LBL-30141

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Presented at the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, August 26–September 1, 1990, and to be published in the Proceedings

End-Use Load Shape Data Application, Estimation, and Collection: A State-of-the-Art Review

J.H. Eto, H. Akbari, R.G. Pratt, and S.D. Braithwait

June 1990

APPLIED SCIENCE DIVISION

LOAN COPY
Circulates
for 2 weeks
Bldg. 50 Library.
LBL-30141
Copy 2

Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-30141

Prepared for ACEEE 1990 Summer Study
on Energy Efficiency in Buildings

END-USE LOAD SHAPE DATA APPLICATION, ESTIMATION, AND COLLECTION

A STATE-OF-THE-ART REVIEW

Joseph H. Eto and Hashem Akbari, Lawrence Berkeley Laboratory,
Robert G. Pratt, Battelle Pacific Northwest Laboratories, and
Steven D. Braithwait, Electric Power Research Institute

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

June 1990

The work described in this study was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Utility Technologies, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

END-USE LOAD SHAPE DATA APPLICATION, ESTIMATION, AND COLLECTION

A STATE-OF-THE-ART REVIEW

Table of Contents

EXECUTIVE SUMMARY iii

1. INTRODUCTION 1

2. APPLICATIONS OF UTILITY END-USE LOAD SHAPE DATA 1
   - 2.1 Demand-Side Management Applications of End-Use Load Shape Data 2
   - 2.2 Forecasting Applications of End-Use Load Shape Data 3
   - 2.3 Integrated Resource Planning Applications of End-Use Load Shape Data . . . 4
   - 2.4 The Need for End-Use Load Shape Data 5

3. ESTIMATING END-USE LOAD SHAPES 5
   - 3.1 Historical Development of End-Use Load Shape Data 6
   - 3.2 Current State-of-the-Art 6
   - 3.3 Validating End-Use Load Shape Data Estimates with Measured Data 9

4. END-USE LOAD SHAPE DATA COLLECTION 10
   - 4.1 Historical End-Use Load Shape Data Collection Efforts 10
   - 4.2 Current State-of-the-Art 11
   - 4.3 Lowering the Costs of End-Use Load Shape Data Collection 13
   - 4.4 Using End-Use Load Shape Data Collected by Others 14

5. TOWARDS THE NEXT GENERATION OF END-USE LOAD SHAPE DATA DEVELOPMENT 16

6. ACKNOWLEDGEMENTS 18

7. REFERENCES 18

EXECUTIVE SUMMARY

As demand-side management (DSM) and integrated resource planning become more routine elements of the utility planning process, utilities' energy information needs have expanded well beyond sales and peak loads by customer class. An increasing number of utilities require credible estimates of both end-use load shapes and load shape changes associated with DSM options in order to assess the cost-effectiveness of alternative resource options. However, end-use energy data, especially on an hourly basis, are notoriously difficult and expensive to collect. Recently, the value of these data has lead several utilities to establish large-scale metering projects while others have attempted to use estimation techniques that involve some combination of engineering simulation, secondary data, and statistical analysis of building energy-use data. Utilities eager to obtain end-use data wonder whether the findings from the metering projects are applicable to their service territory; they are also concerned whether the estimation techniques are reliable for use in planning.

This paper discusses the importance of end-use load shape data for utility integrated resource planning. It summarizes leading utility applications and reviews progress to date in obtaining load shape data. The review describes major end-use data development efforts, including load shape estimation studies and recent end-use metering projects. The historic origins of and current state of the art in each topic area are discussed. Major conclusions of the paper are: (1) current metering projects are producing valuable data that have broad applicability to other service territories; and (2) load shape estimation techniques have matured sufficiently to represent reliable tools for planning. Finally, the paper outlines directions for future research by arguing for closer coordination between future metering efforts and load shape estimation technique development and, in fact, suggests that the most promising avenue for cost-effective development of end-use load shape data is an optimal combination of data transfer, simulation, statistical analysis, and end-use metering.

1. INTRODUCTION

As electric utilities increasingly adopt least-cost integrated resource planning processes, their information needs about demand-side management (DSM) options expand considerably. Numerous DSM alternatives offer the potential to meet a significant share of consumers' demands for energy services by means of increased energy efficiency (Krause and Eto 1988). However comprehensive information on the cost and performance of these alternatives has been slow to develop. Current utility supply-side planning methods involve detailed assessments of alternative resource plans that take explicit account of the time-varying nature of customers' demands for electricity. In order for demand-side options to be treated comparably to generation resources, planners need reliable information on their impact on system loads.

Yet information on the components of aggregate electricity loads (i.e., end uses) and how they can be modified, especially at the level of temporal disaggregation used to evaluate generation options, is not widely available. A recent assessment of least-cost planning (LCP) concludes that uncertainty about the performance of demand-side management (DSM) activities, including their impact on load shapes, is a major barrier to increased utility reliance on DSM for meeting customer's demands for electricity services (Goldman et al. 1989). The goal of this paper is to assess progress in reducing this uncertainty by reviewing leading efforts to apply, estimate, and collect end-use load shape data for utility planning purposes.

We begin by reviewing utility applications of end-use load shape data. For the purposes of this paper, these applications constitute the primary "demand" for load shape data. (Accordingly, other, distinct "demands" for load shape data, in particular those unique to the building energy research community, are not addressed). In the subsequrnt two sections, we review current efforts to obtain end-use load shape data by estimation and by direct metering. Our discussion of these three topics begins with a brief historical summary and is followed by a review of the current state-of-the-art. We also speculate on promising future areas of research. These speculations form the basis for a final section, which describes our vision of the next generation of end-use load shape data applications, estimation, and collection.

2. APPLICATIONS OF UTILITY END-USE LOAD SHAPE DATA

End-use load shape data play a crucial role in several aspects of utility planning including load forecasting, demand-side program screening, supply- and demand-side resource integration, and demand-side technology or program performance. The increased importance of these planning functions is the principal reason for current utility interest in acquiring end-use load shape data.

At the same time, the end-use load shape data required by these applications are not identical. For forecasting system load shapes for capacity planning, average load shapes by customer or rate class may be sufficient. However, seasonal or weekly fluctuations, in addition to the hourly pattern of daily load shapes may be required. For assessing a list of potential

DSM options or developing a comprehensive integrated resource plan, additional load shapes for major end uses, and even specific technologies within those end uses may be needed. The precision required of these load shapes will also vary depending on whether the analysis is of a preliminary nature or whether it represents the final review prior to resource acquisition. Finally, a comprehensive analysis of the measured performance of a demand-side technology or program will also require substantial supplementary (non-load shape) data in order to assign causal linkages between the demand-side intervention and its measured consequences.

In this section, we review some of these applications in order to better understand the motivation for efforts to estimate and collect end-use load shape data to be described in the following sections.

2.1 Demand-Side Management Applications of End-Use Load Shape Data

Some of the earliest applications of end-use load shape data also can be found in early evaluations of demand-side management programs designed to modify utility load shapes. Examples include old reports by the Association of Edison Illuminating Companies's (AEIC) Load Research Committee examining the load shape impacts of marketing specific end uses, such as electric water heating and air conditioning (AEIC 1974); Department of Energy (DOE) and Electric Power Research Institute (EPRI) sponsored research on the impacts of time-of-day electricity tariffs on various customer classes (Caves, Christensen, and Herriges 1984); and evaluations of the aggregate impacts of utility direct load control programs.

