A REVIEW OF EXISTING COMMERCIAL ENERGY USE INTENSITY AND LOAD-SHAPE STUDIES

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This paper reviews and compares existing studies of energy use intensities (EUIs) and load shapes (LSs) in the commercial sector, focusing on studies that used California data. Our review of EUI studies found fairly good agreement on electric lighting and cooling EUIs. Other EUIs, notably electric miscellaneous in offices, retail, and food stores; electric refrigeration in restaurants and warehouses; electric cooking in restaurants; and electric water heating and ventilation for all types of premises exhibited the largest variations. The major variations in gas EUIs were found in restaurants (all end uses) and food stores (cooking and water heating).

Our review of LS studies, which included existing LSs in use by Southern California Edison (SCE) Company, the California Energy Commission (CEC), and a Lawrence Berkeley Laboratory (LBL) study, uncovered two significant features of existing LS estimates. First, LSs were generally not consistent between studies (e.g., SCE and CEC had different load shapes for the same end use in the same type of premises), but these differences could often be related to differences in assumptions for operating hours. Second, for a given type of premise, LSs were often identical for each month and for peak and standard-days, suggesting that, according to some studies, these end uses were not affected by seasonal or climatic influences.

INTRODUCTION

Energy use and peak demand modeling is an integral part of electricity forecasting programs for both electric utilities and various governmental agencies. Supply-side planning (and more recently, demand-side planning) is based on estimates of the current and future energy use and peak power demand.

Various forecasting models--from simple extrapolation of the historical trends to more detailed end use modeling--are used throughout the country to estimate energy use by sector. The more detailed models segregate the market into major components such as buildings (commercial and residential), industry (assembly, process), agriculture, and model the energy and peak demand of each component separately. The basic ingredient of all the sub-models include: estimates of annual energy use intensity (EUI) (or unit energy consumptions), estimates of unit peak power demand, estimates of market size (e.g., floor area of office buildings), and estimates of saturation of particular end uses or technologies (e.g., saturation of fluorescent lighting in small office buildings or saturation of adjustable speed drives in process industries).

For the building sector, end-use energy demand forecasting is data intensive. End use energy data, either in the form of energy use intensities (EUIs) or load shapes (LSs), are difficult and costly to collect. Eto et al. (1990) present a state-of-the-art review of end-use load shapes data application, collection, and estimation methods. Yet, they are a crucial input to the development of meaningful forecasts. In California, major utilities and the California Energy Commission (CEC) are constantly improving the quality of the forecasting models by obtaining more accurate EUI and load-shape data. This paper reviews and compares existing studies of EUIs and LSs in the commercial sector, focusing on studies that used California data.

EUI STUDIES

We have reviewed 12 commercial sector EUI studies that have been carried out over the past eight years. Of these, seven were conducted for California utilities. Other studies have been carried out for Florida Power and Light (FPL), Northeast Utilities, Wisconsin Power and Light (WEPCO), and New York State Electric and Gas (RER 1987, NEU 1985, 1986a, 1986b, 1987a, 1987b, McMenamin 1986, Parti 1986). One study was national (Parti 1984).

The methodologies used in these studies can be grouped into four general categories:

1. Submetering of energy using equipment;
2. Computer simulation of prototypical buildings with and without reconciliation against the measured data;
3. Statistical studies using conditional demand analysis; and
4. Energy auditor estimates and bill disaggregation from on-site visits,

An in-depth review of these methods can be found in Turiel (1987).

COMPARISON OF EUI STUDIES

The above-mentioned studies have developed EUIs for up to 11 building types (small office, large office, restaurant, retail, food store, warehouse, school, college, hospital, hotel/motel, and miscellaneous) and 12 electric and gas end uses. Electric end uses include: lighting, miscellaneous, refrigeration, cooking, water heating, ventilation, space cooling, and space heating; gas end uses include: cooking, miscellaneous, water heating, and space heating. The data for all these building types and end uses are presented and compared in Akbari et al. (1989). In this paper, we will restrict our attention to four electrical end uses by presenting and discussing EUI data for lighting, miscellaneous, refrigeration, and cooling end uses for all building types.

Lighting (Figure 1):

Agreement among studies was generally good. Food stores, because of both longer hours of operation and higher intensities, had the highest EUI for this end use, with a range from 10 to 16 kWh/ft^2-yr. Except for large offices in the LBL study, offices and retail stores both had similar EUI ranges (5.5-8.5 kWh/ft^2-yr). The agreement among studies was not as good for schools, hospitals, and hotels/motels. Some variation in lighting energy use was expected among studies because of differing equipment efficiency and usage, but we did not expect as much as we found for the latter business types. One explanation for such wide ranges can be found in differences between the definition of building types among these studies. For instance, hospitals may actually be a combination of general health, clinics, and hospitals, all with dissimilar energy use characteristics. Similarly, schools may be a mix of primary, secondary, and vocational schools, again all with different end-use characteristics.

