) 2267946	e) 1223420		2.22		

COOLING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2	OTHER CHANGES in Input Data during cycle 2	OTHER CHANGES in Input Data during cycle 3
	100000	2.70	3.00		
			1.90		
186000	168000				
	180000				
e) 182969	e) 161558		2.05		

COOLING PLANT capacity: BTU/h cycle 1	cycle 2	COP cycle 1	cycle 2	OTHER CHANGES in Input Data during cycle 2	OTHER CHANGES in Input Data during cycle 3
	2400000		3.90		
444000	780000				
e) 478000	e) 677000	3.70	3.00		

NOTES

Cycle 1 data same as Cycle 2 except as noted

Missing entries may not have been reported
or readily determinable. Imputed values in parentheses

a) Subcontractor; Air Force bin data
b) Supplier's Yakima file, adjusted for Richland
c) 4 zones total in two "building" models
d) includes usage factor
e) autosized

f) DOE 2.1 shows EIR of .37 (COP=2.7) but uses 1.00
g) area of a perimeter strip or reduced area
h) cycle 1 gas load included
i) external gas incinerator also simulated,
but excluded from tabulations
j) including opaque frames, etc.

k) perhaps annotate constant values, such as % outside air
l) basement area reduction did not achieve
intended reduction in simulated heat loss
m) reverse computation based on 65F rise
n) included in Other Internal Loads
o) peak demand calculation; autosized

p) program does not simulate water heating
q) BPA/OSU bin weather data, using Weathermaker
r) not specified in this software
s) Cycle 3 result
t) continuous heat/cool availability

u) lights use: 95% was 0.95% (corrected)
v) occupied
w) unoccupied

Care was taken to tabulate representative values, but
there may be errors in interpretation and transcription.

SIMULATED MONTHLY ENERGY CONSUMPTION

SMALL RETAIL : EUGENE

MODELER		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
	EWEB 1987	85500	13080	9540	7680	3780	4860
	Cycle 1						
A	ADM2	89236	10501	8812	9235	7580	6158
B	SEA	107105	18115	13753	13443	8898	5938
J	SEA	71683	10365	7622	7287	5716	4632
D	TRAKLOAD	66179	8148	6008	6008	4998	4868
E	TRAKLOAD	91588	11724	8775	8983	7141	6282
D	VCACS	87594	13825	8793	8733	7197	6496
K	VCACS	98620	13325	9833	9878	8272	7561
F	DOE 2.1	128277	17810	14807	14278	10932	7928
	Max by month	128787	18115	14807	14278	10932	7928
	Min by month	58977	8148	6008	6008	4998	4632
	Cycle 2						
A	ADM2	71989	7776	6307	6440	5531	5294
B	SEA	76700	13136	9555	9072	5980	4077
J	SEA	84591	12087	8897	8501	6669	5439
D	TRAKLOAD	85801	11313	8275	8288	6247	5625
E	TRAKLOAD	83332	10173	7683	7922	6513	5903
D	VCACS	85133	11324	8070	8378	7361	6786
K	VCACS	82406	13049	10230	7920	5100	4469
F	DOE 2.1	90822	13072	10823	10229	6936	5181
	Max by month	99233	13136	10823	10229	7361	6786
	Min by month	56676	7776	6307	6440	5100	4077

LARGE RETAIL : RICHLAND

MODELER		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
	RICHLAND 1987	1321200	144480	125280	102960	107520	103440
	Cycle 1						
A	ADM2	1506401	130650	112003	114848	111921	121501
H	ADM2	1080448	108749	81652	71378	68323	78954
C	SEA	1369550	180645	136105	119581	87718	86280
J	SEA	2334861	317068	231055	221996	159823	143364
E	TRAKLOAD	1084561	122261	89277	87556	77535	80213
F	DOE 2.1	1529639	192472	142176	125888	105694	104551
	Max by month	2334861	317068	231055	221996	159823	143364
	Min by month	1029610	108749	81652	71378	68323	78954
	Cycle 2						
A	ADM2	1442555	116688	101429	113116	111230	119889
H	ADM2	1266240	131865	108014	93922	90054	92273
C	SEA	1288088	151125	112077	108019	88169	90284
J	SEA	1323009	145165	112221	113686	103004	100451
E	TRAKLOAD	1184965	127937	95095	94832	85854	90023
F	DOE 2.1	1227975	134307	95722	94553	87041	91867
	Max by month	1520631	151125	112221	113686	111230	119889
	Min by month	1165994	116688	95095	93922	85854	90023

CYCLES 1 AND 2

JUN	JUL	AUG	SEP	OCT	NOV	DEC
4920	5880	5160	5520	4140	8220	12720
5444	5415	5371	5470	6844	8217	10389
3388	2251	2185	3251	6886	12771	16214
3517	3943	3556	3891	5132	6934	9288
4699	5278	5163	4903	5078	6000	7032
5482	5886	5801	5823	6930	8713	10048
5287	4829	4358	3942	5186	7412	11556
5475	5761	5495	5276	6990	8837	11917
5204	4924	4904	5755	9636	13229	16870
5482	5886	5801	5823	9636	13229	16870
3388	2251	2185	3251	5078	6000	7032
5280	5670	5561	5409	5406	5806	7521
2718	2458	2284	2762	4665	8682	11331
4221	4811	4344	4686	5994	8069	10853
5139	5623	5670	5411	6157	8103	9750
5303	5741	5663	5592	6384	7699	8756
5689	5628	5164	4525	5278	7285	9867
4230	4860	5310	4440	3450	6870	12480
4036	4501	4429	4000	6172	9260	12183
5689	5623	5670	5592	6384	9260	12480
2718	2458	2284	2762	3450	5806	7521

JUN	JUL	AUG	SEP	OCT	NOV	DEC
96240	103200	96280	152880	95040	85440	109440
127256	148483	147007	125039	119252	111047	137394
89389	106915	104062	83754	75605	85698	125969
88175	100058	96345	85299	92575	129075	167494
139213	157919	153773	137038	157685	223607	292340
84256	95461	91983	81189	79522	88726	106562
112823	142284	143442	112764	97562	94810	155393
139213	157919	153773	137038	157685	223607	292340
84256	95461	91983	81189	75605	85698	106562
125360	145739	143007	121732	115730	105647	122988
94430	105865	103745	93186	94337	109481	149048
94879	109695	106041	92192	89368	111864	134195
97682	109451	99810	100418	106040	104169	130932
94879	106275	102777	91281	88621	95456	112155
97640	114238	111197	94336	89633	92270	124971
125360	145739	143007	121732	115730	111864	149048
94430	105865	99810	91281	88621	92270	112155

SIMULATED MONTHLY ENERGY CONSUMPTION

SMALL OFFICE : EUGENE

MODELER		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
	EWEB 1987	177280	20040	19560	12720	6720	11800
	Cycle 1						
H	ADM2	174243	17940	14797	13982	12923	12889
B	SEA	225545	21121	17937	19511	18709	18432
G	SEA	128801	11939	10114	11025	10564	10529
D	TRAKLOAD	208672	17384	15352	16972	16852	17752
I	TRAKLOAD	209695	18501	16075	17755	16853	17301
F	DOE 2.1	116741	12806	10185	10348	8987	8343
	Max by month	227270	21121	17937	19511	18709	18432
	Min by month	114994	11939	10114	10348	8987	8343
	Cycle 2						
H	ADM2	173445	25412	21530	21493	20283	7477
B	SEA	160765	16146	13475	14460	13294	12691
G	SEA	185767	19921	16347	17639	15610	14500
D	TRAKLOAD	142605	13123	10857	11791	11333	11714
I	TRAKLOAD	170257	15631	13517	14600	13823	13907
F	DOE 2.1	166277	19295	16041	16429	13357	11490
	Max by month	209750	25412	21530	21493	20283	14500
	Min by month	124099	13123	10857	11791	11333	7477

LARGE OFFICE : RICHLAND

MODELER		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
	RICHLAND 1987	1767320	189400	183360	136640	146080	136960
	Cycle 1						
A	ADM2	2125422	356451	291161	269491	243221	32651
B	SEA	989483	95743	76140	79644	72667	75743
I	TRAKLOAD	1670195	125387	122869	139515	140269	147210
D	VCACS	1089262	123300	88607	82920	77508	82166
K	VCACS	647906	76123	58540	58071	51733	49618
F	DOE 2.1	986363	140263	95337	87283	67257	59056
	Max by month	2730676	356451	291161	269491	243221	147210
	Min by month	606156	76123	58540	58071	51733	32651
	Cycle 2						
A	ADM2	2187102	274361	198051	174111	159421	151371
B	SEA	766717	88069	64500	64341	54147	54817
I	TRAKLOAD	1732105	138765	124005	138033	139310	150125
D	VCACS	1764319	185120	168400	154880	146080	136960
K	VCACS	1722237	187260	174880	145760	121920	126160
F	DOE 2.1	1692104	203994	152345	150641	129293	120972
	Max by month	2287451	274361	198051	174111	159421	151371
	Min by month	766717	88069	64500	64341	54147	54817