More recently, it has become evident that planners must be aware of the load shape impacts of all demand-side technologies and programs, not just those that address utility peak demands. For example, the Hood River Conservation Project, a landmark demonstration of the "blitz" approach for deploying residential DSM aimed primarily at saving energy, also had measurable load shape impacts. The Project involved the wholesale retrofitting of an entire community in Oregon; the retrofits stressed improvements to the thermal integrity of the homes. As part of the project, the electrical demands of 320 homes were separately monitored. The monitoring permitted building energy researchers to quantify peak demand savings of more than 0.5 Kw/household overall and more than 0.8 Kw/household for electrically heated homes (Stovall 1989). More importantly, these peak demand savings, when combined with overall energy savings, indicated that household load factors had declined (a load factor is defined as the average demand divided by the peak demand). This observation led to the suggestions that further improvements could be made by re-sizing (downward) home heating equipment in response to the reduced thermal loads.

Similarly, the availability of end-use data has permitted substantial refinements to evaluations of demand-side technologies or programs. For example, in evaluating the net impact of utility direct load control programs (DLC), it is well known that the normal cycling behavior of controlled appliances may or may not be affected by a utility's program (i.e., absent the program, significant cycling may already be the pattern of normal operation). Thus, the aggregate load shape impact of a DLC program is a function of how the distribution of appliance

cycling times for a population has been modified. Evaluating these distributions requires large samples and data collection on days both when the program is operating and when it is not. See Braithwait (1989) for a recent evaluation of a DLC program that takes explicit account of these distributions.

We expect that applications of end-use load shape data for DSM evaluation will assume increased importance as demand-side planning becomes more integrated into utility planning processes. In particular, the use of competitive resource acquisition mechanisms (such as demand-side bidding) to solicit demand-side resources from third parties will increase the need for explicit measurement of demand-side program savings. End-use load shape data should play a prominent role in these evaluations.

2.2 Forecasting Applications of End-Use Load Shape Data

Forecasting utility system load shapes through the summation of end-use load shapes is the logical consequence of utility adoption of the end-use framework for forecasting annual energy use. One of the earliest examples of this linkage is the system of forecasting models developed by the California Energy Commission (CEC). In response to a statutory charge to prepare forecasts of future energy use that explicitly capture the effects of California's building and appliance standards, CEC developed the first generation of end-use forecasting models for application to distinct utility service territories. The modeling system, which continues to undergo improvements by the CEC, included an end-use peak demand forecasting model that forecast hourly system loads for a utility peak day separately by end uses (Jaske 1980). The model operates as a post-processor to forecasts of annual end-use electricity demands, which are produced by a separate model. The explicit linkage between the annual energy demand forecast and the system peak day load shape ensures an important consistency between the forecasts of annual energy and peak demand that is often lacking when the two quantities are forecast separately.

The commercially available counterpart to the CEC's peak demand model is the Hourly Electric Load Model (HELM). HELM is a flexible load shape forecasting model that takes as input forecasts of annual energy sales at a user-selected level of disaggregation (e.g. total system, customer class, end use), and monthly, daily and hourly allocation factors, again at optional levels of detail (typical days, 8760 hours), and produces a system load shape forecast (ICF, Inc. 1985). With regard to current practice, however, most utilities use HELM at the customer class level, although some utilities model weather-sensitive loads separately. Indeed, much utility interest in end-use load shape data is for monthly and annual aggregations of these data for non-load shape or energy forecasting purposes.

For the future, we expect forecasting applications for end-use load shape data to increase. For example, Eto et al. (1988) believe it may soon be possible to produce annual energy forecasts through the aggregation of hourly end-use load shape forecasts. Use of an annual time-step for forecasting energy use is largely a matter of convenience. Many important energy use decisions (such as the usage as opposed to the purchase of an energy-using durable) take

place at a much finer level of temporal disaggregation. These forecasting efforts will only proceed, however, after significant advances in improving our understanding of the causal factors influencing energy at this finer level of time-resolution.

2.3 Integrated Resource Planning Applications of End-Use Load Shape Data

A distinguishing feature of early applications of load shape data is that they were not fully integrated into the process of utility resource planning. Despite producing forecasts of hourly system loads for the peak day, for example, the CEC model only passed a forecast of total annual energy and peak demand to the resource integration planners. Similarly, for most evaluations of demand-side resources, the load shape impacts of specific demand-side resources are manually "subtracted" from aggregate system load shapes, which may ignore interactive effects among end uses and other DSM programs. An emerging application of end-use load shape data is better integration of demand-side resources into the utility planning process. From a purely mechanical standpoint, these improvements are exemplified by the recent availability of demand-side screening and integrated resource planning models, which facilitate the analysis of demand-side resources. From a more conceptual standpoint, end-use load shape data are beginning to play an extremely important role in extending demand-side planning into the realms of transmission and distribution system planning and fuel-switching.

Detailed analysis of all available demand-side resources is inefficient because initially only a handful of demand-side options will be appropriate for serious consideration. Reducing the long list of available resources is called screening analysis. At this initial stage of the planning process, short-cuts are taken to facilitate rapid analysis of a large number of options. For example, program implementation rates may be parameterized and marginal costs fixed regardless of the size of the demand-side intervention. At the same time, due to their importance for utility planning, the load shape characteristics of demand-side resources and time-differentiated marginal costs of electricity generation will often be retained for this stage of analysis. Models which support screening analyses using end-use load shape data include COMPASS (SRC 1989) and DSManager (EPS 1989).

Having identified a manageable list of demand-side resources for further analysis, the need to consider these resources on an equal footing with those on the supply-side has led to a whole new class of planning models. These models, called integrated resource planning models, combine historically distinct modeling capabilities, such as load forecasting and production costing, into a single piece of software. While extensive calibration and coordination of data transfer with the more detailed stand-alone models for each modeling task are required, the ability of these models to carry out an integrated analysis rapidly makes them extremely attractive for strategic planning. Well-known integrated planning models that feature end-use load shape data handling capabilities include UPLAN (Lotus Consulting Group 1986), MIDAS (Farber et al. 1988), and LMSTM (DFI 1982). (See also Eto (1990) for an overview of issues associated with the use of demand-side screening and integrated resource planning models.)

Published examples of the application of end-use load shape data with an integrated resource planning model are rare, although many such studies exist as proprietary consultant reports or as parts of utility regulatory filings. A recent exception is Comnes et al. (1988), which used the LMSTM model to evaluate the cost-effectiveness of utility incentives to stimulate adoption of cooling thermal energy storage technologies for buildings.

Most integrated resource planning efforts consider only the potential for demand-side activities to modify utility generation capacity expansion decisions. The availability of end-use load shape data and geographically differentiated utility substation metering has led to the possibility of also deploying demand-side programs to avoid transmission and distribution (T&D) investments. A recent study by Rosenblum and Eto (1986) examined utility T&D planning and concluded that significant savings could be realized by targeting DSM to specific geographic locales where the avoided cost of T&D was high due to the imminent need to upgrade the capacity of substation distribution transformers.