Miscellaneous Electrical Equipment (Figure 2):

This end-use category is fairly difficult to understand and compare. The difficulty arises mainly because of the fact that the definition of this end use is almost arbitrary. The estimates among building types in this category ranged from about 1.0 to 5.0 kWh/ft^2-yr. The SDG&E study (McCollister 1987) estimated higher miscellaneous electricity use than the other studies for almost all building types.[1] When the SDG&E study is removed, the agreement among studies is improved significantly.

Refrigeration (Figure 3):

Restaurants and food stores had the highest refrigeration EUIs. This is reasonable since large capacity refrigeration equipment is most prevalent in these two business types. The EUI for food stores ranged from about 10 to 30 kWh/ft^2-yr, while the EUI for restaurants ranged from about 2 to 22 kWh/ft^2-yr. The CEC (1987a) study estimates for restaurant refrigeration in the SDG&E and SCE service territories were low compared to the other studies. The

[1] *We speculate that the reason may be the SDG&E's inclusion of ventilation in miscellaneous end uses.*

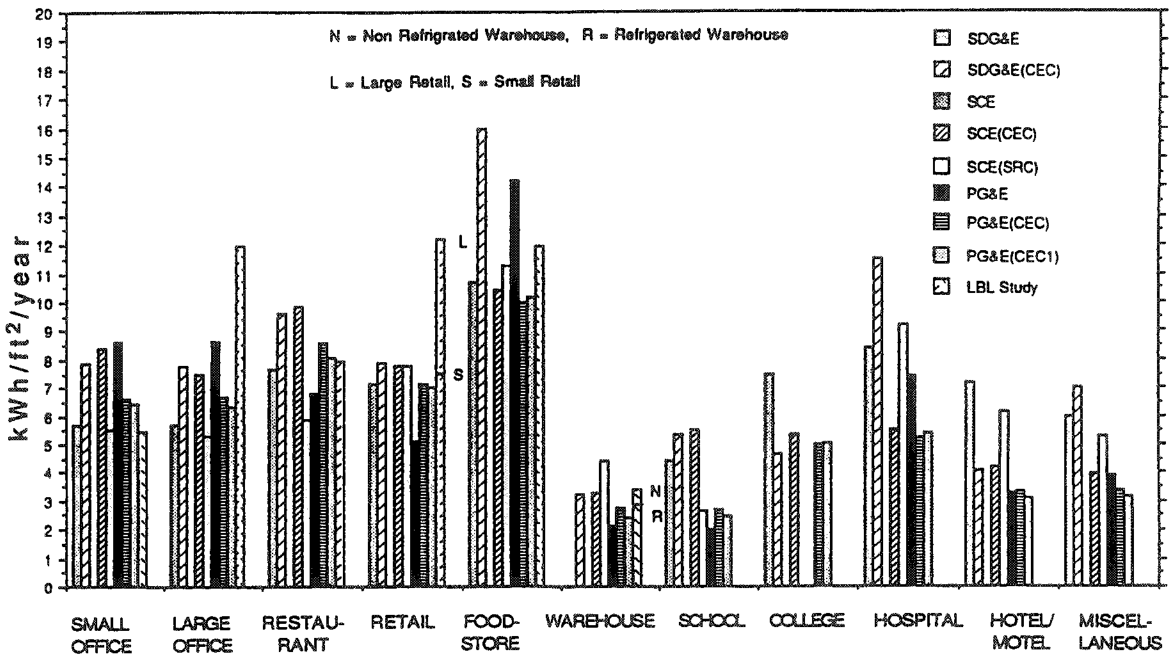


Figure 1. Lighting EUIs Comparison

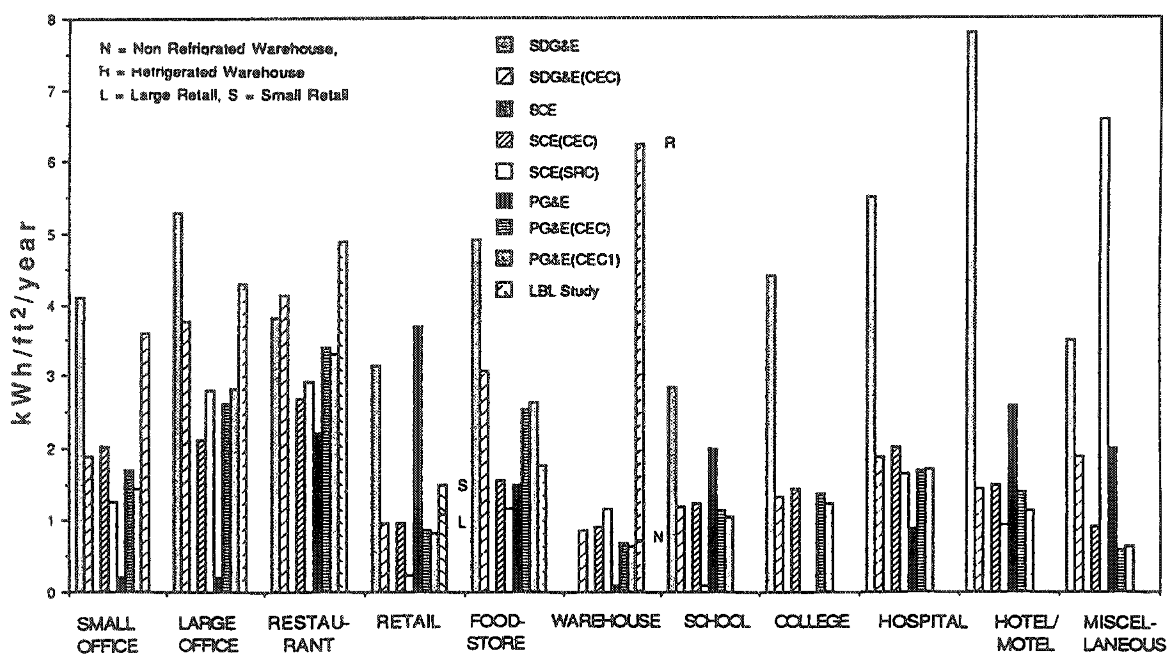