CYCLES 1 AND 2

JUN	JUL	AUG	SEP	OCT	NOV	DEC
12360	10800	11520	12480	13680	18240	27360
12446	14463	13889	12307	14211	15410	19186
17422	19132	17398	18104	19231	17881	20667
10088	10789	10727	10184	10655	10871	11316
17657	19071	18888	17868	17613	16371	16892
17042	18483	18373	17259	17301	16956	17798
8365	9471	9401	8322	8581	9807	12125
17657	19132	18888	18104	19231	17881	20667
8365	9471	9401	8322	8581	9807	11316
9979	12136	11473	9355	8495	7655	18157
11753	12867	11728	12256	13291	13318	15484
12828	12574	12574	12870	15428	17159	18521
11586	12848	12496	11812	11747	11419	12060
13319	14170	14094	13504	14076	14191	15025
10300	11066	10688	10632	12533	15386	18860
13319	14170	14094	13504	15428	17159	18860
9979	11066	10688	9355	8495	7655	12060

JUN	JUL	AUG	SEP	OCT	NOV	DEC
126880	130560	134880	130720	120640	158560	172840
46681	68031	64411	40571	28401	296231	390121
77284	89050	82421	77227	75751	75749	92084
145607	151529	151082	143414	145158	130522	127833
93176	107284	98781	61686	66878	63612	106164
47750	53025	54907	45608	45080	45558	61895
58674	64156	62774	57457	72566	94074	129466
145607	151529	151082	143414	145158	296231	390121
46681	53025	54907	40571	28401	45558	61895
128521	127411	129131	138591	176491	202131	327511
56336	67083	61001	56282	56160	61968	82033
152032	161517	160401	150053	144809	134852	138203
126880	130560	134880	130719	120640	158560	172840
124720	124559	131040	126160	128679	156560	168619
111741	121275	121078	113423	129627	147709	190006
152032	161517	160401	150053	176491	202131	327511
56336	67083	61001	56282	56160	61968	82033

END USE DATA COMPARISONS: SMALL RETAIL BUILDING : EUGENE CYCLE

		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
ADM2	TOTAL	82953	9717	7924	7831	6191	5664
Cycle 3	Heating	33176	6391	4912	4422	2579	1300
Modeler A	Mixed HVAC	18122	637	584	720	1011	1675
*	Interior Lighting	25784	2190	1978	2190	2119	2190
	Exterior Lighting	2400	204	184	204	197	204
	Water Heating	1813	154	139	154	149	154
	Receptacles	1658	141	127	141	136	141
* = added for sensitivity study							
SEA	TOTAL	88953	13240	9742	9358	6720	5335
Cycle 3	Heating	44060	9653	6512	5884	3201	1611
Modeler B	Mixed HVAC	12182	820	684	724	759	947
	Interior Lighting	28089	2377	2188	2379	2371	2386
	Exterior Lighting	0					
	Water Heating	0					
	Receptacles	4602	390	358	391	389	391
SEA	TOTAL	81248	10787	7818	7429	6055	5480
Cycle 3	Heating	28170	6711	4211	3479	1985	909
Modeler J	Mixed HVAC	16527	946	795	872	1038	1440
	Interior Lighting	34873	2965	2682	2937	2891	2988
	Exterior Lighting	0					
	Water Heating	0					
	Receptacles	1678	145	130	141	141	143
TRAKLOAD	TOTAL	85500	11275	8246	8259	6226	5605
Cycle 3	Heating	39274	8187	5420	5040	2702	1562
Modeler D	Mixed HVAC	10887	94	133	201	589	1025
	Interior Lighting	29836	2527	2273	2548	2479	2548
	Exterior Lighting	0	0	0	0	0	0
	Water Heating	2460	209	188	210	203	210
	Receptacles	3043	258	232	260	253	260
TRAKLOAD	TOTAL	94003	11788	8855	9097	7339	6537
Cycle 3	Heating	38185	7821	5207	4939	2939	1684
Modeler E	Mixed HVAC	20357	953	952	1143	1475	1836
	Interior Lighting	30874	2624	2347	2625	2547	2626
	Exterior Lighting	0					
	Water Heating	1874	159	143	159	154	160
	Receptacles	2713	231	206	231	224	231
VCACS	TOTAL	85462	13078	9538	7677	3778	4857
Cycle 3	Heating	34421	8706	5498	4167	1688	1677
Modeler D	Mixed HVAC	8923	119	76	171	234	502
	Interior Lighting	31781	3209	2991	2519	1401	2021
	Exterior Lighting	0					
	Water Heating	1573	159	148	125	69	100
	Receptacles	8764	885	825	695	386	557
VCACS	TOTAL	84120	11045	8132	7972	6547	6230
Cycle 3	Heating	31104	6992	4484	3910	2484	1849
Modeler K	Mixed HVAC	15392	858	761	867	970	1186
	Interior Lighting	33346	2832	2558	2832	2741	2832
	Exterior Lighting	0					
	Water Heating	1544	131	119	131	127	131
	Receptacles	2734	232	210	232	225	232
DOE 2.1	TOTAL	81097	12168	9318	7918	5703	4573
Cycle 3	Heating	34359	8304	5788	3976	2052	997
Modeler F	Mixed HVAC	16447	1265	1208	1364	1086	1001
	Interior Lighting	26176	2251	1997	2231	2223	2227
	Exterior Lighting	0					
	Water Heating	1524	127	127	127	127	127
	Receptacles	2591	221	198	220	215	221

JUN	JUL	AUG	SEP	OCT	NOV	DEC	
5637	6096	5945	5713	5753	7154	9328	TOTAL ADM2
467	126	158	724	2063	4023	6011	Heating
2569	3281	3096	2388	1001	530	628	Cooling + Fan/Pump
2119	2190	2190	2119	2190	2119	2190	Indoor Lighting
197	204	204	197	204	197	204	Outdoor Lighting
149	154	154	149	154	149	154	Hot Water
136	141	141	136	141	136	141	Total - Sum
4433	4802	4504	4683	5695	8983	11458	TOTAL SEA
589	211	201	556	2124	5626	7932	Heating
1171	1806	1644	1373	805	688	761	Cooling + Auxiliaries
2296	2393	2285	2366	2377	2294	2377	Lights & Equip
							(included below)
							(included below)
377	392	374	388	389	375	388	Total - Sum
4912	5663	5317	5282	5765	7151	9589	TOTAL SEA
153	75	30	242	1375	3459	5541	Heating
1792	2438	2270	2009	1247	788	892	Cooling + Auxiliaries
2632	3004	2882	2891	2997	2774	3010	Lights & Equip
							(Included below)
							(included below)
135	146	135	140	146	130	146	Total - Sum
5122	5803	5649	5391	6134	8073	9717	TOTAL TRAKLOAD
715	426	447	822	2363	4969	6621	Heating
1519	2361	2202	1676	768	210	109	Cooling + Fans
2438	2547	2533	2443	2535	2444	2521	Lights
0	0	0	0	0	0	0	(included in Lights)
201	209	209	201	210	201	209	Hot Water
249	260	258	249	258	249	257	Equipment
5780	6242	6154	6123	7147	8827	10114	TOTAL TRAKLOAD
656	301	330	874	2508	4822	6104	Heating
2207	2920	2803	2342	1627	1104	995	Cooling + Fans
2540	2631	2631	2531	2622	2525	2625	Lights
							(included in Lights)
154	159	159	154	160	154	159	Hot Water
223	231	231	222	230	222	231	Equipment
4916	5876	5156	5516	4136	8217	12717	TOTAL VCACS
437	0	0	23	476	3954	7795	Heating
1210	2263	1858	1614	550	222	104	Cooling + Fans + Auxiliaries
2467	2726	2489	2927	2347	3049	3635	Lighting
							(included in Lights)
122	135	123	145	116	151	180	Hot Water
680	752	686	807	647	841	1003	Equipment
5330	6038	5492	4963	6081	6769	9521	TOTAL VCACS
323	326	328	325	1744	2856	5483	Heating
1914	2517	1969	1545	1142	820	843	Cooling + Fans
2741	2832	2832	2741	2832	2741	2832	Lights
							(included in Lights)
127	131	131	127	131	127	131	Hot Water
225	232	232	225	232	225	232	Equipment
4156	4874	4847	3943	4560	7713	11324	TOTAL DOE 2.1
207	58	31	237	1050	4103	7556	Space Heating
1467	2245	2152	1314	939	1163	1243	Space Cooling + Vent
2143	2223	2315	2054	2223	2110	2179	Lighting
							(included in Lights)
127	127	127	127	127	127	127	DHW
212	221	222	211	221	210	219	Equipment