Similarly, an integrated resource planning process should also (but typically does not) consider fuel-switching as a means for meeting customer's demands for energy services. End-use load shape data for the usage profiles of both electric and gas energy-using equipment can play an important role in these evaluations. At this time, we are aware of only one study that has begun to compare these profiles, focussing on residential appliances (Quantum Consulting 1989).

2.4 The Need for End-Use Load Shape Data

It is probably safe to say that the sophistication of utility applications for end-use load shape data (in particular, currently available software models) exceeds the quality and quantity of currently available data. We see no sign that this trend will end soon. Acquiring end-use load shape data, however, is an expensive undertaking with large differences in cost between end-use load metering and load shape data estimation. Therefore, the relevant economic question to which we now turn is, given the value of end-use load shape data for utility planning, what is the most cost-effective means for obtaining them?

3. ESTIMATING END-USE LOAD SHAPES

Prior to the recent wave of end-use metering projects, the only means for obtaining load shape data unique to local conditions was estimation. Estimation methods have historically relied on extensive and largely unverifiable "engineering judgment." Indeed, concern over the reliability of these judgments has been a major impetus for the end-use metering efforts to be described. At the same time, increased supplementary data collection such as customer mail surveys and load research data has led to a whole new generation of estimation methods. Moreover, the availability of end-use metered data provides, for the first time, the potential for validation of the estimation methods. When validated, these methods offer the promise of producing end-use load shape data at a fraction of the cost of metering.

3.1 Historical Development of End-Use Load Shape Data

The earliest approaches to load shape estimation typically involved engineering simulations. The basic approach is to use available supplementary data (e.g., mail surveys) on a subset of the population (e.g., single family, large office, etc.) and, through application of "engineering judgment" create a single prototype intended to represent the energy use of that stock. Use of a hourly building energy simulation program produces the end-use load shapes. The basic issue, as for all estimation methods, is one of calibration. For the earliest of these efforts, calibration was only possible at an extremely high level of end-use and temporal aggregation (e.g., monthly total energy bills). Even, then, because lighting and equipment load shapes are assumed inputs to the thermal simulation, calibrations typically estimate only their relative magnitude, not their shape. In the absence of more detailed data, independent judgment as to the accuracy of simulated hourly load shapes was largely a matter of faith. Indeed, many early load shapes developed by this method exhibit the characteristic "square" load shape that arises from the simulation of prototypes. (See, for example, Akbari et al. 1990 for a review of some of these studies.)

3.2 Current State-of-the-Art

The passage of the Public Utilities Regulatory Policy Act of 1978 (PURPA) provided an unanticipated benefit for end-use load shape estimation. PURPA directed utilities to carry out detailed cost-of-service studies for the purpose of rate design reform based on hourly measurement of customer loads. As a result, hourly whole-building load shape data have become widely available. The benefit for end-use load shape estimation lies with the fact that these data provide a control or reconciliation total for end-use load shapes at an hourly or even finer interval. Unfortunately, until recently little or no information on customer characteristics was collected along with the load research data. A number of utilities, seeing the value of load research data for other than cost-of-service applications, have begun to collect characteristics data, and in some cases expand the samples to represent market segments, in addition to rate classes.

At least six distinct end-use load shape estimation methods have been used by different researchers to analyze these data. The methods are: (1) one dimension application of the Stephan-Deming Algorithm; (2) the variance allocation approach; (3) the End-Use Disaggregation Algorithm; (4) the conditional demand approach; (5) the bi-level regression approach; and (6) the SAE approach. For purposes of exposition, it is useful to separate the methods that are primarily deterministic from those that are primarily statistical (although, as we shall see, this distinction breaks down for several of the methods).

The deterministic methods, which include methods 1 through 3, rely on exact reconciliation to an hourly control total, which is provided by the whole-building load research data. Of the three methods we are aware of, the starting point for the reconciliation is an engineering simulation of the sort relied upon by the earliest load shape estimation methods. The methods typically rely on much more detailed information to develop the simulation input

(thereby minimizing the extensive reliance on engineering judgment that characterized many early efforts). More importantly, they start with the assumption that an engineering simulation will not equal the measured, whole-building load shape. Each method differs in the manner by which the difference between the observed total and the sum of the initial, simulated estimates is allocated to constituent end uses.

The most straightforward allocation method, called the one-dimensional application of the Stephan-Deming Algorithm, is simple pro-ration of the difference between the observed total and the sum of the simulated end uses based on the magnitude of the original simulated estimates (SRC 1988). If, for example, there are only two end uses and one is simulated to be twice the size of the other, two thirds of the difference between the simulated total and the control total is allocated to the larger end use. This approach has been used to estimate commercial sector end-use load shapes for the Southern California Edison Company. More flexible versions of this simple allocation have been implemented in the RELOAD software discussed in the next section.

Another allocation rule, called the variance allocation approach, involves pro-rating the difference between the simulated and control totals based on the observed statistical variation in the simulated end-use loads (Schon 1990). The basic intuition for this approach is that loads which are highly variable are more likely to account for any differences between a point estimate of their magnitude, as produced by a simulation, than loads which are relatively stable. (Of course, the magnitude of the observed variation is also related to the magnitude of the initial load.) This approach has been applied to a study of commercial buildings in the Florida Power and Light Company service territory.

A final deterministic reconciliation method, called the End-Use Disaggregation Algorithm, treats weather-sensitive end uses (cooling and heating) separately from other end uses (Akbari et al. 1988). An exact estimate of the weather-sensitive end use is first derived from a regression of the control totals on temperature for each hour of the day. (An intercept for the weather sensitive end-use estimated from an analysis of the simulated end-use data is also included to account for non-weather-sensitive cooling or heating.) The allocation of any remaining differences between the simulated and control total takes place only after the weather-sensitive end use has been subtracted from the control total. The allocation is based on the magnitude of the initial simulated loads (as is done in the Stephan-Deming method), subject to continuity constraints placed on adjacent hours. The motivation for this approach is the assumption that the correlation of measured whole-building loads to observed weather is superior to simulations for estimating weather-sensitive, end-use load shapes. The approach has been used to develop end-use energy utilization intensities (EUIs) and load shapes for commercial buildings in the Southern California Edison service territory (Akbari et al. 1989).

Statistical methods, which include methods 4 through 6, represent another major approach for utilizing whole-building load shape data in developing load shapes. As with the deterministic methods, the principal challenge is reconciliation of selected explanatory variables with some control total. For the deterministic methods, the explanatory variables are taken from an engineering simulation so as to provide a physical basis for the reconciliation (i.e., we are

adjusting estimates of end-use loads to match an observed or estimated, control total) and the reconciliation to the control total is exact. The statistical methods typically rely on regression techniques that correlate explanatory variables with the hourly control total. These variables need not all be physical, and the "reconciliation" to the control total is usually expressed as a goodness of fit.

