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THERMAL SENSITIVITY OF THE COMMERCIAL SECTOR

Z. T. Taylor

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SUMMARY

Observed differences between forecasted and actual electricity consumption (loads) in the Pacific Northwest commercial sector prompted an analysis to characterize the sensitivity of commercial buildings to weather variations. At the request of the Bonneville Power Administration, the Pacific Northwest Laboratory (PNL) used both electricity consumption and weather data from the End-Use Load and Consumer Assessment Program (ELCAP) database to determine the answers to three research questions:

- To what extent is the commercial building sector sensitive to annual variations in weather?
- How does the weather response vary between the different types of commercial buildings?
- How do the size, age, and primary heating fuel of buildings affect their thermal sensitivity?

With the answers to those questions, PNL researchers were then able to indicate the potential benefit of developing a weather normalization method for use with commercial sector forecasting models, to improve the models' prediction accuracy.

We examined the thermal sensitivity of building total loads and heating, ventilating, and air-conditioning (HVAC) loads in all nine commercial building types. In groceries and restaurants, refrigeration loads were also studied. The data indicated that the thermal sensitivity of building total and HVAC loads is small for all types of buildings. We found the thermal sensitivity of refrigeration loads also to be small for groceries and restaurants. These findings led us to conclude that, although corrections for weather might improve forecasted loads, the improvement is probably too small to justify the effort required to do so.

We next examined the effects of building size (floor area), age (year built), and primary heating fuel (electric versus nonelectric) on thermal sensitivity. We compared our results with common expectations that small

buildings are more thermally sensitive than larger buildings, old buildings are more thermally sensitive than new buildings, and electrically-heated buildings are more thermally sensitive than those heated by other fuels. As expected, small buildings (except for restaurants and warehouses) were found to be more sensitive to the weather because of the higher ratios of envelope area to conditioned volume. However, neither vintage nor fuel type was found to affect HVAC loads.

We investigated the use of heating and cooling degree-days calculated to a base temperature of 65°F as the basis for a weather-adjustment procedure. We concluded that a simple degree-day correlation is a promising prospect because it would be easy to develop and implement.

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Section 1

INTRODUCTION

As part of their ongoing power planning efforts for the Pacific Northwest, the Bonneville Power Administration (Bonneville) and the Northwest Power Planning Council (the Council) forecast future demand for electricity. The forecasting models these agencies use combine projections of economic trends and fuel prices with estimates of conservation savings and information on the energy requirements of various electric devices in residential, commercial, industrial, and agricultural sectors. Models used to predict future demand are calibrated against the known energy usage of past years (generally, 1979 to the present). The models dealing with electricity consumption in the residential sector account for variations in weather (outdoor temperature) during the calibration period. However, the models used to project consumption in the commercial sector include no such adjustment.

It is generally assumed that the electricity requirements of commercial buildings are less affected by outdoor temperatures than by other factors such as operation schedules, lighting requirements, and the types of equipment used in the building. However, difficulties in resolving differences between forecasted loads and historical billing data suggested that the assumption be examined further. High time-resolution data are available from Bonneville's End-Use Load and Consumer Assessment Program (ELCAP), which is conducted by the Pacific Northwest Laboratory (PNL). The ELCAP database is uniquely rich in that it represents a large number of buildings of various types and contains both electricity consumption and weather data.

This report documents a PNL analysis conducted for Bonneville to characterize the weather sensitivity of the monitored ELCAP buildings. The thermal descriptions are used with over 30 years of historical weather data to gauge the potential magnitude of weather-related discrepancies between forecasted loads and actual loads in calibrating the forecasting models.

The key findings and major observations resulting from the PNL analysis are presented in Section 2. Section 3 details the motivation for the work and the specific objective of our analysis. The thermal characterization methodology we used is described in Section 4. In Section 5, the detailed results of the analysis are presented. Here also we attempt to explain the observations in the context of the forecasting process.

Section 2

KEY FINDINGS

In this section, we present the key findings of our analysis. Because the sample sizes of some of the building types are very small, we report the findings related to only the five building types with substantial samples: offices, retails, groceries, restaurants, and warehouses.

THERMAL SENSITIVITY OF COMMERCIAL LOADS

We defined thermal sensitivity in terms of year-to-year load deviations from the long-term mean annual load. The standard deviation of the year-to-year loads, averaged across buildings, was the primary metric used for comparison. Using this metric, we examined the thermal sensitivity of building total and heating, ventilating, and air-conditioning (HVAC) loads in all building types, and refrigeration loads in groceries and restaurants.

Building Total Loads

The thermal sensitivity of building total loads is small for all building types. The standard deviation of year-to-year loads is less than 2% of the mean annual loads for all building types except warehouses, for which the average is about 3%. Extreme deviations from the mean, occurring in severe or mild weather years, are also relatively small. The least sensitive of the building types, groceries and restaurants, deviate by 1% to 2%. Offices and retails display a 3% to 4% deviation, and warehouses exhibit a 5% deviation.

Weather variations appear to account for less than 5% of mean loads in years of the greatest deviation.

HVAC Total Loads

The thermal sensitivity of HVAC loads is also small for all building types. The standard deviations of year-to-year loads are typically between 4% and 6%. Extreme deviations from mean annual loads, occurring in severe or mild weather years, range from 8% to 10% for all building types except retails, which show a deviation of 12% to 15%.