Figure 2. Electrical Miscellaneous EUIs Comparison

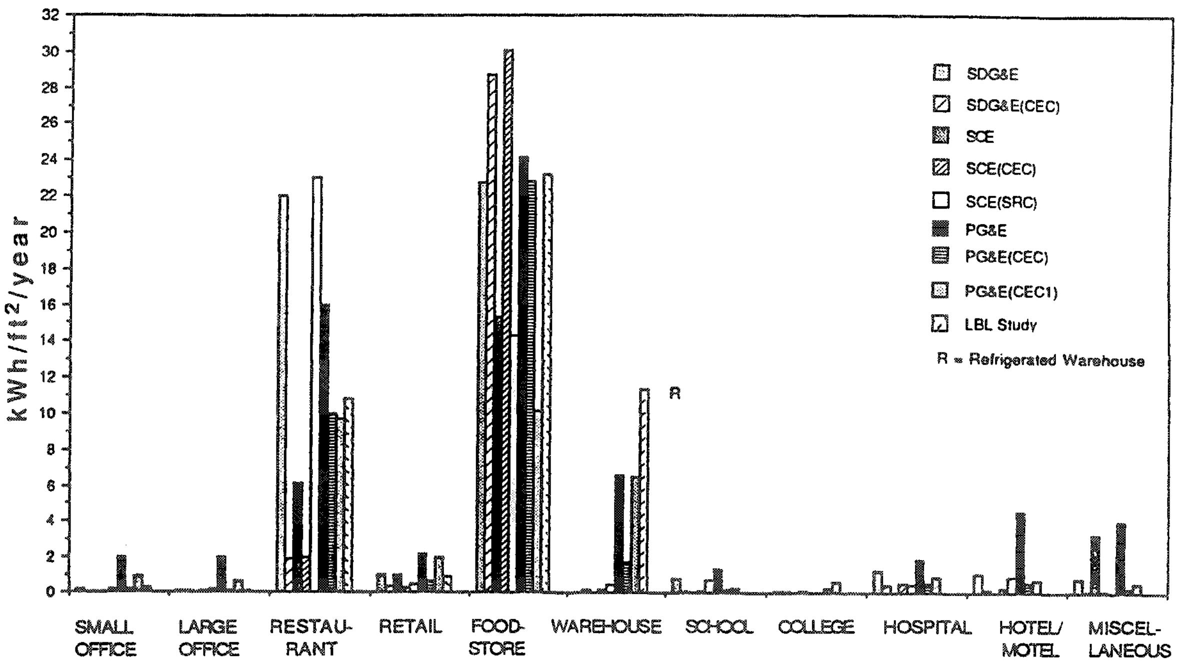


Figure 3. Refrigeration EUIs Comparison

warehouse category, which is a combination of refrigerated and non-refrigerated buildings, had the next highest refrigeration EUI, although it was much lower than for food stores and restaurants. The large ranges of values for warehouse is likely because of differences among studies in the definition of the end use and floor areas used in estimating EUIs.

Space Cooling (Figure 4):

For most building types, the average EUI for cooling appeared to be around 3.0 kWh/ft^2-yr. Restaurants, hospitals, and hotels/motels had the highest cooling EUIs, about 6 kWh/ft^2-yr. Some of the variation in cooling EUIs was because of the differences in climate among the three utility regions. Additionally, the definition of floor space was different among the studies. For example, the PG&E (McCollister 1985) and SDG&E studies used conditioned floor space for cooling and space heating end uses. The large difference between the conditioned and unconditioned floor area in warehouses may account for the relatively high EUI from the PG&E study (relative to other studies) for this building type.