The earliest application of the statistical method to end-use load shape estimation was a direct extension of the conditional demand techniques used to estimate annual energy utilization intensities (EUI), which express end-use energy use per unit floor area, or unit energy consumption (UEC), which express energy use per appliance. The conditional demand approach is essentially a correlation analysis of the energy use of many separate premises (e.g., households or firms) against the energy-using equipment in each of these premises. The analysis seeks to determine the difference in observed load due to the presence of a given energy-using device, all other things being held equal. This difference is taken to be the energy contribution of the device. The technique was first applied to annual and monthly billing data (Parti and Parti 1980). With the availability of whole-building load shape data, the extension of the technique to an hourly time-step was an obvious one. Published applications of this approach include Hill (1982), Parti and Sebald (1984), and Aigner, Soorishian, and Kerwin (1983).

Purely correlational methods for end-use load shape estimation can be criticized for ignoring (or making little explicit use of) known engineering principles that affect energy use (such as the influence of weather on heating and cooling loads). Recently, two very different methods for incorporating these principles within a statistical framework have been developed. In effect, these methods are hybrids of the engineering approaches that underlie the deterministic methods and the previously described statistical correlations.

The first method, called the bi-level regression approach, involves two levels of time-series and cross-section regression analyses (SSI 1986). In the first level, the hourly load of individual households is regressed against both weather-related variables, and sine and cosine functions, which capture daily, weekly, and seasonal periodicity in loads that are independent of weather. In the second level, the coefficients estimated in the first level (separately for each individual household) are regressed as a group against customer characteristics.

The second method, called the Statistically Adjusted Engineering approach (SAE), is very close in spirit to the deterministic reconciliation methods (CSI/CA/ADM 1985). First, an engineering simulation is developed to provide an initial estimate of end-use loads. (A more recent implementation of this approach incorporates metered end-use load shape data from a limited sample of premises as the initial estimate for selected end-uses. See Caves, et al. 1988.) Next, the initial estimates are regressed against the control totals, which are averages of hourly energy use for typical days. The estimated coefficients can then be thought of as adjustment factors that reconcile the initial estimates to the control total. In other words, correlational analysis is used to perform the allocation of differences statistically, whereas, in the first three methods, the allocation is performed deterministically.

Deterministic and statistical estimation methods both exhibit desirable qualities for end-use load shape development. Deterministic methods rely on engineering simulations that provide a direct physical link between loads and their causes. Explicit specification of an engineering simulation also facilitates subsequent planning analyses of the likely effect of introducing demand-side technologies. The price of such explicitness is the cost of obtaining the detailed information required to specify an engineering simulation. Statistical methods are valuable because the information typically used to develop an engineering simulation is unable to capture the behavioral dimensions of energy use. Physically identical structures will use energy differently because energy-use decisions are made by individuals, not buildings. To the extent that the explanatory variables are independent, exhibit variation across the sample, and most importantly, are statistically significant, statistical techniques can capture these behavioral influences implicitly. However, the resulting models of energy use may not be equally amenable to "what if" types of analysis because the physical underpinnings of energy use are suppressed. Of course, from the more limited standpoint of end-use load shape data development, the issue is one of the accuracy of these methods (and their cost relative to alternative methods of obtaining these data).

3.3 Validating End-Use Load Shape Data Estimates with Measured Data

The availability of end-use metered data provides, for the first time, the opportunity to validate end-use load shape estimation methods. However, efforts to use these data for this important task remain in their infancy; we are aware of only two studies, both examining only residential end uses, that have used end-use load shape data for validation purposes.

The first study focussed not on end-use load shapes, per se, but on the integrated sum of the hourly values to annual energy use totals by end use (Pratt et al. 1990). In this study, metered residential end-use data from several metering projects were compared to estimates of these end-uses developed by conditional demand and engineering studies. The conditional demand estimates were found to be in good agreement ($\sim 10\%$ at the level of annual energy use totals) with the metering studies for refrigerators, freezers, dryers, ranges, and central air conditioning. Poor agreement was found for dishwashers (the conditional demand estimate was too high), hot water (too low) and space heating (too high; although the comparison is suspected as having been influenced by the weather normalization method applied to the various study results). The engineering estimates were found to be in good agreement with the metering studies for water heating, refrigeration, and clothes washing (clothes washing was not examined by the conditional demand studies), but were in poor agreement for space heating (too high), central air conditioning (too high), ranges (too high), and dishwashers (too high).

A second study evaluated the accuracy of load shapes estimated using the SAE and the bi-level regression approaches described above (CSI/CAI/SSI 1989). The validation was performed using residential end-use metered data gathered by the Pacific Gas and Electric Company and an engineering simulation for each load. For the SAE approach, substantial improvement over the engineering load estimates was observed for the weather-sensitive end uses. For the non-weather-sensitive end uses, the SAE approach appeared to introduce errors

to the engineering load estimates. Finally, the SAE weather sensitive end-use loads were more accurate for average days than for peak days. For the bi-level regression approach, the most accurate loads were estimated for the central air conditioning and clothes drying, while the least accurate loads were those estimated for refrigerators and water heaters.

These validation studies suggest that, at this time, statistical end-use load shape estimation methods may be well-suited for capturing "scheduled," non-weather sensitive end uses. More importantly, they substantiate the potential reliability of the estimation methods for obtaining end-use load shape data at costs far less than end-use metering. The lack of validation effort for the deterministic methods precludes conclusions at this time. Additional validation efforts for all the methods over a wider range of locations, building types (especially, in the commercial sector), and end-uses will be required before the methods can be regarded as complete substitutes for end-use load metering. However, as we shall describe, it is not clear that future load shape data development efforts should be faced with such an either/or decision.

4. END-USE LOAD SHAPE DATA COLLECTION

The most intuitively appealing approach for developing end-use load shape information is to collect the data directly by metering the desired end-uses. Given the high cost of end-use metering (which should, but often does not, include the necessary costs of analysis following the collection of data), it has been impractical to carry out data collection for more than a small sample of the population. Efforts to reduce these costs and to increase the explanatory power of data already collected are the focus of future work.

4.1 Historical End-Use Load Shape Data Collection Efforts

The earliest efforts to collect end-use load shape data for utility planning date back to publications in the 1960's by the Load Research Committee of the AEIC. These studies of individual, predominantly residential loads, such as electric water heating and air conditioning, were performed in support of utility electricity marketing efforts (AEIC 1974). In the late 1970's and early 1980's, these studies were joined by a host of individual building metering studies that were typically parts of research studies of the performance of conservation technologies. (A good summary of many commercial sector projects can be found in Heidell et al. (1984).)

The distinguishing feature of these early studies is that the statistical representativeness of the results was not a major focus of the analyses (by definition, in the case of individual building studies). In large part due to the high cost of direct metering but also due to the fact that incorporation of the results into a utility planning process was never envisioned as part of the research design, these studies are of secondary importance for most utility planning purposes. Where some degree of statistical representativeness did enter into the research design, as was the case for some of the AEIC studies, the age of these studies (some of which are close to 30 years old) makes continued use problematic.

4.2 Current State-of-the-Art

More recently, electric utilities, realizing the value of end-use load shape data for planning purposes, have engaged in a number of end-use load shape metering studies. What distinguishes these studies is that the samples are often large and, more importantly, use of the results for utility planning is an explicit and major justification for the projects.