When the HVAC end use is viewed in isolation, a weather-adjustment procedure may explain discrepancies for 10% to 15% of the mean loads. However, typical deviations caused by the weather are closer to 5%.

Refrigeration Loads

The thermal sensitivity of refrigeration loads is very small in groceries and restaurants. Standard deviations of year-to-year loads are generally less than 1% of the mean annual loads. Even in extreme weather years, the deviations are typically no more than 1% to 2%.

EFFECTS OF BUILDING CHARACTERISTICS ON THERMAL SENSITIVITY

Although the magnitude of weather-induced load variations was found to be small, we investigated the effects of three building characteristics on thermal sensitivity: 1) floor area (building size); 2) vintage (year built); and fuel type (electric or nonelectric heating). We compared our results against the common expectations that small buildings are more thermally sensitive than larger buildings, old buildings are more thermally sensitive than new buildings, and electrically-heated buildings are more thermally sensitive than those heated by other fuels (because only electric loads are considered).

Floor Area

As expected, floor area does affect HVAC loads. Except in restaurants and warehouses, small buildings are more sensitive to the weather because of the higher ratios of envelope area to conditioned volume. Restaurants show the opposite trend, which may reflect proportionally higher needs for cooling and ventilation in larger buildings. Warehouses contradict the expectation, but the subsamples are too small to lend confidence to this finding. If a weather-adjustment procedure is pursued, only smaller buildings may need to be considered.

Vintage and Fuel Type

We found that neither vintage nor primary heating fuel affects thermal sensitivity. Newer buildings--that is, those built after 1981, when the 1980 Seattle Energy Code was enacted--were presumed to be less temperature-dependent. However, our analysis results show that this is not the case. The trends are either contradictory or undiscernible for all building types.

Buildings that are heated primarily by other fuels and, thus, expected to exhibit less thermal sensitivity in electric loads, do not. This could be a result of cooling sensitivities dominating in many buildings or correlations between heating fuel and other variables.

These observations suggest that a weather-adjustment procedure might not need to differentiate between new and old buildings or between all-electric and mixed-fuel buildings.

CORRELATION OF THERMAL SENSITIVITY WITH DEGREE-DAYS

Because heating and cooling degree-days^(a) calculated to a base temperature of 65°F are the most common and easily-obtained parameters describing regional weather, we investigated their potential use as the basis for a weather-adjustment procedure. A useful adjustment procedure should be easy to implement, requiring that the weather data inputs be readily available.

Base-65 degree-days generally correlate well with the occurrence of extreme-year loads. This indicates that a simple weather adjustment procedure based on degree-days might account for discrepancies between measured and predicted loads. However, we did not investigate the extent to which a simple degree-day multiplier would adjust loads from one weather year to another.

Approximately half of the ELCAP buildings exhibited maximum annual loads in severe winter years; the other buildings exhibited maximum annual loads in severe summer years. This indicates that both heating and cooling corrections would be required in an effective weather adjuster.

Based on our analysis, if a weather-adjustment procedure is pursued, a simple degree-day correlation is a promising prospect. This is an important finding, because such a procedure would be easy to develop and implement, an obvious requirement of an adjustment expected to account for relatively little year-to-year variance.

(a) A degree-day is a measure of the departure of the mean daily temperature from a given standard. One degree-day is recorded for each degree of departure above (or below) the standard during a single day. Degree-days are used to estimate the energy requirements for building heating and, to a lesser extent, cooling (Parker 1984, p. 424).

Section 3

ANALYSIS OVERVIEW

The reason for undertaking this analysis is described in this section. The analysis objective is explained in terms of the research questions for which we sought answers.

MOTIVATION

The fundamental motivation for this task was the observed divergence between actual and forecasted loads in the commercial sector. To calibrate the commercial forecast, several past years' loads are forecasted and compared with actual utility billing data. It has been speculated that some of the observed differences during the calibration period might be caused by variations in the annual weather.

The residential sector forecast uses a weather normalization factor, based on population-weighted heating degree-days, which adjusts the sector billing data to the normal weather-year embedded in the forecast of space heating. No counterpart to this weather normalization factor exists for the commercial sector. The sole purpose of this analysis was to examine the magnitude and nature of the variation in commercial sector loads caused by variations in annual temperature. The results should indicate the potential benefit of developing a weather normalization method.

OBJECTIVE

The objective of this analysis was to determine the answers to the following research questions:

- To what extent is the commercial building sector sensitive to annual variations in weather?

- How does the weather response vary between the different types of commercial buildings?
- How do the size, age, and primary heating fuel of buildings affect their thermal sensitivity?