END USE DATA COMPARISONS

LARGE RETAIL BUILDING : RICHLAND

CYCLE

		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
ADM2	TOTAL	1388128	122752	102534	107465	104380	110666
Cycle 3	Interior Lighting	727889	61821	55838	61821	59828	61821
Modeler A	Mixed HVAC	600828	55894	42146	40607	39679	43806
	General Mixed	59309	5037	4550	5037	4875	5037
ADM2	TOTAL	1266234	133004	103373	95042	89254	93393
Cycle 3	Interior Lighting	607301	51579	46588	51579	49915	51579
Modeler H	Mixed HVAC	565255	73469	49599	35507	31639	33858
	General Mixed	93678	7956	7186	7956	7700	7956
SEA	TOTAL	1268068	151125	112077	108019	88169	90264
Cycle 3	Interior Lighting	746867	61969	57620	64039	61678	64119
Modeler B	Mixed HVAC	520085	87312	52835	42176	24547	24333
	General Mixed	21336	1824	1622	1804	1744	1812
SEA	TOTAL	1442371	133497	112914	121084	114555	118662
Cycle 3	Interior Lighting	803282	68754	61944	68346	66207	68335
Modeler J	Mixed HVAC	529595	54717	42306	43376	39456	41212
	General Mixed	109514	10026	8664	9362	8892	9115
TRAKLOAD	TOTAL	1184963	127937	95094	94832	85854	90022
Cycle 3	Interior Lighting	635092	53819	48473	53913	52450	53934
Modeler E	Mixed HVAC	474689	67743	40874	34539	27198	29703
	General Mixed	75182	6375	5747	6380	6206	6385
DOE 2.1	TOTAL	1219656	154332	89579	82381	82619	81128
Cycle 3	Interior Lighting	612673	52784	46903	51888	50781	52525
Modeler F	Mixed HVAC	500067	92517	34248	21471	22997	19572
	General Mixed	106916	9031	8428	9022	8841	9031

JUN	JUL	AUG	SEP	OCT	NOV	DEC	
115054	133897	131005	111429	109870	105139	135135	ADM2 TITLES
59826	61821	61821	59826	61821	59826	61821	Indoor Lighting
50353	67039	64147	46728	41812	40436	68277	Heating + Cooling + Fan/Pump
4875	5037	5037	4875	5037	4875	5037	[all other]
93630	106984	104864	92385	95456	108681	150168	ADM2 TITLES
49915	51579	51579	49915	51579	49915	51579	Indoor Lighting
36015	47449	45329	34770	35921	51086	90633	Heating + Cooling + Fan/Pump
7700	7956	7956	7700	7956	7700	7956	[all other]
94879	109895	108041	92192	89368	111884	134195	SEA TITLES
62184	63652	63613	61507	63829	60033	62004	Lgts-Equip
30937	44444	40427	28948	23734	50039	70353	Cooling + Heating + Auxiliaries
1758	1799	1801	1737	1805	1792	1838	[all other]
118348	125638	124325	116609	118070	113737	124932	SEA TITLES
68483	68269	68243	65880	68361	64171	68269	Lgts-Equip
43008	48279	46997	41951	40545	40742	47008	Cooling + Heating + Auxiliaries
8859	9090	9085	8778	9164	8824	9855	[all other]
94678	106275	102777	91262	88621	95456	112155	TRAKLOAD TITLES
52865	53934	53788	51889	54204	52024	53799	Lights (includes exterior lighting)
35561	45956	42621	33231	28002	37275	51986	Heating + Cooling + Fans
6252	6385	6368	6142	6415	6157	6370	Equipment + Hot Water
108854	113592	127634	84795	78984	98691	119067	DOE 2.1 TITLES
50183	51735	52752	49843	52525	49319	51435	Lighting (includes exterior)
49850	52826	65848	26134	17428	38563	58613	Sp Heat + Sp Cool + Vent
8821	9031	9034	8818	9031	8809	9019	Equipment + DHW

END USE DATA COMPARISONS

SMALL OFFICE BUILDING : EUGENE

CYCLE

		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
ADM2	TOTAL	173445	25412	21530	21493	20283	7477
Cycle 3	Heating	63984	16290	13421	12728	11850	0
Modeler H	Mixed HVAC	12145	74	67	74	69	59
base	Ventilation	9974	1630	1342	1273	1185	0
	Interior Lighting	39976	3395	3067	3395	3286	3395
	Exterior Lighting	2955	251	226	251	243	251
	Other	44411	3772	3407	3772	3650	3772
SEA	TOTAL	160766	16146	13475	14460	13294	12691
Cycle 3	Heating	22843	4944	3424	3193	1758	818
Modeler B	Mixed HVAC	44004	2741	2769	3269	3704	4042
base	Ventilation	1824	406	271	251	140	65
	Interior Lighting	77210	6761	5875	6491	6453	6508
	Exterior Lighting	0					
	Other	14885	1294	1138	1256	1239	1258
SEA	TOTAL	185767	19920	16347	17640	15611	14500
Cycle 3	Heating	62707	9870	7247	7460	5291	3962
Modeler G	Mixed HVAC	15218	572	708	896	1223	1465
base	Ventilation	4176	701	471	481	350	266
	Interior Lighting	95073	8047	7262	8073	8041	8077
	Exterior Lighting	0					
	Other	8593	730	659	730	706	730
TRAKLOAD	TOTAL *	142805	13123	10859	11793	11333	11713
Cycle 3	Heating	11684	3107	1648	1422	746	354
Modeler D	Mixed HVAC	16122	278	427	608	1095	1576
base	Ventilation	493	42	38	42	41	42
	Interior Lighting	42017	3564	3215	3575	3475	3581
	Exterior Lighting	0					
	Other	72289	6132	5531	6146	5976	6160

* total and detail disagree with other summaries due to use of automatic conforming routine

TRAKLOAD	TOTAL	197165	18368	15696	17150	16011	16122
Cycle 3	Heating	32308	6002	4225	4189	2898	1620
Modeler I	Mixed HVAC	34070	1246	1489	1627	2547	3347
base	Ventilation	31477	2671	2405	2679	2588	2681
	Interior Lighting	44010	3746	3357	3747	3625	3757
	Exterior Lighting	0	0	0	0	0	0
	Other	55302	4703	4220	4708	4553	4717
DOE 2.1	TOTAL	168297	19320	16025	16433	13355	11494
Cycle 3	Heating	54512	10171	7904	7397	4516	2312
Modeler F	Mixed HVAC	6407	222	201	234	216	392
base	Ventilation	29499	2505	2264	2505	2425	2505
	Interior Lighting	41591	3656	3188	3552	3520	3540
	Exterior Lighting	0					
	Other	32288	2766	2468	2745	2678	2745