In general, EUIs obtained from different studies but for the same end use and building type, are expected to differ somewhat. The stock of buildings in each utility's service area will be of varying vintages, as will be the equipment found within. Climate variations will affect space heating, cooling, and water heating EUIs. Floor space definitions will affect EUIs. The composition of a building type (e.g., fast food restaurant vs. sit down restaurant) may have a large affect on EUIs. For example, fast food restaurants are more energy intensive than sit down restaurants.

Two other major reasons for large variations in EUIs among these studies are the definition of floor areas and end-use categories. Errors as much as 50% have been noted in the reported estimates of the floor areas for individual buildings. Also, end use definitions for lighting may or may not include task lighting; some space heating is included in the 'miscellaneous' end use; etc.

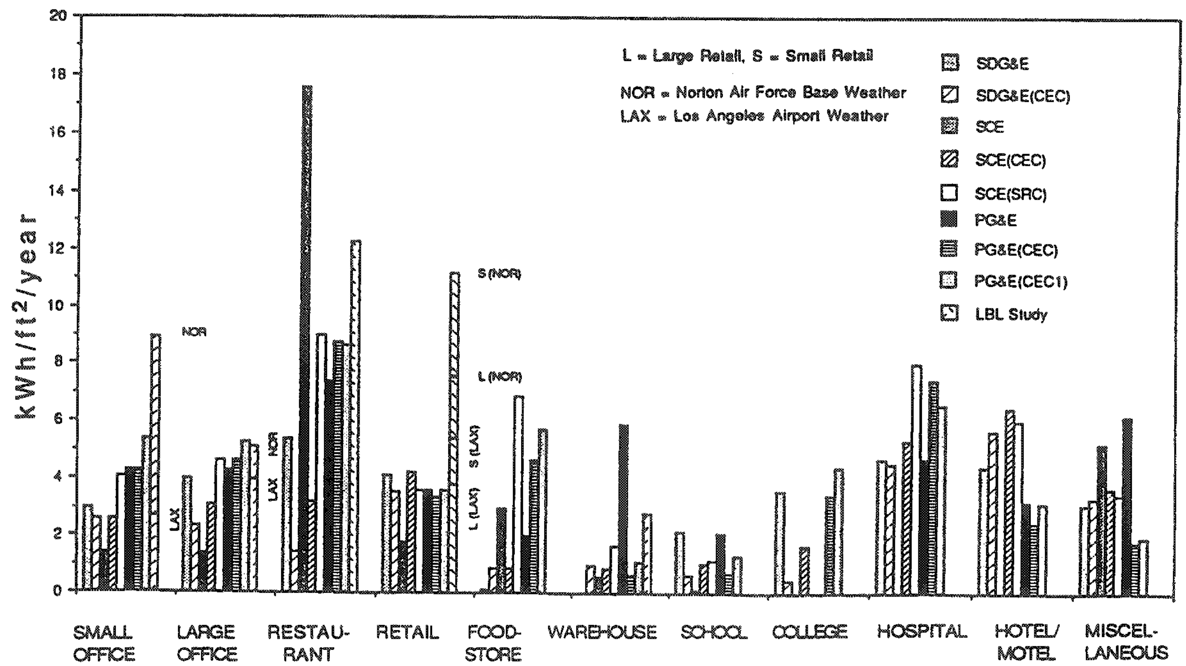


Figure 4. Cooling EUIs Comparison

LOAD SHAPE STUDIES

Because of added complexity, the larger amount of data required, and to a certain extent less historical interest, there were fewer commercial sector LS studies available than EUI studies. In a recent study Akbari et al. (1989) identified and reviewed four major sources of load-shape data (three in California and one outside California): LBL integrated load-shape and EUI analysis for SCE service area (will be noted as *LBL data* in the following sections); SRC simulation study for SCE service area (SRC 1987) (*SCE data* and study); CEC peak demand model load shapes (CEC 1987a) (*CEC data*); and selected studies prepared for Northeast Utilities (NEU 1985, 1986a&b, 1987a&b) (*NEU data*).

The methodologies used in developing end-use load shapes are principally computer simulations of prototypical buildings, some augmented with reconciliation of the simulated results against measured data. A few of these studies have also developed load shapes using building survey data and statistical methods to reconcile the audit information with annual (sometimes monthly) utility bills.

Load Shape Comparisons

Table 1 summarizes the load-shape data that we have used in our comparison. A complete discussion and comparison of these load shapes are presented elsewhere (Akbari et al. 1989); in this paper, we only focus our attention on studies that have developed load shapes for California.