HYPOTHESES

We formulated four hypotheses related to the third research question dealing with the effects of certain building characteristics on thermal sensitivity. These hypotheses essentially summarize what we expected to find in this area:

- General - Outdoor temperatures affect only HVAC loads, refrigeration loads, and, to a lesser extent, domestic water heating loads. In practice, some other loads will appear to be correlated with temperature, when they are actually more correlated to seasons than temperatures. An example is the lighting end use, for which some buildings will use less energy in the summer, when daylight is available for many hours, than in winter, when darkness may fall before the end of the workday. In this analysis, we have ignored these phenomena except to acknowledge their existence and to qualitatively consider their impacts when inferring conclusions from the building total results.
- Floor Area - Smaller buildings will have HVAC loads that are more temperature-dependent than those of larger buildings because of larger ratios of envelope surface area to volume. Refrigeration loads might follow a similar trend because of heat recovery equipment on larger, centralized compressor installations, or they might follow the opposite trend because smaller buildings tend to have small, unitary refrigeration cases that exchange heat directly with the indoor air.
- Vintage - Older buildings will have HVAC loads that are more temperature-dependent than those of newer buildings. This is expected to be particularly true in this analysis, where two classes of buildings are studied: those built prior to 1981, when the 1980 Seattle Energy Code took effect (existing buildings) and those built after 1980 (new buildings). The more stringent energy conservation requirements of the new code are expected to reduce buildings' sensitivity to weather.
- Primary Heating Fuel - Because ELCAP measures only electric energy consumption, buildings that are fully or partially heated by other fuels should show lower sensitivity to outdoor temperatures. This study classifies buildings into two categories: those primarily heated by electricity and those primarily heated by other fuels. Because many buildings use a mixture of fuels, the primary fuel is arbitrarily defined as the fuel that heats the greatest amount of floor space.

Section 4

METHODOLOGY

In this section, we document how we used the ELCAP commercial sector database to analyze the year-to-year variations in end-use loads. First, we delineate the scope of the analysis: its focus, limitations, and data source. Next, we document our approach. We explain the process applied to each individual building and end use and then describe the procedure used to obtain normalized values that are easily compared across sites.

SCOPE

Our analysis was limited to the effects of outdoor temperature, excluding the effects of solar radiation, wind, and relative humidity. This is because the primary response was expected in the temperature domain, as indicated by the physics of heat loss in buildings. The residential weather correction factor in the forecast is based on heating degree-days, a measure of temperature. Because this study was designed to indicate the potential value of developing such a weather correction factor for the commercial sector, it was logical to begin in a direction parallel to that of the residential sector, especially because degree-day data are more readily available to forecasters than are solar, wind, and humidity data.

The scope of this task was also limited to analyzing the impact on HVAC loads as a whole, rather than heating, cooling, and ventilation individually. In addition to HVAC loads, we analyzed building total loads for all building types, as well as refrigeration loads for groceries and restaurants. We did not analyze other non-HVAC end uses because any apparent weather sensitivity is probably attributed to seasonal effects. An example is outdoor lighting in buildings with a photocell controller, where the load has a strong but completely coincidental relationship to outdoor temperature.

The results of our analysis are based on hourly end-use data collected from a subset of buildings in the ELCAP sample. Consequently, their validity is limited by that of the sample itself. Our sample comprised the more than 100 buildings in the Commercial Base Study under way in the greater Seattle area. It is well known that the ELCAP Commercial Base sample is biased away from very large buildings and toward smaller buildings, compared to the Seattle commercial tax parcel sample frame from which it is drawn.

The ELCAP database also contains data from another 41 commercial buildings that are part of Bonneville's Commercial Audit Program (CAP) and Purchase of Energy Savings (PES) project. Our analysis did not include data from the CAP and PES samples. About half of these buildings are in eastern Washington and Idaho and could provide some climatic diversity to the sample. However, the buildings do not represent a random sample of the region or of the CAP audit sites, and no claim can be made as to their representativeness of any building population. In addition, their inclusion in the study would have required the processing of many years' weather data for several additional National Oceanographic and Atmospheric Administration sites, an effort not warranted by the marginal benefit to the analysis.

To determine the degree of thermal variation evident, our analysis used 32 years of Seattle weather data. We did not create population-weighted regional average weather data, nor did we apply multiple weather sites to the buildings' response curves to produce a weighted regional average result. Thus, our analysis results represent the thermal sensitivity based on Seattle weather variations using Seattle buildings exclusively.

APPROACH

Our approach was to determine from the ELCAP data the extent of year-to-year variation in end-use loads that can be attributed to weather variations. We first made our assessment in individual buildings. Then we examined load responses across buildings to determine the behavior of the entire sample (within each building type).

The process we applied to each individual building and end use is diagrammed in Figure 4-1. The three distinct steps are as follows:

1. Characterize the response of end-use loads to outdoor temperature.
2. Apply the empirical function to historical temperature data.
3. Produce cross-year statistics.

The three steps and the two intermediate results produced are described in the following three subsections.

Characterization of End-Use Load Response to Temperature

For each end use of interest (building total, HVAC, or refrigeration), we plotted daily average loads against daily average outdoor temperature, both of which are measured by the ELCAP metering equipment. A typical resulting plot is shown in Figure 4-2. Note that, because of the highly scheduled nature of commercial buildings, workdays and nonworkdays are plotted separately. Within each of these day types, a clear trend is visible. As outdoor temperatures drop below a balance temperature of about 60°F, the building total load increases as more heating is required. As temperatures rise above the balance point, the load remains relatively constant, indicating that this building has very little cooling sensitivity to outdoor temperature.

A statistical procedure was then used to fit a smooth curve through each scatter plot (workdays and nonworkdays). The procedure, known as LOWESS (locally weighted regression scatter plot smoothering), involves a series of piecewise linear regressions (Cleveland 1979). The LOWESS procedure is robust, meaning it is resistant to the effects of extreme outliers in the data. This results in a smooth curve showing the relationship between temperatures and loads. The two smooth curves on the plot in Figure 4-2 illustrate the LOWESS fits. The data points comprising these example curves--the direct outputs from the LOWESS procedure--are shown in Table 4-1.

