ANNUAL AND MONTHLY PEAK DEMAND FOR ELECTRICITY IN COMMERCIAL BUILDINGS

Eugene M. Burns Energy Information Administration¹

Using both annual and monthly billing period data, this paper examines the correlates of peak demand for electricity in commercial buildings. The data are from the 1986 Commercial Buildings Energy Consumption Survey (CBECS), the Energy Information Administration's national survey of commercial buildings and their energy suppliers.

The first part of this paper introduces the CBECS, and presents some peak demand and load factor estimates from the 1986 survey. The second part presents previously unpublished medians and quartiles for monthly load factors. To ascertain possible weather-related components of peaking, the monthly peak demand is then modeled as a function of the mean cooling degree-days associated with each billing period. The third part of this paper relates the results of the monthly analyses to various building characteristics.

INTRODUCTION

The topic of demand-side management has been growing in importance, to national and local policymakers, to utilities, and to electricity consumers. One resource for the analysis of demand-related consumer behavior is the data available from the Energy Information Administration's Commercial (formerly Nonresidential) Buildings Energy Consumption Survey (CBECS, formerly NBECS). Beginning with the publication of results from the 1986 survey, the CBECS has included data on peak electricity demand. Topics covered in the 1986 Consumption and Expenditures Report (Energy Information Administration 1989a) include the incidence of peak demand-metering, peak demand, season of peak demand, median Watts per square foot, and load factors. In addition, the public use data file (Energy Information Administration 1989b) contains seasonal average peaks and load factors.

The CBECS, conducted every three years, is based on a national probability sample of approximately 6,000 buildings. The CBECS is the only publicly available source of data on commercial buildings that is both national in scope and statistically reliable. The CBECS is conducted in two parts: (1) a Building Survey, administered by personal interview with building managers and owners, and (2) a Supplier Survey, which collects a year of billing information from the suppliers of energy to the interviewed buildings. The 1986 Building Survey collected data on topics such as building size and construction, occupancy and ownership, heating and cooling equipment, conservation practices, and the sources and end-uses of energy.

In the 1986 Supplier Survey, EIA requested sets of bills covering the fourteen-month period from

¹ The opinions and conclusions expressed herein are solely those of the author and should not be construed as representing the opinions or policy of any agency of the United States Government.

December 1985 through January 1987 for each of the buildings interviewed in the Building Survey. Typically, each set contained 14 bills. Each bill included the billing period ending date, the total consumption of electricity (kWh) during the period, the peak demand (kW) during the period, and the total expenditures for electricity during the period. Each bill was then matched with weather data from the nearest National Oceanic and Atmospheric Administration (NOAA) weather division. The weather for the corresponding time period was recorded in the form of heating degree-days and cooling degree-days for 10 different bases, ranging from 50 degrees to 80 degrees Fahrenheit.

The sets of bills formed the basis for the annual estimates contained in the 1986 Consumption and Expenditures Report. To obtain annual consumption and expenditures estimates, on a 365-day basis, the amounts reported on bills at the beginning and end of 1986 were prorated, and the 1986 billing amounts were summed. A building's peak annual electricity demand was calculated as the maximum of the peak demand values reported on any of the bills wholly (or more than half) contained in 1986. The annual load factor was computed as

annual load factor =
$$\frac{\text{annual consumption}}{\text{peak annual demand x 365 x 24}}$$
 (1)

Further details on how the demand data were handled can be found in Burns (1988b) and Energy Information Administration (1989a, Appendix B).

Two special data problems limited the amount of useable peak demand data. First was the problem that, although almost all electricity consumers have consumption meters, not all have peak demand metering. Second, in multicustomer buildings, each demand-metered customer has its own peak. Since these peaks would rarely be coincident, the total building peak could not be taken as the sum of the individual peaks.

For buildings completely missing supplier data and for multicustomer buildings, a two-step imputation was performed. First, it was necessary to impute whether the building would have been demandmetered. If the building was imputed to be demandmetered, then the peak and season of the peak were imputed. No imputations were done in cases where the supplier reported billing period consumption but not peak demand, since these buildings, classified as "not demand-metered," tended to be smaller than those classified as "demand-metered," and thus imputation would involve extrapolation beyond the range of the reported data.

The 1986 CBECS found that 42 percent of the 4 million buildings with electricity consumption had metered peak demand. These buildings, however, contained 60 percent of the commercial floorspace, and accounted for 73 percent of the electricity consumption in commercial buildings in 1986. Since it is important for utilities to monitor and charge for demand in buildings that contribute more to the utilities' peaks, buildings with higher peaks are more likely to have metered demand.