We have identified some 27 recent end-use metering projects in the U.S. (see Table 1.). The list of commercial sector projects is felt to be reasonably complete and includes several just getting underway; however, the list of residential projects may reflect biases due to the authors' location in the western part of the U.S. We are not aware of any industrial sector end-use metering efforts involving sample sizes approaching those of the projects in Table 1.

The first four columns of Table 1 describe the sponsor of the project, the geographic area under study, the project name, and the customer sectors under study. Note that several sponsors have more than one project (or one project that covers multiple segments of the residential, multifamily, and commercial building sectors). Multiple projects by a given sponsor are a testament to the increased importance these sponsors place on the use of metered data for improving planning assumptions and estimates.

Column five indicates the type of sample design used. Recall that the applications described in the first section provided two primary motivations for the designs of metered samples: (1) characterization of the building population for planning and forecasting purposes; and (2) evaluation of the impacts of specific demand-side technologies or programs. Statistically-based sample designs are generally used to obtain data in support of the planning/forecasting process. These designs are based on customer billing or survey data so that the metered buildings can be analyzed as representing a larger population. The use of metering to support evaluations of individual technologies or programs is typically based on a non-random sample of participants in the program, although some retrofit programs have relied on statistical sampling procedures. For new building programs, the samples are almost always a somewhat arbitrary (statistically speaking) set of experimental buildings from a pilot test of the program. Some of these projects will also include a parallel set of newly constructed buildings representing current practice as controls for the experiment. Other sample types indicated in Table 1 include studies of buildings selected for specific reasons such as high consumption or presence of particular appliances (termed Special) and those studies that seek to capture geographical diversity within a region (termed Geographical). In general, these latter two sample types do not formally incorporate statistical sampling procedures.

Columns six, seven, and eight indicate the scope of the projects as measured by the number of buildings, average number of end uses per building, and total number of end uses metered.

Columns nine and ten indicate the monitoring protocol and primary method used for quality control by each project. The protocols used to define end uses are split into three groups:

TABLE 1. Recent Major End-Use Metering Projects

Sponsor	Geographic Area	Project Name	Sector[1]	Sample Type[2]	N. of Bldgs	EU/ Bldg[3]	Total EUs	Protocol Type[4]	Quality Control[5]	Time Resol.	Duration (Yrs)	Status
Bonneville Power Administration	Hood R., OR	Hood River	RES	Retro/Stat	314	3	942	All EU-Sub	Limit	15-Min	5	Completed
	Pacific NW	RSDP	RES	Exp/Ctrl	422	3	1266	All EU-Sub	Limit	Weekly	2	Completed
	Pacific NW	ELCAP-Base	RES	Statistical	288	8	2304	All EU	Sumcheck	Hourly	5	On-Going
	Pacific NW	-Case	RES	Special	56	8	448	All EU	Sumcheck	Hourly	5	On-Going
	Pacific NW	-RSDP	RES/MF	Exp/Ctrl	155	8	1240	All EU	Sumcheck	Hourly	6	On-Going
	Seattle, WA	-Base	COM	Statistical	103	12	1236	All EU	Sumcheck	Hourly	4	On-Going
	Pacific NW	-CREUS	COM	Retrofit	40	12	480	All EU	Sumcheck	Hourly	4	On-Going
	Pacific NW	Energy Edge	COM	Experimental	28	7	196	All EU	Sumcheck	Hourly		Start Up
Seattle City Light	Seattle, WA	CHEUS	COM	Retro/Stat	7	3	21	All EU-Sub	Limit	Hourly	6	Completed
Tacoma City Light	Tacoma, WA	Multifamily	MF	Exp/Ctrl	100	3	300	All EU	Sumcheck	Hourly	-	Start Up
U.S. DOE & EPRI	National	MRI	RES	Statistical	150	6	900	Select EU	?	Monthly	1	Completed
Pacific Gas & Electric	N. Calif.	AMP	RES	Statistical	750	3	2250	Select EU	Visual	30-Min	2+	?
	N. Calif.	MYCE	COM	Statistical	45	5	225	All EU	Sumcheck	30-Min	-	Start Up
Southern California Edison	S. Calif.		RES	Special	124	4	496	Select EU	Visual	5-Min	2+	?
	S. Calif.		RES	Geographical	100	4	400	Select EU	Lim/Vis	5-Min	-	Start Up
	S. Calif.	RESA	COM	Geographical	53	4	212	All EU-Sub	Lim/Vis	15-Min	2	Ongoing
Sierra Pacific	Nevada, E.Ca.	EIP-Res	RES/MF	Statistical	105	4	420	Select EU	Visual	?	?	?
		-Com	COM	Statistical	105	4	420	Select EU	Visual	?	?	?
Wisconsin Electric	Milwaukee, WI		COM	Statistical	50	4	200	Select EU	Visual	15-Min	-	Start Up
Northeast Utilities	Connecticut		RES	Exp/Ctrl	250	4	1000	Select EU	Visual	15-Min	-	Start Up
	Connecticut		COM	Exp/Ctrl	75	5	375	Select EU	Visual	15-Min	-	Start Up
Several Utilities	Massachusetts	JUMP	RES	Statistical	28	3	84	Select EU	Visual	?	2+	?
Arizona Public Service	Arizona	LCEP	RES	Exp/Ctrl	100	3	300	Select EU	Visual	15-Min	2	?
Gulf States Utilities Co.	?		RES	Special	232	4	928	All EU-Sub	Lim/Vis	?	?	?
Consolidated Edison	New York		RES	Statistical	396	2+	792+	Select EU	Visual	?	?	Completed
State of Texas	Texas		COM	Retrofit	-	-	-	-	-	-	-	Start Up
Pennsylvania Power & Light	Pennsylvania		COM	Statistical	49	3	147	All EU-Sub	Lim/Vis	?	1	Completed

[1] Sectors: RES - Residential MF - Multifamily COM - Commercial

[2] Sample Type Abbreviations: Retro/Stat - Retrofit/Statistical Exp/Ctrl - Experimental and Control

[3] Average number of end-uses per building (approximate); one may be by end use by subtraction for All EU-Sub

[4] End Use Protocol Type: All EU - separately metered; All EU-Sub - one by subtraction; Select EU - selected end uses/appliances only

[5] Quality Control Abbreviation: Lim/Vis - Building total limit and visual reasonableness checks

(1) those in which all defined end uses and a separate building total are metered (All EU); (2) those which meter at least the total and the major end uses but obtain the remainder by subtraction (All EU-Sub); and (3) those which meter only selected appliances or end uses in each building (Select EU). Among other things, the protocols determine the quality control procedures that may be applied. These procedures include: a continuous energy balance using the building total as a sum-check; limit checks against monthly utility bills (if the "remainder" end use is small relative to the total consumption); and visual reasonableness and continuity checks when only selected end uses are metered.

Column eleven indicates the level of aggregation of the metered data. The time resolution of the data is typically 5- or 15-minute intervals for regions where peak loads are the central planning issue, and hourly where annual energy is the primary concern (the Pacific Northwest).

Finally, columns twelve and thirteen indicate the duration of the projects and their current status, where known.