FIGURE 4-1

Annual Energy Estimation Procedure Flow Diagram for a Site and End Use

FIGURE 4-2

Typical Plot Characterizing End-Use Load Response to Outdoor Temperature

TABLE 4-1
Building Total LOWESS Fits for Site 2

Then the estimated daily average load (W) is:		
If Daily Average Outdoor Temperature (°F) is:	Workdays	Nonworkdays
20	81821.77	70306.51
22	78228.49	66188.31
24	74645.97	62075.88
26	71077.69	57983.77
28	67520.00	53891.66
30	63962.26	49799.55
32	60401.72	45724.73
34	56846.26	41684.39
36	53323.80	37686.49
38	49886.83	33747.99
40	46539.62	29844.07
42	43217.27	26003.13
44	39834.75	22400.45
46	36654.71	19322.61
48	33874.87	16730.53
50	31515.30	14469.93
52	29651.17	12454.92
54	28349.40	10814.63
56	27555.66	9608.09
58	27185.71	8914.83
60	27120.85	8482.09
62	27198.26	8279.17
64	27365.30	8133.62
66	27558.66	8001.54
68	27761.43	7883.55
70	27975.20	7783.96
72	28201.45	7708.28
74	28443.63	7659.05
76	28700.75	NA

For the analyses presented in this report, the LOWESS procedure was applied to as many as three day types for each building: workdays, nonworkdays (if any), and legal holidays. Holidays, a small fraction of the days in a year, are treated separately to avoid having to determine whether or not each site is open for business on holidays. For some sites, the holiday curve fit is similar to the nonworkday fit. For others, it is similar to the

workday fit. If a site is open on some holidays and closed on others, the holiday lowess line may lie between the workday and nonworkday curves.

Applying the Empirical Function to Historical Temperature Data

Once the curve fits were obtained for an end use, they could be used to estimate the end-use energy consumption on any day for which the average outdoor temperature is known. For example, referring to the dotted lines on Figure 4-2, if the average outdoor temperature for a given weekday is 40°F, the average end-use load for that day is estimated at about 55,000 watts (W). By following this procedure for every day of a given year and summing the daily estimates, total annual end-use loads could be estimated.

For this study, daily average Seattle outdoor temperatures were obtained from the National Weather Service for the years 1956 through 1985. Data from 1986 and 1987 were also available from the ELCAP database. Thus, 32 years' daily temperatures were used to estimate end-use loads for each building. The daily load estimates were then aggregated to the annual level, resulting in 32 estimated annual loads for each building and end use.

Figure 4-3 illustrates this for the same building for which data appear in Figure 4-2. The solid line represents the 32 annual building total load estimates. The dotted line represents the average of all 32 years' estimates. The dashed line is included only for reference and represents the estimated load for Typical Meteorological Year (TMY) weather. The TMY data are commonly used in computer simulations of building energy consumption that form the basis for many regional load assessment activities. In this example, the TMY data produce an annual load that exceeds the average estimated load over the 32 years by about 2.5%.

Producing Cross-Year Statistics

The 32 annual load estimates were next subjected to simple statistical summarizations. In addition to the mean annual load (shown in Figure 4-3),

FIGURE 4-3

Estimated Annual Loads for Example Site

three other statistics were calculated: the standard deviation of year-to-year loads, the minimum annual load over the 32 years, and the maximum annual load.

Because this analysis specifically concerns the *variations* in loads rather than the actual magnitudes of loads, each of the three statistics may be divided by the mean annual load to obtain normalized values that are easily compared across sites. For example, dividing the maximum annual load by the mean annual load and multiplying the result by 100 gives the peak yearly load as a percentage of the mean yearly load. The minimum load and standard deviation of loads are similarly normalized. These three mean-normalized measures--the standard deviation of loads, the minimum load, and the maximum load--are the values presented in all graphics used to illustrate our analysis results in Section 5.

The standard deviation of loads, expressed as a percentage of the mean annual load, is an indicator of the typical amount of year-to-year variation that can be expected because of temperature differences. Standard statistical theory suggests that approximately two-thirds of the loads are expected to fall within ± 1 standard deviation of the mean. Ninety-six percent of the loads should be within ± 2 standard deviations. For example, if a site has a standard deviation equal to 5% of the mean load, then about 68% of the years would be expected to have loads between 95% and 105% of the mean load. About 96% of the yearly loads should fall between 90% and 110% of the mean.

The minimum and maximum annual loads simply show the extremes of deviation from the mean. For example, a load forecaster trying to calibrate a forecast model to known data would benefit from knowing the worst-case deviation from mean loads that might occur in a severe weather year.

Section 5

RESULTS

As was explained in Section 4, this analysis resulted in 32 estimated annual end-use loads for each site. The load estimates were obtained from empirical functions relating end-use loads to outdoor temperatures. Thus, year-to-year variations in the estimated loads are caused solely by differences in year-to-year outdoor temperature patterns.^(a)

The results we obtained are discussed and illustrated in this section. Before we present our results, we provide some explanatory background to assist the reader in interpreting the statistical information that appears here.

EXPLANATION OF REPORTED STATISTICS

For each end use at each site, three summary statistics were calculated:

- the standard deviation of loads
- the minimum annual load
- the maximum annual load.

These three statistics are explained in the following paragraphs.