In comparing these load-shape data bases, the following should be noted:

1. LBL and SCE studies have developed standard, non-standard, and peak day load-shape data for all 12 months of the year; CEC data only contain one set of hourly load-shape data (for the peak day).
2. The non-HVAC end-use load shapes for all studies, except LBL study, do not change across seasons.

Table 1. Load Shape Comparison - Data Summary

Study	LBL	Southern California Edison	California Energy Commission	Northeast Utilities
Types of days	Peak, Standard Weekend	Peak, Standard Weekend	Peak	Peak, Standard Weekend[5]
Load shapes for	12 Months	12 Months	Winter, Summer	Winter, Summer
Building Types:				
Office (Large & Small)	•[1]	•[1]	•	•
Retail (large & Small)	•[1,2]	•[1,2]	•	•[5]
Restaurant	•	•[3]	•	•
Food Store	•	•	•	•[5]
Warehouse	•[4]	•[4]	•	•
School		•	•	•[5]
College		•	•	•[5]
Hospital		•	•	•[5,6]
Medical Office		•		
Hotel/Motel		•	•	•
Miscellaneous		•	•	•[5]
End Uses:				
Heating	•	•	•[9]	•
Cooling	•	•	•[9]	•
Ventilation	•	•	•	•[7]
Lighting	•	•	•	•
Cooking	•		•	•
Refrigeration	•	•[8]	•	•
Water Heating	•		•	•
Other	•	•	•	•

Notes:

1. Load shapes for large office and department store were simulated with both central and package air conditioning units.
2. Separate load shapes were estimated for small retail and department store.
3. Load shapes were estimated only for fastfood restaurant.
4. Separate load shapes were estimated for refrigerated and non-refrigerated warehouses.
5. We have omitted presentation of data from this category.
6. Northeast Utilities load shapes for hospitals included all categories of health buildings.
7. Ventilation was included in heating and cooling end uses for all building types but office.
8. Refrigeration load shape was only estimated for refrigerated warehouse.
9. Load shapes for heating and cooling were calculated using THI matrices.

3. The cooling load shapes for CEC were calculated using typical year weather data and temperature humidity index (THI) matrices.

The load-shape data from the California data bases differ widely in their development and application. In order to establish a common framework for comparing end-use load shapes of two of these studies, first, we calculate daily allocation factors that apportion annual end-use consumption to daily consumption, then, we apportion daily consumption to hourly consumption with hourly allocation factors, whose 24-hour integral adds up to one.

These studies have developed load-shape data for five electric non-HVAC end uses (lighting, miscellaneous, water heating, cooking, and refrigeration) and three HVAC end uses (cooling, ventilation, and space heating) for all building types and all climate regions. The SCE data for non-HVAC end uses included monthly peak day, monthly average weekday, and monthly average weekend-day load shapes for all 12 months of the year. There is not significant month to month variation for these load shapes. The CEC non-HVAC load-shape data are only for the peak day of the year. Therefore, there is not a one-to-one comparison for all months of the year. The LBL data have been developed by disaggregating prototypical whole-building hourly loads into end uses. The resulting hourly data have been used to develop load shapes for standard, non-standard, and peak days for each month of the year.

We limit our discussion of the load shape data and comparison to providing an example for lighting, briefly discussing the highlights of the load shapes for other end uses, and finally presenting a sample load shape of all end uses from the LBL study for large office buildings.

Lighting (Figures 5a, b, and c):

These figures show the lighting load-shape data for all building types from SCE, CEC, and LBL databases. Each load shape is divided into two parts. The top part presents fractional data, so that when the EUI is multiplied by a fraction, the resulting number is the daily energy use for the given month and the given day type. The bottom part of the graph shows hourly load-shape data for three day types. The hourly end-use load is calculated by multiplying daily consumption by the hourly load-shape fraction. Solid lines represent peak days, dashed lines represent standard days, and dotted lines represent weekend days.

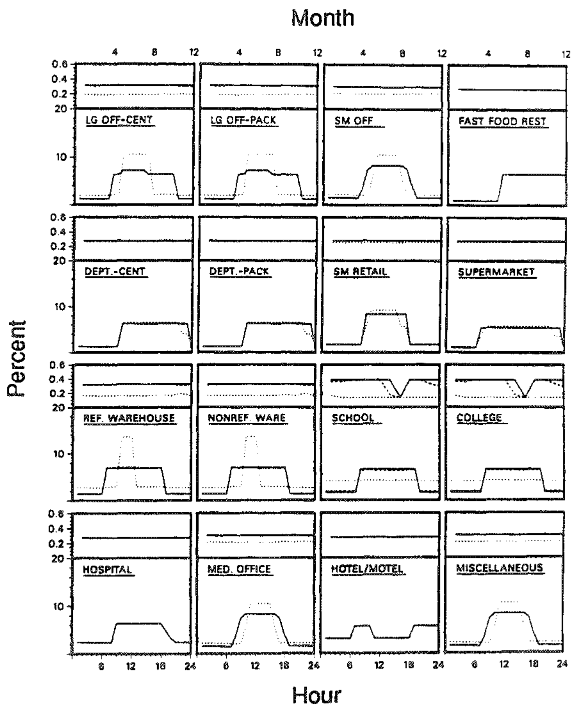
In general, the load shapes are quite different and a detailed comparison is difficult. We observed that:

- The fractions of daily consumptions between CEC, SCE, and LBL data were within about 25% of each other, except for the small office, school, and college (note that LBL has not developed load shapes for a few building types including schools and colleges);
- The load shapes differed mainly during the shoulder hours. Hours of full operation varied among these studies;
- CEC load shapes indicated zero nighttime lighting for schools and small offices;
- CEC data showed an almost flat lighting load shape for warehouses, but a very complicated load shape for the miscellaneous building;
- Peak and weekday load shapes for SCE were nearly identical, except for the school and college.

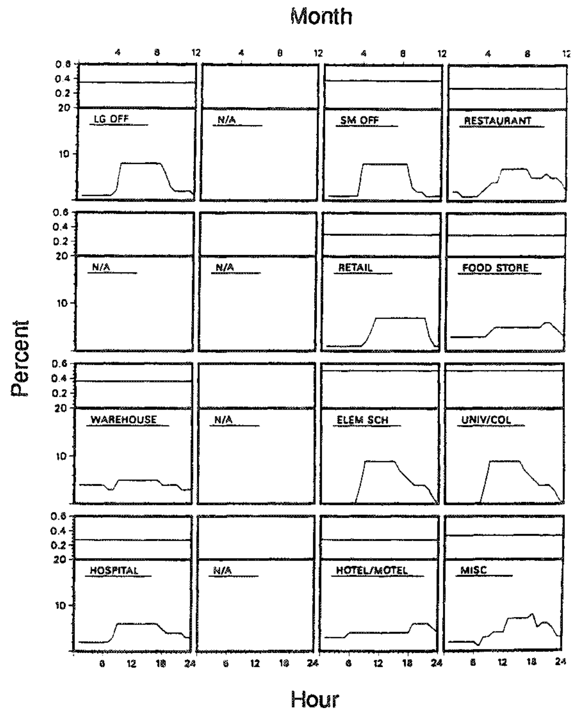
Miscellaneous End Uses:

The comparison of the load shape data for this end use category showed more differences than similarities (Akbari et al. 1989):

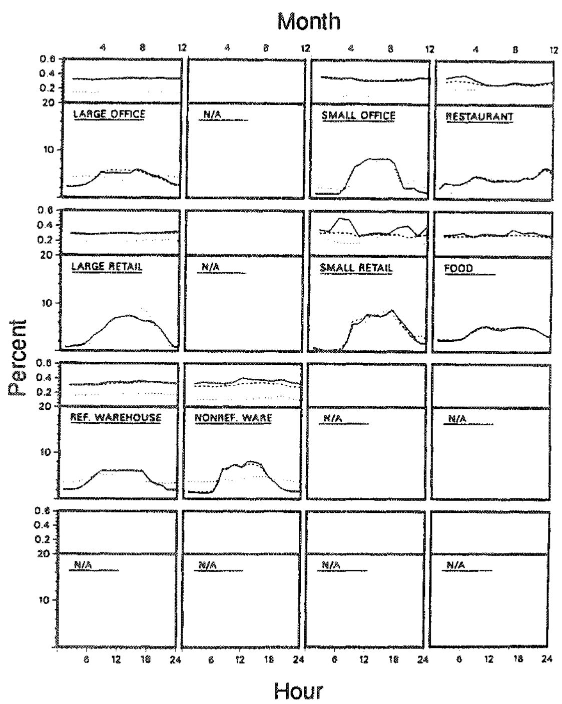
- The fraction of daily consumptions among these studies was within about 25% of each other, except for the small office, school, and college;
- Peak and weekday load shapes for SCE were also nearly identical, except for the school and college;
- CEC uses the same load shape for both the elementary school and college;
- Load shapes for supermarket (food store), warehouse, school, college, hospital, and hotel/motel differed considerably.



a) SCE



b) CEC



c) LBL

Figure 5. Summary Presentation of Lighting Load-Shape Data. a) SCE, b) CEC, c) LBL Data. Each end-use load shape presentation is divided into two parts. The top part presents fractional data, so that when the EUI is multiplied by a fraction, the resulting number is the daily energy use for the given month and the given day type. The bottom part of the graph shows hourly load-shape data for three day types. The hourly end-use load is calculated by multiplying daily consumption by the hourly load-shape fraction. Except where peak, standard, and weekend data are shown in separate graphs, solid lines represent peak days, dashed lines represent standard days, and dotted lines represent weekend days.