Metering end uses for a large sample of building is expensive. The costs depend on the level of detail called for by the measurement protocol and on whether economies of scale can be realized with a given sample size. Fully burdened costs for large, detailed, all end-use protocol projects including sum-check quality control procedures and a duration of two years are currently in the range of $15-25k per commercial building and $3-7k per residential building. This is roughly equally split between installation and maintenance, with the installation costs about equally split between hardware and labor. Importantly, these costs do not include the considerable effort required to develop software in order to archive and analyze the data.

These costs also mean that despite the explicit reliance on statistical techniques in some of the sample designs, the final samples are often not very large for a give strata. As a consequence, the resolution of the analyzed data is often not very precise. For example, it is not uncommon to find that standard deviation across buildings for a given end use are equal to or greater in magnitude than the observed mean. Statistically speaking, this means that the null hypothesis of the measured load being equal to zero cannot be rejected at the 95% confidence level!

4.3 Lowering the Costs of End-Use Load Shape Data Collection

The desire for increased statistical precision in end-use load shape estimates calls for research in three technical areas of end-use load shape data collection: (1) sample size determination; (2) project duration; and (3) metering costs per end use. It also provides a justification for seeking less expensive means for obtaining end-use load shape data such as the estimation techniques described in the previous section and, as we shall describe, the use of end-use load shape data collected by others (or data transfer).

We are not aware of specific studies examining the issue of increased end-use load shape data precision as a function of sample size. We note from our experience, however, that mean

end-use loads tend to stabilize with sample sizes of about 20. Nevertheless, even larger samples may be required to explain observed variances. For example, Pratt et al. (1990) have observed that some causal relationships such as the effect of number of occupants on water heating loads can be obscured by other sources of variance when the sample size falls below 20. At the same time, other variance reduction techniques are possible. Wright and Richards (1989) have suggested that it is possible to link small end-use metered samples with larger, whole-building load research samples to increase sample sizes, thus reducing variance, and thereby make end-use load estimates from very small samples representative of larger populations.

On the issue of reducing the duration (and cost) of metering projects, there is evidence that the seasonal variation in nearly all residential and many commercial end-uses (+10 to 20% of the mean) will preclude metering periods of less than a year from producing accurate results for some end-uses (Pratt et al. 1990 and Taylor and Pratt 1989). On the other hand, for some highly scheduled, non-weather dependent end-uses, such as commercial lighting and water heating, shorter duration metering periods may be warranted. At the same time, it should be recalled that the fixed costs of installing metering equipment are roughly half the total costs of metering (excluding analysis of the data) and that multi-year data also allow for study of price elasticity, occupancy and behavioral changes, retrofits and equipment changes, and the persistence of savings from demand-side measures, among other topics.

More recently, efforts have been made to reduce the direct costs of metering end uses. One approach involves the use of decomposition techniques that track total electricity consumption at an extremely high level of time-resolution in order to capture the "signature" of individual pieces of equipment turning on and off (Jones, and Flagg 1989). Separate end-use loads are automatically produced by this decomposition, which in effect reduces the number of metering points per building to one, while offering the possibility of expanding the number of end uses metered per building to equal the number of individual pieces of electricity-using equipment within the building. Another extremely promising approach involves the use of existing energy management systems as a direct source of equipment operating profiles (Flora, LeConiac, and Akbari 1986). (We also refer the reader to Misurello (1990) for a review of the state of the art in building energy performance monitoring.)

4.4 Using End-Use Load Shape Data Collected by Others

Perhaps the least expensive means for obtaining metered, end-use load shape data lies, not with optimized sampling designs and better hardware, but with the transfer of results from existing metering studies. Prior to the recent era of end-use metering, which began around 1984, almost all utility applications of end-use load shape data relied on either secondary or estimated data. Attitudes were pragmatic: some metered data, from any source, was considered better than none simply because one did not have the ability to judge these data independently.

In addition to the "grey" literature of utility reports on individual metering projects (see the references for a selective listing of the reports underlying the metering studies reported in Table 1), we are aware of few published end-use load shape data compilations. Notably, the

Bonneville Power Authority (BPA) has produced two major compilations of end-use load shape data from its ELCAP project, one for the residential and one for the commercial buildings being metered (Pratt et al. 1989 and Taylor and Pratt 1989). In addition, Ruderman et al. (1989) have compiled and analyzed residential end-use load shape data collected by California utilities in order to provide inputs for the California Energy Commission's peak load forecasting model. Finally, there is a relatively new software package, RELOAD (SRC/LCA/BCD 1988), which is distributed with a library of reference end-use load shapes that have been drawn from a number of sources, including engineering simulation and end-use metering.

Today, the increasingly extensive geographic coverage of end-use metering projects suggests that an adequate range of climatic and cultural diversity may nearly exist to characterize the residential sector for most of the U.S. and that this will also soon be achieved in the commercial sector. However, the wide-spread availability of these data will hinge on resolution of two important institutional and analytical issues.

Institutionally, there remains the need to establish mechanisms for equitably sharing and promoting the use of this expensive resource. An important issue is the confidentiality and propriety of data from "donor" utilities. Currently an informal questionnaire is being circulated to potential users and suppliers of data to help define parameters for some form of institutional data sharing (BPA 1990).

Analytically, substantial transferability issues remain un-addressed. These issues include climate normalization, control for regional structural characteristics, and control for occupant characteristics. We presume that these factors are responsible for a large part of the observed variability of end-use load shapes, along with a number of as yet to be determined possibly random factors. Analysis to determine the nature of the influence of these factors on load shapes, leading to methods to adjust and transfer load shapes, is straightforward conceptually, but complex in practice. Considerable demonstration will be required to convince potential users that transferability is possible.

Two recent studies have begun to explore some of the prospects for load data transferability by comparing end-use load shape data from more than one metering study. The first study examined residential hourly load shape data aggregated to annual totals (or UECs) from four sources (Pratt et al. 1990). Reasonable agreement among the studies was found for refrigeration, freezing, clothes washing, and hot water use, which suggests a certain consistency in behavior in the use of these appliances for these end uses. Larger differences were found for space heating, central air conditioning, clothes drying, ranges, and dish washing.

A second, previously mentioned, study compared end-use metered load shapes from recent residential end-use metering projects sponsored by California utilities (Ruderman et al. 1989). End uses were first normalized by total energy use so that the comparison focussed solely on differences in load shapes (not annual UECs). Not all end uses were metered by each project, but for the non-conditioning end uses that were metered by more than one project (including refrigeration, cooking, clothes drying, and water heating) very good agreement was

observed for normalized load shapes. Conditioning load shapes (room and central air conditioning) were first transformed into a matrix relating energy use to time of day. Temperature-humidity indices and load shapes were produced for peak days in several California climate zones. The normalized load shapes again showed very close agreement with one another.

5. TOWARDS THE NEXT GENERATION OF END-USE LOAD SHAPE DATA DEVELOPMENT

We have reviewed recent efforts to apply, estimate, and collect end-use load shape data. Substantial progress has been made from the days when utility planning relied on independent (non-end-use) forecasts of peak load and energy use, and generally treated these future energy demands as immutable. Today, the value of end-use load shape data to inform and thereby improve utility planning decisions is largely undisputed. (See Gellings and Swift (1988) for example of how this value can be quantified.) Progress in the application, collection, and estimation of end-use load shape data will be rapid. In this section, we sketch our observations on some of these directions.