Standard Deviation of Loads

The standard deviation of loads is an indicator of the typical amount of year-to-year load variation that can be expected from temperature variations. To facilitate comparisons across buildings of differing size and energy

(a) It should be noted that natural effects that are correlated with outdoor temperatures can cause load changes that might be erroneously attributed to weather. A simple example is outdoor lighting loads. Because many such lights are controlled by photocells, the loads are higher in winter when there are fewer daylight hours, giving the appearance of temperature sensitivity. This analysis makes no attempt to correct for such phenomena.

consumption, the standard deviation is expressed as a percentage of the mean annual load. This mean-normalized value is known formally as the *coefficient of variation*.

Statistical theory suggests that approximately 68% of the loads will fall within ± 1 standard deviation of the mean. Approximately 96% of the loads should be within ± 2 standard deviations. For example, if a site has a standard deviation equal to 5% of the mean load, then about 68% of the years are expected to have loads between 5% above and below the mean load. About 96% of the yearly loads should fall between 10% above and below the mean.

Minimum Annual Load

This is simply the minimum annual load occurring over the 32-year period. Again, it is expressed as a percentage of the mean annual load, to facilitate across-building comparisons. The minimum annual load is an indicator of the extreme load deviation expected in the *mildest* of weather years.

Maximum Annual Load

This is simply the maximum annual load occurring over the 32-year period, expressed as a percentage of the mean annual load. This metric is an indicator of the extreme load deviation expected in the most severe weather year.

Illustrations

These statistics are illustrated in Figure 5-1. The solid plotted line depicts the 32 annual load estimates for a sample site, with the minimum and maximum annual loads labelled. The dotted lines represent 1 standard deviation above and below the mean annual load (shown by the dashed line). The sparse dotted lines show 2 standard deviations above and below the mean annual load.

FIGURE 5-1
Computed Statistics for a Sample Site

The three computed statistics for each site and end use must be examined across sites to ascertain the typical behavior of the sample. One way of doing this is to simply average the statistics for all sites. However, simple averages do not show the variation between sites. Another approach is to plot the statistics from all sites. This shows the between-building variations, but it is voluminous and often difficult to interpret.

A better approach is to plot the statistics from all sites in the form of a *box and whisker plot*. Figure 5-2 illustrates the important features of this type of plot. The figure shows a series of *data points* along with a box and whisker representation of the data. The horizontal line drawn roughly through the middle of the box represents the median value of the data. The upper and lower extents of the box represent the upper and lower quartiles of the data. This means that 50% of the data points lie between the y-axis values corresponding to the top and bottom of the box. Twenty-five percent of the data are below the bottom of the box and 25% above the top. Whiskers

FIGURE 5-2
Elements of a Box and Whisker Plot

are drawn outward from the box, extending a distance not exceeding 1.5 times the interquartile range (the difference between the upper and lower quartiles). Any data points beyond these whisker extremes are plotted separately to mark them as potential outliers. Finally, the mean of the data values is plotted as a plus sign (+).

THERMAL SENSITIVITY BY BUILDING TYPE

The methodology described in Section 4 was applied to each of the end uses of interest in each of the ELCAP sites. This section describes building-to-building variations in the three computed statistics within building type boundaries.

Description of the Plots

Figures 5-3 through 5-5 show the mean, median, and distribution of each of the three statistics within each building type for each end use. In each

FIGURE 5-3

Computed Building Total Statistics by Building Type

(ELCAP PADS 12-88 / 17 Dec 1989)

FIGURE 5-4

Computed HVAC Statistics by Building Type

(ELCAP PADS 12-46 / 17 Dec 1999)

FIGURE 5-5

Computed Refrigeration Statistics by Building Type

of these figures, there are three graphs corresponding to the three statistics. Within each graph, there are nine box and whisker plots corresponding to the nine building types. Each box and whisker plot represents the computed statistics from a number of sites (n) shown at the top of the graph.

Figures 5-3 through 5-5 are best explained with an example. In Figure 5-3, the left box plot is for offices. Above the plot is the number of sites (n) for the statistics that are shown (n = 15). Consider the top graph that depicts the standard deviations of estimated annual loads. The upper and lower extents of the box show that 50% of the office sites have year-to-year standard deviations between 1% and slightly over 2% of their mean annual loads. One site, marked by the asterisk, shows a standard deviation as high as 4.5% of its mean. The middle graph shows that half of the offices had a 32-year minimum load of between 98% and 96% of the mean annual load. One site had an annual load as low as 92% of the mean load.

Observations

Some of the major observations from Figures 5-3 through 5-5 are summarized in the following paragraphs.

Groceries and restaurants have the lowest overall (building total) thermal sensitivity, with standard deviations typically at 1% of the mean or less. Loads in these building types are dominated by food preparation equipment, which is not sensitive to the weather, and refrigeration, which is only slightly sensitive to the weather (see below).

Warehouses have the highest overall (building total) thermal sensitivity, with standard deviations at about 3% of the mean. This is not surprising because most warehouses have little or no insulation, frequently have large doors open for loading and unloading, and contain very little heat-generating equipment.

None of the five major building types shows building total variability in excess of 2% except warehouses, with a variability close to 3%.

Building total loads in extreme years deviate from the mean by 3% to 4% for offices and retails, 1% to 2% for groceries and restaurants, and about 5% for warehouses.