Water Heating, Cooking, and Refrigeration:

- For these end uses, SCE did not give load shapes except for supermarket refrigeration (which exhibited no variation, either diurnal or seasonal). In comparing the load shapes from these sources, we observed:
- CEC's load shape for hotels showed very high nighttime water heating energy use;
- CEC's load shapes for the large and small office appeared to neglect water heater standby losses;
- CEC's flat load shape for warehouse cooking was unexpected;
- CEC uses a flat refrigeration load shape for all building types.

Ventilation:

As expected, the variations in the ventilation and HVAC end uses among the three reports were even greater than the ones found for the non-HVAC end uses. SCE data indicated that there was significant variation in ventilation and HVAC end uses for each of SCE's four planning areas. CEC reported heating and cooling load shapes in the form of weather data and THI matrices. LBL load shapes for HVAC end uses are developed by first reconciling simulation against the hourly load data for the entire SCE utility service area and then, using DOE-2 simulations, the load shapes were scaled for these SCE climate regions.

In comparing the ventilation load shapes from these studies, we observed:

- LBL data show a seasonal dependency of the ventilation load shapes for most buildings studied, also the ventilation load shapes for the peak and standard days are significantly different;
- For the SCE data, except for large offices, the ventilation load shapes for all 12 months of the year were nearly identical. Also, for most building types, there was no significant variation between peak and standard day;
- CEC assumes the same load shape for all building types.

Cooling:

Comparison of the cooling load shapes (Note: shapes not intensities) among these studies are difficult. Normalizing load shapes (the area under load shape equal to one) for this end use can be misleading. Normalized load shapes suppress seasonal and operational effects, which can vary markedly. For example, winter month cooling loads may appear more "peaky" than those in the summer, because of shorter cooling hours in winter.

As one would expect, the load shapes for large offices exhibited less monthly variation than do those for other buildings. The school load shapes were interesting because in the month when school is not in session, August, the load shape is similar to the weekend load shape. Also, the January weekend load shape appears to be similar to the standard-day load shape (although much smaller in magnitude).

The CEC load shapes were calculated from THI matrices for each building type using typical year weather data for the four SCE climate regions: Bakersfield, Burbank, Los Angeles Airport, and San Bernadino. The monthly variation was calculated from the daily cooling degree days for each planning area, and did not vary from building to building.

The load shapes did not vary much from planning area to planning area. The load shapes for hotels and hospitals were identical and quite flat, probably because of nighttime occupancy. One might expect, however, that the hospital would have a larger daytime peak, because of "office hours" during the day.

Electric Space Heating:

The heating load shapes were the least uniform of all the load shapes. This comes in part from the fact that during swing seasons there is little heating use, so little that perhaps random fluctuations in demand are magnified when the load shape is normalized, creating confusing results. These months are, however, less important since their overall magnitudes are quite small.

Figure 6 presents the LBL load-shape data for an August standard day for all end uses for large office