Among those buildings that were demand-metered, higher peaks were strongly associated with higher absolute consumption levels. However, higher consumption levels were also associated with higher load factors (Figure 1). The 1986 CBECS also found that many factors related to higher consumption, such as longer hours of operation, larger floorspace, and principal building activity, were also related to higher load factors (Figure 2).

Some preliminary regression models were also developed for the analysis of the annual load factors (Burns 1990). The regression models fit the logistic transformation of the annual load factor as a linear function of building characteristics, and were developed separately for each of 9 principal building activity categories. The logistic transformation is given by

$$logistic(load factor) = -log \left(\frac{1 - load factor}{load factor}\right)$$
(2)

and was chosen to ensure that estimated load factors would lie in the interval from 0.0 to 1.0.

The parameters were estimated by the method of least squares. The results indicated moderately good fit, with R^2 values from .4 to .7. This was encouraging, given the simplicity of the models used. Undoubtedly, better models (and better modeling strategies) will be found as work continues.



Total Electricity Consumption, 1986 (Megawatthours)

Figure 1. Percent of Buildings with Metered Demand and Distribution of Load Factors by Electricity Consumption Level, 1986

Note: For each electricity consumption category, the box covers 50% of the buildings, from the 25th to the 75th percentile. The bar in the middle of each box indicates the median. The points indicate the percent of buildings in the category that had metered demand.

Source: Energy Information Administration, Office of Energy Markets and End Use, Energy End Use Division, 1986 Nonresidential Buildings Energy Consumption Survey.



Figure 2. Distribution of Load Factors by Square Footage, Weekly Operating Hours, and Principal Activity, 1986

Note: For each category, the box covers 50% of the buildings, from the 25th to the 75th percentile. The bar in the middle of each box indicates the median.

Source: Energy Information Administration, Office of Energy Markets and End Use, Energy End Use Division, 1986 Nonresidential Buildings Energy Consumption Survey.

Figure 3 indicates which variables were eventually included in each of the nine building activity models. As even a superficial glance at Figure 3 indicates, how the building is used (the occupancy variables) seemed more important than how the building was constructed. The log number of workers was the most important predictor, and the estimated coefficients were fairly close across models. Variables such as weekly operating hours and percent lit during *non*-operating hours were also important. The latter variable is an interesting example of how filling a "valley" (by consuming electricity during non-operating hours) can improve a load factor (by leveling demand).

PEAK BILLING PERIOD ELECTRICITY DEMAND

This paper extends the previous findings from the 1986 CBECS by analyzing the billing period data directly, rather than by using the on annual values derived from the billing period data.

As a first step in the analysis of the billing period data, load factors were calculated for each period, using the values reported for consumption and peak demand. These billing period load factors were plotted versus the month, using the mid-point of the billing period to determine the month. This plot (Figure 4) is in the same form as the plots presented in Figure 2. The data in Figure 4 have been population-weighted, so that each month the distribution for each month represents approximately 760,000 buildings. This number is about 45 percent of the total of 1,673,000 buildings estimated to have metered peak demand. The main reasons for attrition, missing supplier data and multicustomer buildings, were discussed in Section 1.1. An additional source of attrition for this analysis was the requirement that the billing data contain at least 10 bills from 1986. This requirement eliminated cases with bimonthly billing, as well as cases where the utility provided data for 14 months other than December 1985 through January 1987.

Figure 4 shows a weak seasonal pattern, with peaks in both the summer and winter. In a further set of plots (not shown), buildings were categorized based on their end-uses of electricity (as reported in the Building Survey): (1) cooling but not heating, (2) both heating and cooling, and (3) all other patterns. The plots for the cooling-only category and for the heating-and-cooling category both showed seasonal patterns, stronger than that shown in Figure 4, but the plot for the other-patterns category did not.

Examination of Figure 4 shows that seasonal load factor variation exists, but the width of the interval between the 25th and 75th percentile indicates that there nonetheless is a considerable amount of variation in load factors among buildings. The next step was to try using the billing period degree-day data to explain the monthly variation in load factors. Equations were fit at the building level, using the twelve (occasionally ten or eleven) billing period observations. Only buildings from the cooling-only subgroup were modeled, since these buildings had shown the clearest seasonal pattern. The only explanatory variable used for this subgroup was cooling degree-days. The cooling-only subgroup was also the largest, with 874 sampled buildings, representing 480,000 buildings in the population.

Initially the regressions were run using the logistic form of the load factor and degree-days base 65° F. Most of the regressions were not statistically significant. The median R^2 was .139, and only 25 percent were higher than .36. Since the cooling degree-days had a sharper seasonal pattern than load factors, the cooling degree-days were transformed to logarithms, and the regressions were refit. The results were slightly worse, and so the problem was not in the form of the cooling degree-days variable.