Offices, groceries, and restaurants have HVAC variabilities of about 4%. Warehouses are slightly higher at about 5%, with retails at about 6%. These are relatively small deviations, although it is expected that heating changes might be partially offset by cooling changes in some buildings. The ELCAP sample also has fewer electric heating systems than electric cooling systems. This could result in a low bias in the calculated variabilities.

HVAC extremes differ from the means by about 9% to 10% for all major building types except retails (12% to 15%).

Refrigeration is very insensitive to weather. Both groceries and restaurants show year-to-year standard deviations of less than 1% of mean annual loads. Extreme year deviations are generally 1% to 2% of the mean. Weather adjustment of refrigeration loads is not shown to be important.

EFFECTS OF SIZE, VINTAGE, AND PRIMARY FUEL TYPE

In understanding the thermal sensitivity of the commercial sector, it is helpful to know if certain types of buildings are more prone than others to have temperature-dependent end-use loads. For this reason, we examined the effect of three major building characteristics--size (floor area), vintage (year built), and primary fuel type--on thermal sensitivity.

Figures 5-6 through 5-17 show the three computed statistics (standard deviation of annual loads, minimum annual load, and maximum annual load) for each end use in each of the five building types with substantial sample sizes.

FIGURE 5-6

Physical Characteristic Effects on Office Building Total Statistics

(ELCAP PADS 12-38 / 14 Dec 1989)

FIGURE 5-7

Physical Characteristic Effects on Office HVAC Statistics

FIGURE 5-8

Physical Characteristic Effects on Retail Building Total Statistics

FIGURE 5-9

Physical Characteristic Effects on Retail HVAC Statistics

(ELCAP PADS 12-98 / 14 Dec 1999)

FIGURE 5-10

Physical Characteristic Effects on Grocery Building Total Statistics

FIGURE 5-11

Physical Characteristic Effects on Grocery HVAC Statistics

(ELCAP PA06 12-48 / 14 Dec 1999)

FIGURE 5-12

Physical Characteristic Effects on Grocery Refrigeration Statistics

FIGURE 5-13

Physical Characteristic Effects on Restaurant Building Total Statistics

(ELCAP PADS 12-88 / 14 Dec 1989)

FIGURE 5-14

Physical Characteristic Effects on Restaurant HVAC Statistics

FIGURE 5-15

Physical Characteristic Effects on Restaurant Refrigeration Statistics

FIGURE 5-16

Physical Characteristic Effects on Warehouse Building Total Statistics

(ELCAP PADS 12-88 / 14 Dec 1989)

FIGURE 5-17

Physical Characteristic Effects on Warehouse HVAC Statistics

Within each figure are three graphs showing the three computed statistics. Within each graph are three pairs of box and whisker plots representing the three building characteristics.

Observations

The major observations from Figures 5-6 through 5-17 are summarized in Table 5-1. Frequent reference is made to the correlations between some of the characteristic variables. Tables A-1 through A-9 in the Appendix to this report show these referenced cross-tabulations. The observations summarized in Table 5-1 are further condensed into three key findings. These are discussed in the following paragraphs.

As expected, floor area generally affects thermal sensitivity, with smaller buildings being more sensitive, except in restaurants and warehouses. The trend in restaurants is toward more temperature dependence in larger buildings. This may indicate that cooling and ventilation loads dominate in this building type (Taylor and Pratt 1990). Little difference in HVAC loads was seen between large and small warehouses, but this may be the result of small subsamples.

The hypotheses regarding vintage effects were generally not supported by this analysis. Only in warehouse HVAC loads was the expectation of greater thermal sensitivity in older buildings confirmed. For all other building types, the trends were either undiscernible or contradictory.

The hypotheses regarding primary heating fuel effects were generally not confirmed. The trends in HVAC sensitivity were frequently contrary to the expectation that fossil-fuel-heated buildings will show less weather sensitivity in electric loads. This finding might be explained by a dominance of cooling loads in many of the fuel-heated buildings, but could also be the result of correlations between primary heating fuel and other characteristics, or a consequence of small subsample sizes.