Historically, potential applications have always led efforts to develop end-use load shape data. End-use load forecasting was well on its way toward becoming accepted utility planning practice several years before the initiation of recent end-use metering projects. We suspect that as end-use planning methods mature the need for end-use load shape data will increase. In particular, we believe that increased utility reliance on demand-side management options will only come about through increased utility confidence in the performance of these options.

We also believe that increasingly sophisticated end-use planning approaches will also call for new types of end-use data. For example, historic segmentation along building structural/operational characteristics (such as single family residences or large offices) was based on a physical characterization of the ways in which energy is used. Shifting to a more behavioral characterization will call for load shapes segmented along very different lines in which the end user categories become, say, income level, form of property ownership, or membership in a "needs-based" market segment. (See NA/SRC/QEI (1989) for a description of this approach.) In this case, the planning needs are not for a new "end use", per se, but rather for increased supplementary data collection efforts so that existing end uses can be better understood.

As noted above, in the absence of metered data, analysts and planners were forced to develop load shape information through assumptions about usage patterns, engineering simulation, statistical disaggregation of whole-building loads, and various combinations. A certain level of uncertainty exists with each of these techniques because they could not be validated without some end-use metered data. For this reason, all end-use load shape data users owe a debt of gratitude to the pioneering efforts by a handful of utilities to undertake comprehensive, well-designed end-use metering projects. The data from these projects offer the potential for extremely valuable data validation and leveraging efforts. These could take the form of adjustment techniques for transferring the load data from one location to another, testing

and validation of various load shape estimation methods, and incorporation as new information into those same estimation methods.

In the near future, end-use data development techniques that leverage, or combine, features of engineering knowledge, prior end-use metering results, and statistical analysis of survey, billing, and load research data should be able to provide reliable, cost-effective information on end-use load shapes. Moreover, they will do so at a cost far less than that of large end-use metering projects. This scenario would suggest that future end-use metering projects be designed in close coordination with a comprehensive end-use load shape development effort. It might consist of: (1) metering targeted at market segments or technologies for which little or no data are available; and (2) small end-use metering samples designed to be leveraged with less expensive survey and whole-building load data.

For end-use data development efforts to reach this level of maturity, a number of activities must take place. These involve important synergisms, and would benefit greatly by proceeding jointly. The following three general recommendations illustrate the type of process that could take place over the next few years.

First, existing end-use metering projects should soon provide adequate coverage of the most important building types, end uses, and geographic regions. Efforts to more fully exploit these data sources should be a high priority for future research. The primary goal of these efforts should be to develop the analytical procedures necessary to permit meaningful transfer of load shape data from one utility service territory to another. The procedures must explicitly capture the causal relationships underlying observed load shapes in order to control for differences in climate, building characteristics, and occupant behavior between service territories. These analytical efforts should proceed in parallel with institutional efforts to facilitate data transfer in which issues of confidentiality and propriety of data from "donor" utilities must be addressed.

Second, end-use load shape estimation methods should be able to produce data of sufficient accuracy for utility planning purposes. In particular, there is great promise for the use of hybrid estimation methods, which combine the best aspects of simulations, statistical analyses, and measured data. Efforts to utilize recent end-use metered data to validate estimation methods should be given the highest priority for research. From the standpoint of improving the estimation methods, a major challenge lies in determining the optimal amount of non-load shape data collection needed to support load shape estimation.

Third, it is likely that the realization of these two research objectives, again, driven by increased utility applications for end-use load shape, will still call for end-use load shape metering efforts. These efforts will be a healthy sign for load shape development efforts, if incremental metering efforts are informed by the progress in load shape data transfer and estimation methods taking place in coordination.

The costs of developing load shape data for utility planning can be significant, ranging in descending order from end-use metering to estimation, to data transfer. Yet the benefits from improved resource planning will easily outweigh these costs. The issue for future end-use load shape development is not one of whether, but of how. We believe society will be best served when these efforts incorporate all potential sources of data including metering studies from other service territories, estimation based on utility-specific data, and local end-use metering. The challenges for future research lie in determining a cost effective balancing of these sources, not choice of one over the other.

6. ACKNOWLEDGEMENTS

The work described in this study was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Utility Technologies, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

7. REFERENCES

Aigner, D., Sorooshian, C., and Kerwin, P. 1983. Conditional Demand Analysis for Estimating Residential End-Use Load Profiles. Working Paper, University of Southern California, Los Angeles, CA.

Akbari, H., Eto, J., Turiel, I., Heinemeier, K., Lebot, B., Nordman, B., and Rainer, L. 1989. Integrated Estimation of Commercial Sector End-Use Load Shapes and Energy Intensities, Final Report. LBL-27512, Lawrence Berkeley Laboratory, Berkeley, CA.

Akbari, H., Heinemeier, K., LeConiac, P., and Flora, D. 1988. "An Algorithm to Disaggregate Commercial Whole-Building Electrical Loads into End Uses." In Proceedings from the ACEEE 1988 Summer Study on Energy Efficiency in Buildings. American Council for an Energy Efficient Economy, Washington, DC.

Akbari, H., Turiel, I., Eto, J., Heinemeier, K., Lebot, B., and Rainer, L. 1990. "A Review of Existing Energy Use Intensity and Load-Shape Studies." In Proceedings from the ACEEE 1990 Summer Study on Energy Efficiency in Buildings. American Council for an Energy Efficient Economy, Washington, DC.

Association of Edison Illuminating Companies (AEIC). 1974. "Bibliography of Load Research Committee Reports." mimeo, New York, NY.

Bonneville Power Administration. 1990. End-Use Data Interest Survey. Bonneville Power Administration, Portland, OR.

Braithwait, S. 1989. "Measuring Direct Load Control Impacts." EPRI Journal. Electric Power Research Institute, Palo Alto, CA, December.

Brodsky, J. and McNicoll, S. 1987. Residential Appliance Load Study, 1985-1986. Pacific Gas and Electric Company, San Francisco, CA.

Caves, D., Windle, R., and Kendall, D. 1988. "Residential End-Use Load Shapes: A Case Study." Presented at Demand-Side Management Symposium: Managing the Shape of Tomorrow. Albany, New York. May 3-5.

Cambridge Systematics, Inc., Christensen Associates, Inc., and ADM Associates (CSI/CAI/ADM). 1985. Combining Engineering and Statistical Approaches to Estimate End-Use Load Shapes, Volumes 1 and 2. EPRI-EA-4310, Electric Power Research Institute, Palo Alto, CA.

Cambridge Systematics, Inc., Christensen Associates, Inc., and Scientific Systems, Inc. (CSI/CAI/SSI). 1989. End-Use Load Shape Estimation: Methods and Validation. forthcoming, Electric Power Research Institute, Palo Alto, CA.

Comnes, G., Kahn, E., Pignone, C., and Warren, M. 1988. "An Integrated Economic Analysis of Commercial Thermal Energy Storage." IEEE Transactions on Power Systems, v. 3, n. 4, pp. 1717-1722.