Three other possible forms of the dependent variable were tried: the untransformed load factor, the peak demand, and the log of the peak demand. Two forms of cooling degree-days were tried as predictors: untransformed and logarithmic. Three different bases were used for the cooling degreedays: 65° F, 57° F, and 50° F. Results for the R² statistic are summarized in Table 1.

The principal finding was that modeling the load factor (or its logistic transformation) as a function of degree-days does not work, while modeling the peak demand (or its log transform) does work.

Regressor			Regression Mode			a			
<u>Variables</u>	<u>A</u>	E	<u>F</u>	<u>H</u>	L	<u>M</u>	<u>0</u>	<u>W</u>	X
<u>Construction</u> Log(ft ²)	-	+		+				+	+
Log(#floors) Constr. post-1960			+	-			+	÷	
<u>Equipment</u> Elec. 1° heating Non-elec. cooling Hi-effic.ballasts		+			-		+		
<u>Occupancy</u> Postaurant									
log(#workers)	÷	т	-		т.	4	+	+	
Operating hours	+	+	т		1	+		+	
Pct.lit off-hours	+	•	+	+		+	+		+
Owner-occupied Pct.vacant 3+month			-		-				-
<u>Environment</u>									
Metropolitan area CDD base 65°F	+ -			+	+	+			
<u>No. of variables</u>	6	4	5	4	4	4	4	5	3
^a Model (principal bui A = Assembly E = Education F = Food-related	lding	activi H = L = M =	ty) ab Health Lodgin Mercan	brevia h care ng ntile	itions:	0 = W = X =	Office Wareho All of	e ouse ther	

Figure 3. Regressor Variables Included in the Regression Models for Annual Load Factor, by Principal Building Activity (the "+" or "-" indicates the sign of the coefficient)

Models for the untransformed peak demand performed a bit better in the R^2 comparison, as did models using the untransformed cooling degreedays. Of the three cooling degree-day bases tested, the best results were found for base 50°F, the lowest base for which cooling degree-days are currently calculated.

The distribution of \mathbb{R}^2 values for the best-fitting regression, peak demand on mean cooling degreedays base 50°F, showed an interesting pattern (Figure 5). There were two groups of building, those for which this regression specification was satisfactory, and those for which it was not. Further research is needed to determine the conditions under which satisfactory fit was attained. If different degree-day bases are relevant for different buildings, then PRISM-type analysis (Fels 1986) might be appropriate for examining electricity peaking in commercial building.

In the only other major analysis of the CBECS billing period data conducted to date (Burns and Goldberg 1990), natural gas consumption was



Figure 4. Distribution of Load Factors by Month, for Buildings with Monthly Billing Data, 1986

Note: For each month, the box covers 50 percent of the buildings, from the 25th to the 75th percentile. The bar in the middle of each box indicates the median.

Source: Energy Information Administration, Office of Energy Markets and End Use, Energy End Use Division, 1986 Nonresidential Buildings Energy Consumption Survey.

 Table 1. Median R² for Regressions of Billing Period Peak Demand on Mean Billing Period Cooling Degree-Days, for 874 Buildings with Electric Cooling But Not Heating

	Base 65°F		Bas	e 57°F	Base 50°F		
Dependent Variable	<u>CDD</u>	log(CDD)	CDD	log(CDD)	<u>CDD</u>	log(CDD)	
Logistic (load factor)	0.139	0.125	0.151	0.139	0.155	0.141	
Load factor	0.139	0.125	0.152	0.140	0.159	0.149	
Log (peak demand)	0.405	0.255	0.475	0.390	0.506	0.435	
Peak demand	0.429	0.286	0.510	0.427	0.542	0.464	

regressed on heating degree-days for buildings heated with natural gas. In the natural gas study, the median \mathbb{R}^2 was 0.896, and the middle 50 percent of the values were between 0.721 and 0.955. Two factors may explain why the natural gas consumption regressions performed better. First, buildings using natural gas may use it for little other than space heating, so that natural gas usage is more strongly determined by weather conditions. Second, average daily consumption is a more predictable quantity than the peak demand, an extreme value. It is certainly encouraging for future work that average monthly degree-days was found to perform as well as it did.

COMBINING ANNUAL AND BILLING PERIOD MODELS

The previous section dealt with billing period data from the CBECS Supplier Survey, and established that there is a relationship between monthly peak demand and mean monthly cooling degree-days. This section carries the analysis forward through the use of data on building characteristics from the CBECS Building Survey in an attempt to explain differences among buildings in the dependence of peak demand on temperature.