TABLE 5-1

Summary of Observations on Size, Vintage, and Heating-Fuel Effects

	Floor Area	Vintage	Primary Heating Fuel
Office	<ul style="list-style-type: none"> • Trend as expected for both building total and HVAC. 	<ul style="list-style-type: none"> • Trend backwards for building total. Possibly indicates some other end use is varying with season, cancelling the HVAC variations with weather. • Trend as expected for HVAC. 	<ul style="list-style-type: none"> • Trend as expected for building total. • Trend backwards for HVAC. Possibly because many sites labeled Non-electric do have significant electric heating loads, too. Also, there are no Non-electric sites built post-1980. Cooling sensitivity could also be overshadowing heating.
Retail	<ul style="list-style-type: none"> • Trend as expected for both building total and HVAC. 	<ul style="list-style-type: none"> • Trend backwards for building total. Possibly because all New sites are small, but the lack of effect on HVAC is unexplained. Could indicate a seasonally-dependent end use. • No obvious effect on HVAC. Likely because all New sites are also small. 	<ul style="list-style-type: none"> • Trend as expected for building total. Unusual because there is no visible effect on HVAC. • No effect or slightly backwards effect on HVAC. Possibly because all non-electric sites are existing.
Grocery	<ul style="list-style-type: none"> • Expected trend visible, but small for both building total and HVAC. • No visible effect on refrigeration. 	<ul style="list-style-type: none"> • Little or no effect on any end use. 	<ul style="list-style-type: none"> • Trend backwards for building total and refrigeration, but Non-electric subsample is very small. • No visible effect on HVAC.
Rest'nt	<ul style="list-style-type: none"> • Trend as expected for building total. Unusual because HVAC shows a backwards trend. • Trend backwards for HVAC. Could indicate a dominance of cooling over heating loads. • No effect on refrigeration. 	<ul style="list-style-type: none"> • Trend backwards for building total. Unusual because HVAC shows little trend. • No obvious effect on HVAC except than minimum loads are less extreme for new sites. • No discernible effect on refrigeration. 	<ul style="list-style-type: none"> • No effect on building total. • Trend backwards for HVAC. Because all electric sites are small, this could also indicate a dominance of cooling over heating loads. • No discernible effect on refrigeration.
Warehse	<ul style="list-style-type: none"> • Trend as expected for building total. Unusual because HVAC shows no effect. • No effect on HVAC, but the subsample of large sites is small. 	<ul style="list-style-type: none"> • Effect on building total is difficult to discern because of small New subsample. • Trend as expected for HVAC. 	<ul style="list-style-type: none"> • Trend as expected for building total. • Little effect on HVAC.

CORRELATION OF THERMAL LOADS WITH DEGREE-DAYS

A desirable goal of assessing the thermal sensitivity of commercial end use loads is to develop a simple adjustment factor or procedure whereby measured loads may be transformed to normal-weather loads. This would allow more meaningful comparisons between studies conducted at different times or at different locations. Also, forecasters trying to reconcile modeled and measured consumption data would be able to transform the measured data to match the normal weather assumptions in the forecasting models.

This study is directed at assessing the potential usefulness of such an adjustment procedure rather than at actually developing one. In this sense, the assessments of the magnitude of year-to-year variance are the primary products of the analysis. However, one consideration that affects the usefulness of any procedure is its simplicity in terms of data requirements and computational complexity.

The most commonly available data related to yearly weather are degree-days computed to a base temperature of 65°F. Consequently, the usefulness of a weather-adjustment factor or procedure would be greatly enhanced if it could be expressed in terms of simple base-65 degree-days. This section presents some simple graphics that allow easy, albeit subjective, assessments of the correlation between thermally sensitive loads and degree-days.

Description of the Plots

Figures 5-18 through 5-26 are plots of the annual heating and cooling degree-days for the 32-year study period. Superimposed on the plots are arrows indicating the years during which one or more sites experienced end-use load extremes. The arrows at the top of the plots represent maximum annual loads; arrows at the bottom represent minimum loads. Associated with each arrow is a set of numbers indicating, for each end use, how many sites experienced an extreme load in that year.

FIGURE 5-18

Years of Extreme Office Loads

FIGURE 5-19

Years of Extreme Retail Loads

FIGURE 5-20

Years of Extreme Grocery Loads

FIGURE 5-21

Years of Extreme Restaurant Loads

FIGURE 5-22

Years of Extreme Warehouse Loads

FIGURE 5-23

Years of Extreme School Loads

FIGURE 5-24

Years of Extreme University Loads

FIGURE 5-25

Years of Extreme Hotel Loads

FIGURE 5-26

Years of Extreme Other Loads

For example, Figure 5-18 shows the extremes for all office buildings. The solid plotted line represents heating degree-days. The dashed line represents cooling degree-days that must be read from the alternate y-axis scale (also dashed). Consider the year 1964. The plotted lines show that it had relatively cold winters with a mild summer. The arrow at the top of the plot indicates that four sites experienced their highest annual building total loads that year, while only two sites experienced their highest annual HVAC loads. The bottom arrow shows that only one site had its minimum total load in 1964 while four sites had minimum HVAC loads that year.

Observations

The information in Figures 5-18 through 5-26 is best discerned by careful examination of the plots. However, for convenience, Table 5-2 is provided to summarize the major observations for each building type.

TABLE 5-2

Summary of Observations from Extreme Load Plots

Building Type	Observations
Office	Most extremes occurred in years of either severe or mild weather, although there are exceptions (e.g., the minimum load in 1981). With respect to HVAC loads, an equal number of sites peak in severe winters and severe summers, suggesting that the ELCAP sample is evenly split between heating- and cooling-dominated buildings. Building total and HVAC load extremes tend to, but do not always, occur in the same years.
Retail	Most extremes occurred in years of either severe or mild weather, although there are exceptions (e.g., the maximum load in 1987). With respect to HVAC loads, an equal number of sites peak in severe winters and severe summers, suggesting that the ELCAP sample is evenly split between heating- and cooling-dominated buildings. Building total and HVAC load extremes tend to occur in the same years, but not always.
Grocery	All sites had peak refrigeration loads in the same year, 1958. That year was a severe cooling year, although not the most severe. All sites except one had minimum refrigeration loads in the same year (1964) that was characterized by one of the milder summers. HVAC extremes appear to be roughly split between heating- and cooling-dominated behavior.
Restaurant	The majority of HVAC load peaks occur in severe cooling years, indicating a predominance of cooling-dominated buildings. Minimum HVAC loads, however, show higher correlation to mild heating seasons. Refrigeration loads are not as consistent as in groceries, but do appear to follow cooling season patterns more than heating patterns.
Warehouse	HVAC peak loads are evenly split between severe heating years and severe cooling years. The mild heating and cooling seasons of 1983 account for the majority of sites' minimum building total loads. However, HVAC minima are distributed over many years.
School	HVAC and building total loads appear correlated primarily to heating season weather, peak loads corresponding to severe winters and minimum loads corresponding to mild winters.
University	Loads from the single university site appear to be dominated by cooling season effects.
Hotel	Loads from the single hotel appear to be dominated by heating season effects.
Other	Loads from the few other sites follow heating season patterns.