JUN	JUL	AUG	SEP	OCT	NOV	DEC	
9979	12136	11473	9355	8495	7655	18157	ADM2 TITLES
0	0	0	0	0	0	9695	Heating
2111	3575	3092	1657	870	423	74	Cooling
689	1143	983	519	207	53	970	Fan/Pump
3286	3395	3395	3286	3395	3286	3395	Indoor Lighting (pro rata)
243	251	251	243	251	243	251	Outdoor Lighting (pro rata)
3650	3772	3772	3650	3772	3650	3772	Hot Wtr +Refr +Cook +Othr (pr)
11753	12867	11729	12258	13291	13318	15484	SEA TITLES
200	42	44	253	1071	3009	4087	Heating
4105	4720	4263	4312	4085	2968	3028	Cooling
16	3	4	21	86	240	321	Auxiliaries
6224	6803	6205	6438	6757	5938	6757	Lgts-Equip
							(included in next line)
1208	1299	1213	1234	1292	1163	1293	[Total less all of the above]
12626	12573	12574	12870	15426	17159	18521	SEA TITLES
2414	1594	1669	2569	4964	7157	8490	Heating
1684	2075	2015	1722	1314	870	694	Cooling
164	108	113	175	330	468	549	Auxiliaries
7678	8066	8047	7678	8088	7958	8058	Lgts-Equip
							(included in next line)
708	730	730	708	730	708	730	[Total less all of the above]
11584	12849	12498	11811	11746	11417	12081	TRAKLOAD TITLES
104	38	44	172	619	1479	1953	Heating
2075	2675	2732	2222	1307	570	357	Cooling
40	42	42	40	42	40	42	Fans
3442	3564	3557	3447	3594	3427	3576	Lights
							(included in Lights)
5923	6132	6121	5930	6184	5901	6153	Hot Water + Equipment
15409	16281	16224	15596	16321	16487	17500	TRAKLOAD TITLES
706	384	421	930	2306	3951	4874	Heating
3949	4807	4684	3921	2696	1850	1507	Cooling
2589	2663	2679	2585	2679	2579	2679	Fans
3618	3736	3739	3616	3739	3591	3739	Lights
0	0	0	0	0	0	0	(included in Lights)
4547	4691	4701	4544	4701	4516	4701	Hot Water + Equipment
10296	11070	10891	10629	12537	15383	18864	DOE 2.1 TITLES
634	193	145	1058	3437	6833	9912	Sp Heat
1265	2067	1884	1246	222	216	222	Sp Cool
2425	2505	2505	2425	2505	2425	2505	Vent
3320	3540	3587	3273	3626	3282	3505	Lighting
							(included in Lighting)
2652	2745	2770	2627	2745	2627	2720	Equipment + DHW

END USE DATA COMPARISONS

LARGE OFFICE BUILDING : RICHLAND

CYCLE

		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
ADM2	TOTAL	1761809	177783	152052	152893	139159	137433
Cycle 3	Heating	909110	115930	96260	89610	75830	65410
Modeler A	Cooling	247630	10200	9270	11920	13700	20780
	Auxiliaries	275240	23640	21220	23350	22520	23230
	Ventilation	0					
	Interior Lighting	320601	27229	24594	27229	26351	27229
	Other	9228	784	708	784	758	784
SEA	TOTAL	1776691	241637	166961	156455	116965	110647
Cycle 3	Heating	779978	169663	105426	88112	45446	24598
Modeler A	Cooling	169018	0	38	769	4124	16561
	Auxiliaries	334717	28957	23856	26051	26283	27984
	Ventilation	0					
	Interior Lighting	485288	42155	37036	40852	40469	40831
	Other	7890	682	605	671	643	673
TRAKLOAD	TOTAL	1755031	166507	147942	153564	135844	133327
Cycle 3	Heating	289612	75139	42232	34774	16834	6394
Modeler I	Cooling	684221	47967	47442	54268	55529	60370
	Auxiliaries						
	Ventilation	120854	9074	7791	8719	9174	10497
	Interior Lighting	407042	34729	31107	34396	33487	34563
	Other	253302	21598	19370	21407	20820	21503
VCACS	TOTAL	1764274	185117	166397	154876	146076	136956
Cycle 3	Heating	426718	113367	76033	49186	42149	11538
Modeler D	Cooling	228107	0	0	339	1027	23573
	Auxiliaries	118599	3714	4697	9147	10483	11013
	Ventilation	118316	7255	6785	6368	6835	7642
	Interior Lighting	342294	23844	30161	35235	33652	32635
	Other	530240	36937	46721	54561	52130	50555
VCACS	TOTAL	1759638	169246	143178	146578	134546	138375
Cycle 3	Heating	422069	94800	59679	51137	36904	26240
Modeler K	Cooling	132778	0	483	1279	3806	9316
	Auxiliaries	416484	7440	22640	27412	29314	36292
	Ventilation	141654	12085	10770	11829	11372	11606
	Interior Lighting	389550	33085	29883	33085	32018	33085
	Other	257103	21836	19723	21836	21132	21836
DOE 2.1	TOTAL	1691622	209415	144745	138827	122617	121206
Cycle 3	Heating	440700	116300	57500	41000	14000	12100
Modeler F	Cooling	351700	11500	14300	18600	31500	31100
	Auxiliaries	92729	11706	11133	10922	9725	9305
	Ventilation	0					
	Interior Lighting	417197	36333	31732	35231	35054	35696
	Other	389296	33574	30080	33074	32338	33005

JUN	JUL	AUG	SEP	OCT	NOV	DEC	
125099	120673	124663	131609	148763	160309	191373	ADM2 TITLES
43770	24910	29550	55320	82340	100490	129690	Heating
31750	44540	43830	26680	15070	9980	9910	Cooling
22470	23210	23270	22500	23340	22730	23760	Fan/Pump
							(included in fan/pump)
26351	27229	27229	26351	27229	26351	27229	Indoor Lighting
758	784	784	758	784	758	784	(all other)
112325	137369	123165	113173	120454	154000	223740	SEA TITLES
15012	13277	12670	18110	43142	91764	152558	Heating
28750	47428	39742	24691	6845	70	0	Cooling
28638	33783	30313	29282	27770	23586	28214	Auxiliaries
							(included in Auxiliaries)
39271	42217	39759	40448	42027	37918	42305	Lgts-Equip (+ some Other)
654	684	681	642	670	682	683	Non-HVAC Elec
129076	136670	135493	128313	136751	155249	174295	TRAKLOAD TITLES
1109	89	89	2021	13509	40404	57018	Heating
61963	67385	66464	60935	57765	51921	52192	Cooling
							(In Cooling and Fans)
11501	13285	12877	11165	9807	8452	8712	Fans
33586	34465	34548	33408	34446	33578	34729	Lights (includes exterior)
20897	21446	21515	20784	21424	20894	21644	Hot Water + Equipment
126874	130557	134876	130716	120636	156556	172637	VCACS TITLES
728	0	0	1445	18541	25454	86277	Heating: Elec
45410	54983	45179	41162	15812	612	0	Cooling: Elec
14135	13331	11422	11185	8752	16085	4625	Auxiliaries
14366	18598	15966	12319	8385	7936	6041	Fans
20492	17118	24444	25345	27126	42548	29694	Lighting (includes exterior)
31743	26517	37865	39260	42020	65911	46000	Hot Water + Base Loads
142806	158859	160707	141741	134798	136564	152438	VCACS TITLES
5351	1722	572	6014	20135	41285	78230	Heating: Elec
23694	29668	31464	20787	10402	1879	0	Cooling: Elec
48678	59962	60959	49992	37355	26800	7440	Auxiliaries
11535	12586	12791	11798	11985	11450	11847	Fans
32018	33085	33085	32018	33085	32018	33085	Lights (includes exterior)
21132	21836	21836	21132	21836	21132	21836	Hot Water + Base Loads
123094	128802	133679	114468	128376	152519	177874	DOE 2.1 TITLES
2800	2500	2800	12800	27900	65300	85900	Sp Heat
49400	51900	58500	32300	24200	14800	13600	Sp Cool
5466	3702	3303	4138	5266	7594	10445	HVAC Aux
							(Included in HVAC Aux)
33910	35695	35911	33695	35695	33230	35015	Lighting (Interior)
31698	33005	33165	31535	33315	31595	32914	Equipt + DHW + ext lights

COMPARISON OF ECM RECOMMENDATIONS (CYCLE 3)

SMALL RETAIL : EUGENE

ENERGY CONSERVATION MEASURES (kWh savings)

SOURCE: MODELER	SOFTWARE	BASE BUILDING Annual kWh	ENVELOPE Roof/Ceiling Insulate A	ENVELOPE Walls Insulate B	ENVELOPE Windows Thermal C	LIGHTING Delamp D
UTILITY	1987 metered	85300				
ELCAP	1987 metered	85555				
A	ADM2	82953	(sensitivity study only)			
B	SEA	88954	5314	29618	4549 x	5984
J	SEA	81249	4433 x	12615 x	4406 x	
D	TRAKLOAD	85500		16183	5728 x	2192
E	TRAKLOAD	93989	7822	32160	1929	
D	VCACS	85500	4278	2204 x	2139 x	3980
K	VCACS	84153	3745 x	42 x	2102 x	
F	DOE 2.1	81097	7284		4986 x	
CREUS	ASEAM 2.1	85052	6032 x	12258	4034 x	

DESCRIPTION OF MEASURES:

- A Insulate ceiling/roof: add R10 ... R19
- B Insulate walls: add R10 ... R11
- C Install double pane/storm windows
- D Reduce excess lighting: delamp
- E Reduce average watts/sqft lighting; install EE fluor lamps
- F Replace ballasts with efficient electromagnetic

LARGE RETAIL : RICHLAND

ENERGY CONSERVATION MEASURES (kWh savings):