The basis for this analysis were the estimated cooling degree-day coefficients from the billing



R² Values

Figure 5. Distribution of R² Values for Regression of Peak Billing Period Demand on Mean Billing Period Cooling Degree-Days (Base 50°F) for Buildings With Electric Cooling But Not Heating

period regressions for buildings with electric cooling but not heating. These coefficients are buildinglevel measures of the amount (in kilowatts) that the monthly peak demand changes for each change of one degree in the monthly mean cooling degreedays (base 50°F). The coefficients can be regressed on various building characteristics to analyze the factors which determine the sensitivity of peak demand to weather.

As noted in the previous section, there appeared to be two groups of buildings, those with temperature dependencies and those without. For a meaningful analysis of temperature dependency, this part of the analysis was confined to those buildings which had R^2 values of .2 or higher in the regression of monthly peak demand on monthly mean cooling degree-day. The value .2 was the 25th percentile of the R^2 values.

There were a large number of items in the 1986 CBECS Building Survey which could be used to model the temperature dependency. Since this was an exploratory analysis, the initial regression contained 44 explanatory variables (Figure 6). The initial model, with 99 parameters, had an R^2 of .609

and a root mean square error (RMSE) of 8.87. Through successive model-fittings, the number of variables was gradually reduced to a simple model with only five variables (square footage, number of floors, number of workers, percent of floorspace cooled, and principal building activity). This model, with 15 parameters, had an \mathbb{R}^2 of .521 and a RMSE of 9.39.

At this point in the modeling, interactions between the principal activity and the other variables were tested. The rationale for testing these interactions was that the models for the annual load factor (Figure 3) had been developed separately by principal building activity. There are energy-relevant differences between workers at a school and workers at an office, for example. The interactions with principal activity were found to be significant for number of workers and square footage. The final model for this exploratory analysis thus included the number of floors, the percent cooled, a square footage by principal activity interaction, and a number of workers by principal activity interaction. With 26 parameters, this model had an \mathbb{R}^2 of .649 and a RMSE of 8.11.

Building Construction Variables

square footage, square footage category (8 levels), number of floors, wall construction (9 levels), roof construction (7 levels), percent exterior glass, percent exterior glass category (5 levels), roof/ceiling insulation, wall insulation, storm windows, tinted/reflective glass, awnings/shades, stripping year constructed, year constructed category (9 levels), built post-60

Occupancy Variables

principal building activity (12 levels) weekly operating hours, weekly operating hours category (6 levels) number of workers, number of workers category (10 levels), number of occupants, owner occupancy, government ownership, percent vacant 3 months or more

Equipment

percent of floorspace heated, percent of floorspace cooled, percent of floorspace lit, percent of floorspace lit off-hours, central cooling, individual A/C units, packaged cooling units, evaporative coolers, heat pumps, high-efficiency ballasts, day-lighting controls, other lighting controls, delamping energy audit performed, regular HVAC maintenance, heating/cooling controlled by computer

Location

Census region climate zone metropolitan/nonmetropolitan

Figure 6. Explanatory Variables Included in Models Analyzing the Cooling Degree-Day Coefficients

Square footage, number of workers, and percent cooled are all items which directly contribute to the intensity of demand for electricity. The presence of the number of floors in the model is more difficult to interpret. This variable could be a building shape indicator, or else may be a surrogate for some variables not included in the model. Notably absent from this model were the weekly operating hours and percent of floorspace lit during off-hours, two items which were very useful in the models for the annual load factor (Figure 3). While these items may influence a load factor, they do not contribute to peak load.

DISCUSSION

Electricity demand in commercial buildings has patterns and cycles in both the long and the short run. Much attention has been focused, and rightly so, on daily demand cycles (load shapes). This study has used a unique national data base (CBECS) to focus attention on the annual demand cycle.

The analysis of monthly data indicated that, for a significant proportion of buildings, there exists a dependency between peak demand and temperature. Furthermore, use of the CBECS Building Survey

data showed that this dependency can be related to building characteristics. However, more work is needed both to develop reliable degree-day regressions and to analyze the estimated coefficients. This is a promising area for future research.

The results presented in this paper represent an initial attempt to use the CBECS data to understand the determinants of peak demand. Yet, in addition to the goal of understanding peaking behavior better, this study was also motivated by a desire to make these data more useful to analysts. The author is in the rather privileged, but challenging, position of being able to determine the form in which EIA will collect and process billing and weather data. This study has already focused greater attention on the possible need to provide lower bases for CBECS cooling degree-day data.

The CBECS peak demand data collection and dissemination program benefited greatly from comments and discussion regarding the 1983 pilot study. The results have been the publication of peak demand data as a routine part of the CBECS Consumption and Expenditures Report, and the release of the annual peak demand microdata in public use files. Hopefully, the analysis efforts reported in this study will lead to future improvements in the quality and relevance of the CBECS data.

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