In general, the extremes (both high and low) occur in years with extreme weather (as indicated by base-65 degree-days.) However, some buildings are obviously more sensitive to summer loads while others are more sensitive to winter loads. In a few cases, extreme loads occur in years without extreme weather, indicating that simple degree-days are not perfectly correlated with loads. A more thorough analysis would seek to identify physical building characteristics that explain the tendencies toward summer or winter correlation, and would assess the value of additional data beyond simple degree-days. Such an analysis should accompany any attempt to parameterize these results into a simple weather-adjustment factor.

A SAMPLE-WIDE PERSPECTIVE

Because most regional forecasting and load assessment activities are concerned with the character of electric loads in all classes of commercial buildings, it is helpful to combine the building-type-specific information from Figures 5-18 through 5-26 into a single view covering all building types. This allows an assessment, again subjective, of the correlation between simple base-65 degree-days and the commercial sector loads as a whole.

Figures 5-27 through 5-32, like the previous plots, show heating and cooling degree-days for each of the 32 analyzed years. Superimposed on these line plots are bars that represent the total number of sites that experienced extreme loads during each year. To increase readability, only the five building types with substantial sample sizes are included (office, retail, grocery, restaurant, warehouse).

As an example, consider Figure 5-27, which shows the occurrences of minimum annual building total loads. More sites had 32-year minimum loads in 1983 than in any other year. As shown by the degree-day lines, 1983 had mild heating and mild cooling seasons. The second-ranked year (1964) had a very mild summer, but relatively harsh winters. This is indicative of buildings that are dominated by cooling rather than heating loads.

FIGURE 5-27

Years of Occurrence of Minimum Building Total Loads

FIGURE 5-28

Years of Occurrence of Maximum Building Total Loads

FIGURE 5-29

Years of Occurrence of Minimum HVAC Loads

FIGURE 5-30

Years of Occurrence of Maximum HVAC Loads

FIGURE 5-31

Years of Occurrence of Minimum Refrigeration Loads

FIGURE 5-32

Years of Occurrence of Maximum Refrigeration Loads

Figure 5-28 shows the maximum annual building total loads. The year in which most sites experienced maximum loads is 1967, a year with a severe summer, but moderate winter. Two years, 1964 and 1985, also have large numbers of peaking sites. Both of these are clearly severe winter years. While 1964 has a mild summer, 1985 has a moderate-to-severe summer. The next-highest bar is located at year 1958, clearly a severe summer and mild winter year.

Figures 5-29 and 5-30, which also show occurrences of extreme HVAC loads, tell an identical story. It is apparent that, as indicated by simple base-65 degree-days, at least as many ELCAP commercial sites are dominated by cooling loads as are dominated by heating loads.

Figure 5-31 shows that 1964 was the year in which almost all restaurants and groceries had minimum refrigeration loads. That year had a very mild summer and very cold winter; both of these would be expected to lower refrigeration loads. The year in which nearly all these sites had maximum refrigeration loads was 1958, with a very warm summer but mild winter, as shown in Figure 5-32. Apparently, refrigeration loads are sensitive to outdoor temperature year-round. However, the magnitude of the sensitivity is very small.

Section 6

REFERENCES

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APPENDIX

CROSS-TABULATIONS OF IMPORTANT BUILDING CHARACTERISTICS

TABLE A-1

Cross-Tabulations of Office Characteristics
(Small/Large cutoff = 10000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	2	5	3	0
Large	1	3	2	0

TABLE A-2

Cross-Tabulations of Retail Characteristics
(Small/Large cutoff = 20000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	5	3	5	0
Large	1	0	3	0

TABLE A-3

Cross-Tabulations of Grocery Characteristics
(Small/Large cutoff = 7000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	1	3	0	0
Large	5	1	2	0

TABLE A-4

Cross-Tabulations of Restaurant Characteristics
(Small/Large cutoff = 6000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	3	2	1	1
Large	0	0	2	1

TABLE A-5

Cross-Tabulations of Warehouse Characteristics
(Small/Large cutoff = 15000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	2	1	3	2
Large	1	0	4	0

TABLE A-6

Cross-Tabulations of School Characteristics
(Small/Large cutoff = 50000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	0	0	2	0
Large	0	0	1	0

TABLE A-7

Cross-Tabulations of University Characteristics
(Small/Large cutoff = 50000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	0	0	1	0
Large	0	0	0	0

TABLE A-8

Cross-Tabulations of Hotel Characteristics
(Small/Large cutoff = 20000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	0	0	0	0
Large	0	0	0	0

TABLE A-9

Cross-Tabulations of Other Characteristics
(Small/Large cutoff = 5000 ft²)

	<u>Electric</u>		<u>Non Electric</u>	
	<u>Existing</u>	<u>New</u>	<u>Existing</u>	<u>New</u>
Small	0	0	2	0
Large	0	0	2	0

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