SOURCE: MODELER	SOFTWARE	BASE BUILDING Annual kWh	ENVELOPE Ceiling Lower A	ENVELOPE Roof/Ceiling Insulate B	ENVELOPE Walls Insulate C	ENVELOP Windows Thermal D
UTILITY	1987 metered	1391200				
ELCAP	1987 metered	1313313				
A	ADM2	1386128		25747	61441	
H	ADM2	1266239				
C	SEA	1288069		21886	144660	1513
J	SEA	1442372	192937 x	22369 x	67506 x	
E	TRAKLOAD	1184966		34058	186496	6455
F	DOE 2.1	1219858		62022		
CREUS	ASEAM 2.1					

DESCRIPTION OF MEASURES

- A Lower ceiling: reduce wall & lighting
- B Insulate ceiling: add about R11, making R27 to R30
- C Insulate walls to R13 /with R8.7
- D Replace single pane windows with double pane
- E Reduce lighting with existing controls or delamping
- F Relamp incandescent with fluorescent
- G Replace lights with energy efficient lamps and ballasts
- H Replace standard ballasts with electromagnetic

x = not recommended
z = replace at end of current life cycle
other entries are recommended for immediate action

LIGHTING Fluorescent Relamp E	LIGHTING Ballasts Replace F	OUTSIDE AIR Infiltration Weatherize G	OUTSIDE AIR Vent/Infiltr H	OTHER LOADS Water Heater Wrap I	HVAC Heat Pump Install J
		yes	5389		22289 z
4633 z		2966			25271 z
				635	
3352					11903
					20882 x
2829		1163			10431 z
3279		1460			14787 z
2021 x	1778 x	799 x			11077 x

G Calk and weatherstrip/door insulation
H Reduce ventilation and infiltration
I Wrap water heater, 2" insulation
J Install air source heat pump; COP 2.4 ... 3.0
K Install programmable thermostat/setpoints; nite setback
L Install add-on economizer

LIGHTING Delamp & Control E	LIGHTING Incandsent Relamp F	LIGHTING Fluorescent Replace/EE G	LIGHTING Ballasts Replace H	LIGHTING Fixtures Replace I	OUTSIDE AIR Infiltration Weatherize J
172897		143271		260963	5577
	9561				
		108284			
247068		240731			
		127244			
			12598 x		59824

I Install replacement metal halide fixtures
J Install door between grocery, retail; weatherize warehouse
K Install R-11 wrap on hot water tank
L Reduce lighting and warm-up by one hour each before and after hours
M Replace units: air source heat pumps COP 2.6 ... 3.2; capacity change
N Repair abandoned economizers/dampers on RTUs
O a) Inactivate or cycle off 1/3 of HVAC equipment and air supply
b) Supply programmable thermostats for RTUs/ setpoints

HVAC Thermostat Programmable K	HVAC Economizer Install L
5250	
	2844 x
7967 a)	
	3210
3752	
10190	

a) occupied (2771) + unoccupied (5196)

OTHER LOADS Water Heater Wrap K	OCCUPANCY Reschedule L	HVAC Heat Pump Install M	HVAC Economizer Repair N	HVAC Other O
		228601 z	103204	108236 a)
622			75938	112255 b)
	130676	194653		
			226252	
		105486	37208	
		35982 x	negative e c)	

a) Performance Curve
b) Programmable Thermostat
c) negative demand savings

COMPARISON OF ECM RECOMMENDATIONS (CYCLE 3)

SMALL RETAIL : EUGENE

ENERGY CONSERVATION MEASURES (kWh savings)

SOURCE: MODELER	SOFTWARE	BASE BUILDING Annual kWh	ENVELOPE Roof/Ceiling Insulate A	ENVELOPE Walls Insulate B	ENVELOPE Windows Thermal C	LIGHTING Delamp D
UTILITY	1987 metered	85500				
ELCAP	1987 metered	85555				
A	ADM2	82953	(sensitivity study only)			
B	SEA	88954	5314	29618	4549 x	5984
J	SEA	81249	4433 x	12615 x	4406 x	
D	TRAKLOAD	85500		18183	5728 x	2192
E	TRAKLOAD	93999	7822	32160	1929	
D	VCACS	85500	4278	2204 x	2139 x	3980
K	VCACS	84153	3745 x	42 x	2102 x	
F	DOE 2.1	81097	7284		4986 x	
CREUS	ASEAM 2.1	85052	6052 x	12258	4034 x	

DESCRIPTION OF MEASURES:

- A Insulate ceiling/roof: add R10 ... R19
- B Insulate walls: add R10 ... R11
- C Install double pane/storm windows
- D Reduce excess lighting: delamp
- E Reduce average watts/sqft lighting; install EE fluor lamps
- F Replace ballasts with efficient electromagnetic

LARGE RETAIL : RICHLAND

ENERGY CONSERVATION MEASURES (kWh savings):

SOURCE: MODELER	SOFTWARE	BASE BUILDING Annual kWh	ENVELOPE Ceiling Lower A	ENVELOPE Roof/Ceiling Insulate B	ENVELOPE Walls Insulate C	ENVELOP Windows Thermal D
UTILITY	1987 metered	1382200				
ELCAP	1987 metered	1313313				
A	ADM2	1366126		25747	61441	
H	ADM2	1266239				
C	SEA	1268069		21886	144660	1513
J	SEA	1442372	192937 x	22369 x	67506 x	
E	TRAKLOAD	1184966		34058	186496	6455
F	DOE 2.1	1219856		62022		
CREUS	ASEAM 2.1					

DESCRIPTION OF MEASURES

- A Lower ceiling: reduce wall & lighting
- B Insulate ceiling: add about R11, making R27 to R30
- C Insulate walls to R13 /with R8.7
- D Replace single pane windows with double pane
- E Reduce lighting with existing controls or delamping
- F Relamp incandescent with fluorescent
- G Replace lights with energy efficient lamps and ballasts
- H Replace standard ballasts with electromagnetic

x = not recommended
z = replace at end of current life cycle
other entries are recommended for immediate action

LIGHTING	LIGHTING	OUTSIDE AIR	OUTSIDE AIR	OTHER LOADS	HVAC
Fluorescent	Ballasts	Infiltration	Vent/infiltr	Water Heater	Heat Pump
Relamp	Replace	Weatherize		Wrap	Install
E	F	G	H	I	J

COMPARISON OF ECM RECOMMENDATIONS (CYCLE 3)

SMALL OFFICE : EUGENE

ENERGY CONSERVATION MEASURES (kWh savings):

SOURCE: MODELER	SOFTWARE	BASE BUILDING Annual kWh	ENVELOPE Roof Insulate A	ENVELOPE Window Thermal B	LIGHTING Fluorescent Relamp C	LIGHTING Delamp/ Task Lights D
UTILITY	1987 metered	177280				
ELCAP	1987 metered	missing				
H	ADM2	173454	2466		3172	4224
B	SEA	160765	1567 x	2705 x	4282	5000
G	SEA	185769	2762 x	9629 x	4194 z	8546
D	TRAKLOAD	142000		5194 x	14367	14206
I	TRAKLOAD	197161			5633 z	
F	DOE 2.1	145016			3490	
CREUS	ASEAM 2.1					

DESCRIPTION OF MEASURES:

- A Insulate roof, add ~ R19 ... 21
- B Install thermal pane windows or storm windows
- C Replace lights with energy efficient fluorescent lamps
- D Remove excess lamps/install reflectors/ use task lighting
- E Reduce lighting, unoccupied periods; install motion detect
- F Replace incandescent lights with fluorescent
- G Replace fluorescent ballasts with high efficiency units
- H Reduce exterior lighting levels or hours

LARGE OFFICE : RICHLAND

ENERGY CONSERVATION MEASURES (kWh savings):

SOURCE: MODELER	SOFTWARE	BASE BUILDING Annual kWh	ENVELOPE Roof Insulate A	ENVELOPE Window Blind/Shade B	ENVELOPE Windows Thermal C	LIGHTING Occupancy Schedule D
UTILITY	1987 metered	1797360				
ELCAP	1987 metered	1755071				
A	ADM2	1761791	24189 z			
B	SEA	1776889				
I	TRAKLOAD	1755029	49477	negative	99942 x	
D	VCACS	1764320	35709 z		21025 z	
K	VCACS	1759674				31024
F	DOE 2.1	1497993			80655	
CREUS	ASEAM 2.1	1587760			101470	

DESCRIPTION OF MEASURES:

- A Insulate roof, from add-R7..to reach-R38
- B Install window blinds and/or shades
- C Install thermal pane/storm windos, reflective glass
- D Delamp; reduce hours of lighting
- E Improve lighting efficiency/energy efficient low watt lamps
- F Replace lighting fixtures and install more efficient lighting
- G Install lighting controls/daylighting
- H Replace weatherstripping, 8 doors
- I Install CO_2 vent controls to 20 cfm/person
- J1 Install heat recovery from A/C (8436) or heat pump (9688)
- J2 Install solar water heater
- J3 Install timeclock control for DHW circulating pump

x = not recommended
z = replace at end of current life cycle
other entries are recommended for immediate action

	LIGHTING Unoccupied Reductions E	LIGHTING Incandescent Replace F	LIGHTING Ballasts Replace G	LIGHTING Exterior Reduce H	OUTSIDE AIR Ventilation Increase I	OTHER LOADS Water Heater Wrap J
		3983	1128 z			230
					2541	
	9410					
c)	3013 z d)					965
		2086 x		1643 x		
		2447	7575 b)			

	I	Increase ventilation rate
	J	Install 2" or R11 wrap on water heater
	K	Install air source heat pumps
	L	Install [enthalpy] economizers on HVAC (RTU) equipment
re	M	Install programmable thermostat/control: setpoint temperatures
	N	Install timer for entryway heaters
	O	Install energy management and control system

LIGHTING Fluorescent Relamp E	LIGHTING Fixtures Replace F	LIGHTING Controls G	OUTSIDE AIR Infiltrain Weatherize H	OUTSIDE AIR Vent Control I	OTHER LOADS Water Heater Alternative J
8549 z					
	63416	17692			
21025 z	39505 x	11501			18324 {1x
76527					0 {2b)
79685				5334 x	
13782			19097		8486 {3

K1	Install 85% efficient motors in fan coil units
K2	Install temperature controls; deadband thermostats
K3	Modify for perimeter heating
L1	Retrofit lesser chiller capacity 50% to improve partial loading
L2	Retrofit higher efficiency chiller, COP 4.0
M1	Retrofit higher efficiency pump motors for cooling tower
M2	As above (3084) + free cooling/strainer cycle in tower (246750)
N	Install water loop heat pump COP 2.8 for main system (791760): air/air heat pump COP 2.8 for basement and drive-in (28073)
O1	Repair energy management and control system
O2	Install selective control switching

HVAC Heat Pumps Install K	HVAC Economizer Install L	HVAC Thermostats Programmable M	HVAC Entry Heater Timer N	CONTROLS EMCS Install O
	53492	17623	1690	
35670 z	38139 z			
47111 x	5367 x	56397		64832
		2009 x		
67592 z	9627 x	45360		
18519 z		41590 a)		

a) negative payback due to increased demand
b) de-ballast (1272 Kwh) + electronic (6303 Kwh)/z
c) save 1131 delamping + 3075 turn off when unoccupied
d) save 2039: turn off at night + 974 on weekends

HVAC Terminal & Temp Contrl K	HVAC Chiller Upgrades L	HVAC Cooling Twr Upgrades M	HVAC Heat Pump Alternative N	CONTROLS Switching & EMCS O
	123838 {1		817833	
104028 {1				
153761 {2	26557 {2	19125 {1		
250411 {2a)				99061 {1a)
18769 {3		248924 {2		21849 {2

a) negative demand savings
b) Modeler: "Appears to be bug in VCACS solar routine
- should have some savings"

JUN	JUL	AUG	SEP	OCT	NOV	DEC	
4230	4860	5310	4440	3450	6870	12480	
5503	5813	5593	5319	3601	7814	13756	
5505	5808	5599	5313	3596	7822	13755	ELCAP CATEGORIES
17	1064	1214	1250	241	2782	4443	Heating - heat strips
2273	1471	1499	1048	367	2006	6231	Heat pump / air conditioning
2895	2930	2573	2675	2661	2751	2572	Interior lighting
0	0	0	0	0	47	41	Exterior lighting
116	122	117	133	122	125	124	Water heating
204	221	196	207	205	109	344	Receptacles
JUN	JUL	AUG	SEP	OCT	NOV	DEC	
6114	6384	6235	6285	7144	9461	11940	TOTAL ADM2
606	103	141	912	2896	5844	8164	Heating
2599	3275	3088	2464	1242	708	770	Cooling + Auxiliaries
2309	2386	2386	2309	2386	2309	2386	Lights & Equip
197	204	204	197	204	197	204	(included below)
152	157	157	152	157	152	157	(included below)
251	259	259	251	259	251	259	Total - Sum
4960	5249	4916	5357	7461	10772	13912	TOTAL SEA
876	508	338	1030	3513	6943	9840	Heating
1047	1582	1482	1231	797	792	910	Cooling + Auxiliaries
2530	2632	2573	2586	2626	2530	2636	Lights & Equip
							(included below)
							(included below)
507	527	523	510	525	507	526	Non-HVAC
5871	6549	6430	6201	6887	8579	10085	TOTAL TRAKLOAD
499	225	248	676	2152	4603	6102	Heating
2300	3142	3000	2464	1563	921	808	Cooling + Fans
2551	2643	2643	2542	2633	2536	2637	Lights
							(included in Lights)
261	270	270	260	271	261	270	Hot Water
260	269	269	259	268	258	268	Equipment
5796	6069	5403	4787	5064	5740	8104	TOTAL VCACS
891	108	20	145	899	2205	4705	Heating
1888	2843	2265	1625	1047	518	281	Cooling + Auxils + Fans
2195	2268	2268	2195	2268	2195	2268	Lighting
							(included in Lighting)
180	186	186	180	186	180	186	Hot Water
642	664	664	642	664	642	664	Base-Electric
5449	5706	5704	5367	7266	9403	11817	TOTAL DOE 2.1
587	212	178	876	2940	5168	7257	Space Heating
1816	2332	2263	1546	1164	1291	1500	Space Cooling + Vent
2485	2584	2684	2386	2584	2386	2485	Interior Lighting
180	186	186	180	186	180	186	Exterior Lighting
126	127	127	126	127	126	127	DHW
255	265	266	253	265	252	262	Equipment
6874	7962	7614	7521	7706	9511	12221	TOTAL SEA
482	282	171	652	2416	5124	7653	Heating
3355	4522	4347	3774	2139	1350	1406	Cooling + Auxiliaries
2530	2632	2573	2585	2626	2530	2636	Lights & Equip
							(included below)
							(included below)
507	526	523	510	525	507	526	Non-HVAC

APPENDIX I

SMALL RETAIL BUILDING : EUGENE
END-USE DATA

SENSITIVITY

		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
UTILITY billed	86-87 AVG	80280	12360	9900	6810	5100	4470
ELCAP master meter	1987	85563	12963	9096	7246	4212	4647
ELCAP	TOTAL	85550	12950	9094	7246	4216	4646
end use detail	Heating	29126	9100	5257	3362	257	139
	Mixed HVAC	19141	1115	891	565	451	1222
	Interior Lighting	33080	2333	2601	2971	3163	2955
	Exterior Lighting	141	26	27	0	0	0
	Water Heating	1508	156	127	123	122	121
	Receptacles	2554	220	191	225	223	209

		ANNUAL KWH	JAN	FEB	MAR	APR	MAY
ADM2	TOTAL	101519	12480	10285	10236	8109	6846
Sensitivity	Heating	46374	8702	6836	6302	3909	1959
Modeler A	Mixed HVAC	19751	772	733	928	1291	1881
	Interior Lighting	28094	2386	2156	2386	2309	2386
	Exterior Lighting	2400	204	184	204	197	204
	Water Heating	1849	157	142	157	152	157
	Receptacles	3051	259	234	259	251	259
SEA	TOTAL	105887	15396	11542	11045	8540	6735
Sensitivity	Heating	56590	11296	7867	7064	4665	2648
Modeler C	Mixed HVAC	12099	962	801	833	780	882
	Lighting & Equip	31006	2616	2399	2624	2586	2668
	(blank)	0					
	(blank)	0					
	Non-HVAC Electrical	6192	522	475	524	509	537
TRAKLOAD	TOTAL	93151	11802	8676	8767	6952	6352
Sensitivity	Heating	35951	7850	5063	4659	2516	1358
Modeler E	Mixed HVAC	19855	778	772	933	1356	1818
	Interior Lighting	31013	2636	2358	2637	2559	2638
	Exterior Lighting	0					
	Water Heating	3177	270	243	270	261	270
	Equipment	3155	268	240	268	260	268
VCACS	TOTAL	77723	8916	7090	7519	7013	6222
Sensitivity	Heating	27493	5643	3924	3903	3124	1926
Modeler D	Mixed HVAC	13520	155	350	498	872	1178
	Interior Lighting	26705	2268	2049	2268	2195	2268
	Exterior Lighting	0					
	Water Heating	2190	186	168	186	180	186
	Receptacles	7815	664	599	664	642	664
DOE 2.1	TOTAL	97272	12451	10109	9800	7811	6389
Sensitivity	Heating	41621	7767	5981	5293	3481	1881
Modeler F	Cool & Vent	18600	1504	1310	1346	1182	1346
	Interior Lighting	30234	2602	2266	2584	2584	2584
	Exterior Lighting	2190	186	168	186	180	186
	Water Heating	1519	127	126	127	126	127
	Equipment	3106	265	238	264	258	265
alternate							
SEA	TOTAL	106886	13682	10163	9825	8183	7624
Sensitivity	Heating	42162	9072	5992	5222	3279	1817
Modeler C	Mixed HVAC	29529	1471	1298	1455	1809	2603
	Interior Lighting	31002	2616	2398	2624	2585	2667
	Exterior Lighting	0					
	Water Heating	0					
	Receptacles	6193	523	475	524	510	537