Decision Focus, Inc. (DFI). 1982. Load Management Strategies Testing Model. EPRI-EA-2396, Electric Power Research Institute, Palo Alto, CA.

Electric Power Software (EPS). 1989. DSManager User's Guide. EPRI- CU-6564-CCML, Electric Power Research Institute, Palo Alto, CA.

Eto, J. 1990. "An Overview of Integrated Resource Planning Models." Energy, the International Journal, accepted for publication.

Eto, J., Blumstein, C., and Jaske, M. 1988. "Changing Needs in Electricity Demand Forecasting: A California Perspective." In Proceeding from the ACEEE 1988 Summer Study on Energy Efficiency in Buildings. American Council for an Energy Efficient Economy, Washington, DC.

Farber, M., Brusger, E., and Gerber, M. 1988. Multiobjective Integrated Decision Analysis System (MIDAS), Volume 1, Model Overview. EPRI-P-5402, Electric Power Research Institute, Palo Alto, CA.

Flora, D., LeConiac, P, and Akbari, H. 1986. "Methods to Obtain Building Energy Performance Data: Are Energy Management Systems Promising Sources?" In Proceedings from the Energy Technology Conference. Washington, DC.

Gellings, C. and Swift, M. 1988. "The Value of Load Research," Public Utilities Fortnightly, June, 9.

Goldman, C., Hirst E., and Krause, F. May 1989. Least-Cost Planning in the Utility Sector: Progress and Challenges. LBL-27130, Lawrence Berkeley Laboratory, Berkeley, CA.

Heidell, J., Mazzucchi, R., and Reilly, R. 1984. "Development of a Data Base on End-Use Energy Consumption in Commercial Buildings." In Proceedings from the ACEEE 1984 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington, DC.

Hill, D. 1982. "The Time-of-Day Demand for Electricity by End Use: An Analysis of Wisconsin Data." In Analysis of Residential Response to Time-of-Day Prices. EPRI-EA-2380, Electric Power Research Institute, Palo Alto, CA.

ICF, Inc. 1985. The Hourly Electric Load Model (HELM), Volume 1: Design, Development, Demonstration. EPRI-EA-3698, Electric Power Research Institute, Palo Alto, CA.

Jaske, M. 1980. "Analysis of Peak Load Demand Using and End-Use Load Forecasting Model." In Proceedings of the EPRI End-Use Models and Conservation Analysis Workshop. EPRI-EA-2509, Electric Power Research Institute, Palo Alto, CA.

Jones, R. and Flagg, D. 1989. "A Preliminary Qualification Testing of EPRI's Non-Intrusive Load Monitor." In Proceedings from the Information and Automation Technology Serving Electric Utility Customers in the 1990's Conference. EPRI-CU-6400, Electric Power Research Institute, Palo Alto, CA.

Krause, F., and Eto, J. 1988. Least-Cost Utility Planning, A Handbook for Public Utility Commissioners, Volume II, The Demand- Side: Conceptual and Methodological Issues. National Association of Regulatory Utility Commissioners, Washington, DC.

Lotus Consulting Group. 1986. UPLAN Reference Manual. USAM Center, Los Altos, CA.

Misurello, H. 1990. "A State-of-the-Art Review: Building Energy Performance Monitoring." In Proceeding from the ACEEE 1990 Summer Study on Energy Efficiency in Buildings. American Council for an Energy Efficient Economy, Washington, DC.

National Analysts, Synergic Resources Corporation, and QEI, Inc. (NA/SRC/QEI) 1989. Residential Customer Preference and Behavior: Market Segmentation Using CLASSIFY. EPRI-EM-5908, Electric Power Research Institute, Palo Alto, CA.

Parti, M., and Parti, C. 1980. "The Total and Appliance-Specific Conditional Demand for Electricity in the Household." The Bell Journal of Economics, Spring, pp. 309-321.

Parti, M., and Sebald, A. 1984. "Integrated Load and Time of Day Models for Electricity in Residences." In Proceedings from the ACEEE 1984 Summer Study on Energy Efficiency in Buildings. American Council for an Energy Efficient Economy, Washington, DC.

Pratt, R., Conner, C., Richman, E., Ritland, K., Sandusky, W., and Taylor, M. 1989. Description of Electric Energy Use in Single Family Residences in the Pacific Northwest. DOE/BP-13795-21, Bonneville Power Administration, Portland, OR.

Pratt, R., Conner, C., Cooke, B., and Richman, E. 1990. "Metered End-Use Consumption and Load Shapes from the ELCAP Residential Sample of Existing Homes in the Pacific Northwest" accepted for publication in Energy and Buildings.

Quantum Consulting, Inc. 1989. Residential Appliance End Use Survey: Collection of Residential Appliance Time of Use Energy Load Profiles, 1987/1988, Final Report. Southern California Edison Company, Rosemead, CA.

Quantum Consulting, Inc. 1990. Residential Energy Usage Comparison Project: An Overview. forthcoming report for EPRI RP2863-3, Electric Power Research Institute, Palo Alto, CA.

Rosenblum, B., and Eto, J. 1986. Utility Benefits from Targeting Demand-Side Management Programs at Specific Distribution Areas. EPRI-EM-4771, Electric Power Research Institute, Palo Alto, CA.

Ruderman, H., Eto, J., Heinemeier, K., Golan, A., and Wood, D. 1989. Residential End-Use Load Shape Data Analysis. LBL-27114, Lawrence Berkeley Laboratory, Berkeley, CA.

Schon, A., Rodgers, R. 1990. "An Affordable Approach to End Use Load Shapes for Commercial Facilities." In Proceedings from the ACEEE 1990 Summer Study on Energy Efficiency in Buildings. American Council for an Energy Efficiency Economy, Washington, DC.

Scientific Systems, Inc. (SSI). 1986. Residential End-Use Load Shapes. EPRI-EM-4525, Electric Power Research Institute, Palo Alto, CA.

Stovall, T. 1989. "Load Shape Impacts of the Hood River Conservation Project." Energy and Buildings, 13, pp. 31-37.

Synergic Resources Corporation (SRC). 1989. SRC/COMPASS Comprehensive Market Planning System, Users Guide. Synergic Resources Corporation, Bala Cynwyd, PA.

Synergic Resources Corporation, Laurits R. Christensen Associates, and Batelle-Columbus Division (SRC/LCA/BCD). 1988. DSM Customer Response, Volume 1: Residential and Commercial Reference Load Shapes and DSM Impacts. EPRI-EM-5767, V. 1, Electric Power Research Institute, Palo Alto, CA.

Taylor, Z., and Pratt, R. 1989. Description of Electric Energy Use in Commercial Buildings in the Pacific Northwest. DOE/BP-13795-22, Bonneville Power Administration, Portland, OR.

Wright, R., and Richards, D. 1989. "Developing Information for Commercial Sectors Through Direct Metering." In Proceedings of the End-Use Load Information and Application Conference. The Fleming Group, East Syracuse, NY.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
INFORMATION RESOURCES DEPARTMENT
BERKELEY, CALIFORNIA 94720