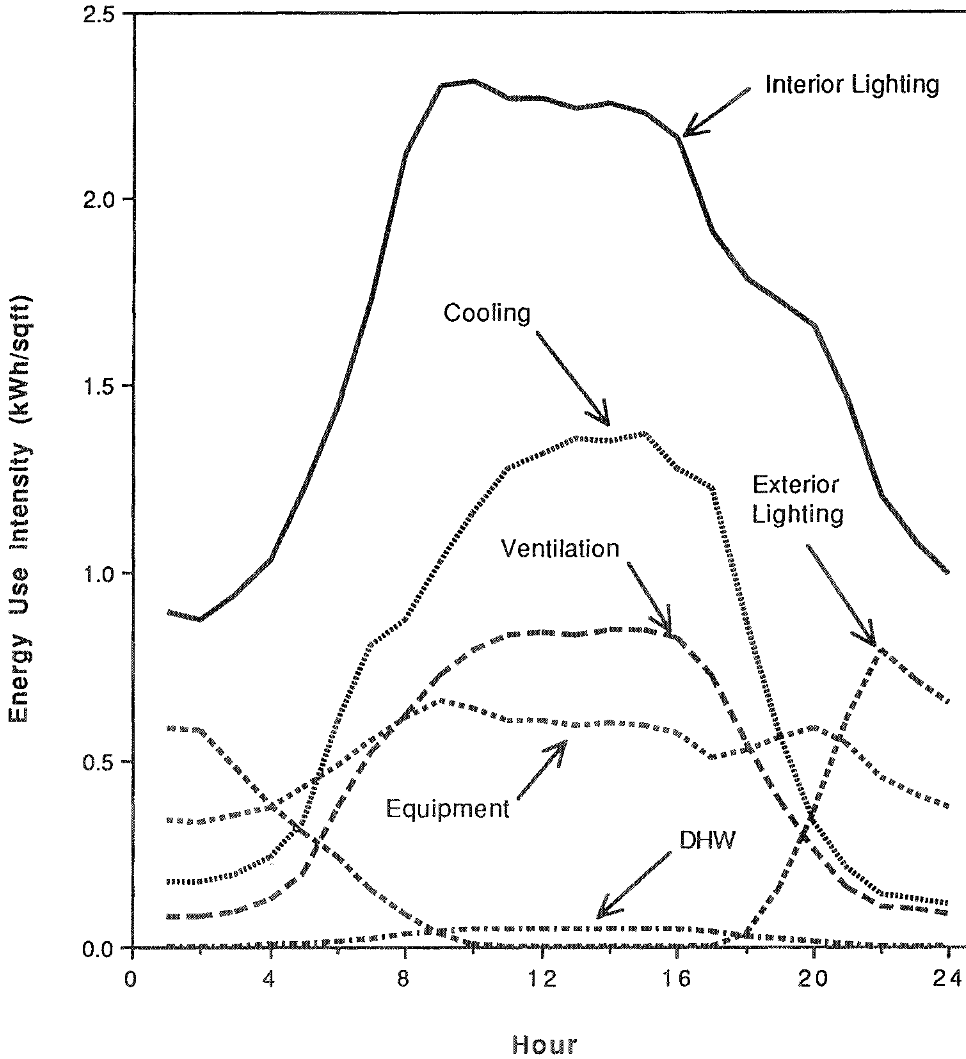


Figure 6. LBL Load Shapes for Large Office End Uses. The end use load shapes are for an August standard day. Note the high nighttime lighting usage. The peak lighting intensity is comparable to the total air conditioning and ventilation peak intensities.

buildings. The data indicate that lighting has the highest energy use intensity for all hours of operation. The sum of cooling and ventilation loads are comparable to the lighting load. The energy use during the nighttime in large offices is appreciable. The sample of large office buildings in the LBL study had large whole-building EUIs. In the development of load shapes, the large whole-building EUI resulted in a higher nighttime energy use, particularly for lighting and equipment.

In summary, our review of the three LS studies in California uncovered two significant features of existing LSs. First, LSs were generally not consistent among studies, but these differences could often be related to differences in assumptions and the estimation methodologies of the studies. Second, for a given building type within one study, only one of these studies show significant seasonal variations for non-HVAC load shapes.

CONCLUDING REMARKS

Current energy use and peak demand forecasting models are simple in principle but complicated in application. The models estimate energy use by summing up the products of energy use intensities (for each end use, building type, and end-use technology options) and the estimates of the market size. The same method is principally used to estimate the peak energy demand. Tolerance for errors in the forecasting models is not large. A 10 percent error in forecasting peak electricity demand in California, for example, could mean four large power plants (4 GW) too many or too few. Classically, to avoid these problems, the results of the forecasting models are calibrated with historical energy demand. Better EUI and LS data would probably yield better forecasts and hence would require less model calibration.

The estimates of the EUIs and LSs show significant differences among various studies. Some of these difference are because of inherent variations in the building stock and equipment among utility service areas. Additionally, there are statistical uncertainties in the sample designs and in the estimates derived from various models. Some of the uncertainties can be traced back to lack of quality raw data used in developing EUIs and LSs. Since, most estimates start with some sample population data that characterizes the market (on site audits, mail surveys, sample utility bills, etc.) the resulting EUIs and LSs are associated with some statistical variance. At this time, we are not aware of a thorough study addressing this sampling variation. A limited attempt by Akbari et al. (1989) showed that their EUI estimates were subject to 10 to 20% statistical error. Greater relative errors were reported for the smaller EUIs. No such attempt was made to analyze variance of LSs.

Most LS and EUI estimation methods have utilized some sort of simulation tools with heavy doses of "engineering judgment" to arrive at their results. Reconciliation of engineering estimates to measured EUIs and LSs have then been used as a final calibration tool. Detailed case studies of the energy use in buildings sometimes have questioned the validity of some of these engineering estimates, indicating that there is a need for improved estimating methods. It is not clear that additional EUI and LS comparison studies will add much to our understanding in this area. Individual utilities will still wish to conduct EUI and LS studies for their service territories. They should expect similar variations between their studies and others. In order to understand some of the differences discussed *what is required is more measured data.*

The quantity of measured data is increasing in size. Many utilities have collected or started to collect detailed end-use data for their residential and commercial customers. Eto et al. (1990) identified 27 metering projects throughout the country. Analysis of these data and development of an integrated *measured* data base can substantially help to improve our understanding of end-use EUIs and LSs.

ACKNOWLEDGEMENT

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