SMALL RETAIL BUILDING : EUGENE

			SOFTWARE	ADM2	SEA	TRAKLOAD	VCACS
			MODELER	A	C	E	D
					annual energy consumption, kWh		
			BASE BUILDING	101525	105888	93154	77754
MEASURE			Alternate Base		108888		77903
	CHARACTERISTIC	CHANGE			annual energy consumption, kWh		
1	Orientation	rotate 90 degrees		100435	104044	99035	86156
2	Floor loss	decrease loss 23.1%		101166	104845	92233	79277
3	Roof insulation	add R19		95787	99816	89028	75963
4*	Wall insulation	add R11		86647	77792	73395	78038
5	Glazing area	increase/decrease 30%		101680	99685	96956	79864
6	Glazing R value	increase 30%		101307	102825	90421	79050
7	Shading coefficient	decrease 30%		102098	109949	94529	75434
25	Building mass	increase to maximum		99972	105960	95282	77754
8	Outside air supply	50% more cfm		114834	112009	94641	79461
9	Fan operate, unocc	toggle on/cycle		84308	106515	155473	96964
13	Economizer	toggle yes/no		96876	106411	93215	72524
14	Supply air	increase 30%		101992	113512	95799	78597
10	Lighting energy	decrease 30%		99911	99578	88936	69627
11	Lightg heat to space	decrease 30%		97911	106462	92946	78783
12	Water heating	increase 100%		103375	107117	94925	80842
15	Cooling COP	increase 30%		98664	104601	90499	76890
16	Heat pump	change system type		81615	82892	78442	73299
17	Multizone system	change system type		146184	163451	127892	75907
18	VAV system	change system type		141288	100608	100610	76017
19	Heating setpoint	increase 5 degrees		108266	116680	101137	81184
20	Cooling partial load	50% more capacity		104544	110005	97737	77948
21	Occupied hours	increase 2 hours		111946	115992	108602	85519
22	Occupants	increase 50%		100596	105101	96354	78472
23	Vacation schedule	add July vacation		95692	103417	86606	71844
24	Weather files	swap Eugene/Richland		120408	113508	100163	85361

* determined from Alternate Base

SENSITIVITY ANALYSIS

DOE 2.1 F		ADM2 A	SEA C	TRAKLOAD E	VCACS D	DOE 2.1 F	ADM2 A	SEA C
			annual energy consumption, kWh					annual
97293		101525	105888	93154	77754	97293	101525	105888
			108888		77903			108888
			annual energy savings, kWh					percent
97533		1090	1844	-5881	-8402	-240	1.1	1.7
96628		359	1043	921	-1523	665	0.4	1.0
92493		5738	6072	4126	1791	4800	5.7	5.7
75968		14878	28096	19759	-284	21325	14.7	26.5
94949		-155	6203	-3802	-1961	2344	-0.2	5.9
94943		218	3063	2733	-1296	2350	0.2	2.9
98274		-573	-4061	-1375	2320	-981	-0.6	-3.8
97105		1553	-72	-2128	0	188	1.5	-0.1
101166		-13309	-3121	-1487	-1707	-3873	-13.1	-2.9
108819	**	-17217	-2373	-62319	-19061	-11526	-17.0	-2.2
97096		4649	2477	-61	5379	197	4.6	2.3
101187		-467	-4624	-2645	-843	-3894	-0.5	-4.4
92455		1614	6310	4218	8127	4838	1.6	6.0
97430		3614	-574	208	-1029	-137	3.6	-0.5
98948		-1850	-1229	-1771	-3088	-1655	-1.8	-1.2
96121		2861	1287	2655	864	1172	2.8	1.2
72857		19910	22996	14712	4455	24436	19.6	21.7
119555		-44659	-57563	-34738	1996	-22262	-44.0	-54.4
96101		-39763	5280	-7456	1737	1192	-39.2	5.0
111611		-6741	-10792	-7983	-3430	-14318	-6.6	-10.2
112010		-3019	-4117	-4583	-45	-14717	-3.0	-3.9
113393		-10421	-10104	-15448	-7765	-16100	-10.3	-9.3
96540		929	787	-3200	-569	753	0.9	0.7
98010		5833	2471	6548	5910	-717	5.7	2.3
113490		-18883	-7620	-7009	-7607	-16197	-18.6	-7.0

** = ADM2 and SEA signs reversed for consistency

SENSITIVITY MEASURES

TRAKLOAD	VCACS	DOE 2.1
E	D	F
energy consumption, kWh		
93154	77754	97293
	77903	
annual energy savings		
-6.3	-10.8	-0.2
1.0	-2.0	0.7
4.4	2.3	4.9
21.2	-0.4	21.9
-4.1	-2.5	2.4
2.9	-1.7	2.4
-1.5	3.0	-1.0
-2.3	0.0	0.2
-1.6	-2.2	-4.0
-66.9	-24.5	-11.8
-0.1	6.9	0.2
-2.8	-1.1	-4.0
4.5	10.5	5.0
0.2	-1.3	-0.1
-1.9	-4.0	-1.7
2.9	1.1	1.2
15.8	5.7	25.1
-37.3	2.6	-22.9
-8.0	2.2	1.2
-8.6	-4.4	-14.7
-4.9	-0.1	-15.1
-16.6	-10.0	-16.5
-3.4	-0.7	0.8
7.0	7.6	-0.7
-7.5	-9.8	-16.6

APPENDIX K: APPROVED COMPUTER PROGRAMS - CALIFORNIA ENERGY COMMISSION

Building Energy Efficiency Standards

California Energy Commission

Approved Computer Programs

March 22, 1990

TO ALL INTERESTED PARTIES:

The following list of energy analysis computer programs includes all Alternative Calculation Methods approved by the California Energy Commission, in accordance with Title 20, section 1409, of the California Administration Code, for use in complying with the energy budgets of Title 24, Part 2, Chapter 2-53. The individual programs are listed below under specific categories as follows:

Residential Buildings, Second Generation
Solar Water Heating

Nonresidential Buildings, First Generation

Nonresidential Buildings, Second Generation

These are the only programs that should be used under the energy budget alternative methods of compliance.

Note: Price listings of proprietary programs are available from the vendors at addresses and telephone numbers listed.

P400-00-012

Residential Buildings
Second Generation

Program Name	Contact Person	Address and Telephone
**CALRES 1.0	P400-88-009 $17.00	California Energy Commission Publications, MS-13 P. O. Box 944295 Sacramento, CA 94244-2950
**MICROCHECK 1.0	P400-89-001 $22.00 Energy Hotline (916) 324-3376 (800) 772-3300	
CALPAS 4/TAKE OFF 1.10	Bruce Wilcox	BSG Software 2560 9th Street, Suite 212M Berkeley, CA 94710 (415) 841-5735
EASY CALC 010189A	Eric Torney	Energy Toolworks 207 Kent Avenue, #1 Kentfield, CA 94904 (415) 925-0847
MICROPAS 3.0	Ken Nittler	Enercomp 123 C Street Davis, CA 95616 (916) 753-3400

Solar Water Heating

F-Chart 4R Version 2.00	Rick Rodgers	California Micro Utility 1195 Park Ave. Suite 202A Emeryville, CA 94608 (415) 658-1273
F-Chart 3 & 5 Series	Sylvia Beckman	F-Chart Software 4406 Fox Bluff Road Middleton, WI 53562 (608) 836-8536
Solargy-F	Tom Rotchford	Solargy, Inc. 22028 Ventura Blvd., Ste. 207 Woodland Hills, CA 91364 (818) 347-6096
F-Chart 4.0 & 4.1		Solar Energy Laboratory University of Wisconsin Madison, WI 53706 (608) 263-1589

** Microcheck and Calres are energy budget compliance tools which have the same goals and fixed assumptions. They do virtually the same calculations, yet their input styles are different. Both programs reference the Energy Conservation Manual (P400-88-002).

Microcheck has a tutorial and color screen option. Also it was originally designed to be a plan check tool using input information of other certified programs. Thus, one can input information from a CF1R form to verify compliance.

Calres has pull down screens.

NONRESIDENTIAL STANDARDS
FIRST GENERATION

Approved Energy Analysis Computer Programs for "Old" Nonresidential Energy Standards (Title 24, Part 2, Chapter 2-53, Sections 2-5321 through 2-5333) for use with Energy Budgets in Section 2-5322.

Program Name	Contact Person Address and Telephone Numbers	Designation Code Number	Appropriate Correction Facto
AC PROG 1, REV 1.4 and Energy 1, REV 2.4 July 19, 1979	Robert Z. Gibson, P.E. 3118 Fulton Avenue, Suite 1 Sacramento, CA 95821 (916) 484-6716	CPO 03	1.000
DOE 2.0A March 30, 1978	Programs and service are no longer available.	CPO 15	0.780
DOE 2.0A September 1, 1980		CPO 16	1.000
DOE 2.1A February 1982	National Energy Software Center 9700 South Cass Avenue Argonne, IL 60439 (708) 972-7250	CPO 19	1.000
DOE 2.1B October 1986		CPO 06	1.020
DOE 2.1C September 1987		CPO 09	1.044
DOE 2.1C September 1, 1980	Zulifikar Cumali Consultants Computation Bureau 1 Wild Wood Gardens Piedmont CA, 94611	CPO 13	1.000
ESAS August 3, 1981	Ross F. Meriwether Consulting Engineering 3315 Outrider San Antonio, TX 78247-4405 (512) 490-7081	CPO 17	1.240
MICRO-DOE 2.1C September 1987	Acrosoft International, Inc. 9745 East Hampton Ave. Suite 230 Denver, CO 80231 (303) 368-9225	CPO 10	1.044
PC-DOE January 1987	Program and services are no longer available	CPO 08	1.020
TEMPMASTER September 14, 1979	Jim Dean Tempmaster Corporation 1222 Ozark Street N. Kansas City, MO 64116 (816) 741-6060	CPO 11	1.080
Trace II April 6, 1983	Mick Schwedler The Trane Company 3600 Pammel Creek Road La Crosse, WI 54601 (608) 787-4339	CPO 04-II	1.000
Trace II August 3, 1981		CPO 04	1.000
Trace 500 July 13, 1978	Boeing Computer Service	CPO-04	1.000
EP 3.3 March 1, 1979	Energy Management Service	CPO-08	1.000
Axcess VI April 1, 1978	Edison Electric Institute	CPO-10	1.080
Westinghouse Energy Study Program May 21, 1979	Westinghouse Electric Corp.	CPO-12	1.240

NONRESIDENTIAL STANDARDS
SECOND GENERATION
Approved through December 31, 1990

Approved Energy Analysis Computer Programs for New Office Energy Efficiency Standards (Title 24, Part 2, Chapter 2-53, Sections 2-5341 through 2-5343) for use with Energy Budgets in Section 2-5341.

Program Name	Contact Person Address and Telephone Numbers	Designation Code Number	Appropriate Correction Facto
ADM 2 Version 4.1	Taghi Alereza ADM Associates 3299 Ramos Circle Sacramento, CA 95827 (916) 363-8383	CPO 03	1.030
Comply 24 Version 2.1	Mike Gabel or Martyn Dodd Gabel Dodd Associates 1818 Harmon Street Berkeley, CA 94703 (415) 428-0803	CPO 07	1.027
DOE 2.1A DOE 2.1B DOE 2.1C	Bruce T. Maeda California Energy Commission 1516 9th Street MS 25 Sacramento, CA 95814-5512 (916) 324-3383	CPO 01 CPO-06 CPO-09	1.000* 1.020 1.044
Or Data General Version	The National Energy Software Center 9700 South Cass Avenue Argonne, IL 60439 (708) 972-7250		
HAP Version 1.1	James A. Hall Carrier Corporation 1900 Embarcadero, Suite 101 Oakland, CA 94606 (415) 536-5250	CPO 11	1.012
MICRO-DOE Version 2.1C	Acrosoft International, Inc. 9745 East Hampton Ave. Suite 230 Denver, CO 80231 (303) 368-9225	CPO 10	1.044
PC-DOE	Program and services are no longer available.	CPO 08	1.020
SCM Version 2.0H	Jay Roman California Energy Commission 1516 9th Street, MS - 25 Sacramento, CA 95814 (916) 324-3376 1-800-772-3300	CPO 02	1.027* +
OR TO PURCHASE ORDER:			
	SCM 2.0H P400-86-013 ($19.98) California Energy Commission Publications, MS - 13 P.O. Box 944295 Sacramento, CA 94244-2950		
Trace 500 Trace II	Mick Schwedler The Trane Company 3600 Pammel Creek Road La Crosse, WI 54601 (608) 787-4339	CPO 05 CPO 05-II	0.980 0.980

* Climate Dependent Energy Use Multiplier applied only to Heating, Cooling, Fans, and Pump Energy Uses.

\+ Program internally uses this Multiplier to produce adjusted results.

APPENDIX L: GLOSSARY

1. average energy end-use divergence: A statistical measure of how far the monthly energy simulated for a building on an end-use basis departs from a defined standard, such as metered end-use consumption data.

2. average monthly divergence: A statistical measure of how far the total monthly energy simulated for a building departs from a defined standard, such as the energy billed by the utility

3. base building: An energy simulation model representing an existing building or an initial design concept for a new building, and used as a "base" for comparisons with other models that simulate ECMs.

4. BPA--Bonneville: Bonneville Power Administration

5. a. building energy simulation model: A computer-based mathematical model of the way energy is consumed in a building
   b. building energy simulation software: Computer software used to simulate the energy consumed in a building represented by a building energy simulation model simulation software

6. CAP: Commercial Audit Program, a commercial-sector energy conservation program sponsored by Bonneville.

7. CFM: Cubic feet per minute

8. COP: Coefficient of Performance. The ratio of how much energy is extracted from an equipment compared to the energy needed to perform the work, expressed in the same energy units.

9. CREUS: Commercial Retrofit and End-Use Study, a commercial sector energy conservation program sponsored by Bonneville, focused on comparing the predicted and actual energy savings achieved when energy conservation measures are installed in existing buildings

10. ECM/ECO/energy conservation measure: Energy Conservation Measure. A specific effort to reduce the building energy consumption, involving a change in a building or equipment component, or their operation and maintenance

11. ELCP: End-Use Load and Conservation Assessment Program, an energy conservation program sponsored by Bonneville, focused on field measurements of energy used in various buildings

12. end-use data: Energy consumption data categorized by "end uses" - the way the energy is used within the building, such as heating, cooling, lighting, water heating, and miscellaneous equipment

13. end-use energy profile: A graphic representation of a building's energy use by end-use categories, for each month of the year.

14. input data file: One or more computer files, usually on disk, containing information that defines a building energy model.

15. latent heat: Thermal energy associated with changes in state, usually evidenced in the amount of water vapor present in air.

16. Level 1/Level 2/Level 3: Building types, by size and complexity, defined for the Commercial Audit Program. Level 1 is a small, simple structure approximately comparable to a residence. Level 3 is a large, complex structure usually in excess of 5000 square feet and/or with central air distribution often of more than one type.

17. MCS: Model Conservation Standard. Recommended practices for design and construction of energy efficient buildings.

18. modeler: A user of building energy simulation software. The person who constructs computer models and conducts simulations to obtain estimates of building energy consumption and savings

19. OSA: Outside air. Air brought into the building through the HVAC system.

20. sensible heat: Thermal energy evidenced in changes in temperature

21. tweaking: Changing the values of input parameters to achieve a particular output from an energy simulation model. Changes may be related to real-world conditions, or simply whatever is necessary to get the desired result.

22. user: A user of building energy simulation software. A modeler

23. weather data file: A computer file containing weather data (such as dry bulb temperatures, by bin or hourly) in a format compatible with the programming requirements of building energy simulation software

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