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End-Use Energy Consumption Estimates for U.S. Commercial Buildings, 1989

D. B. Belzer
L. E. Wrench
T. L. Marsh

November 1993

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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ABSTRACT

An accurate picture of how energy is used in the nation's stock of commercial buildings can serve a variety of program planning and policy needs within the Department of Energy, by utilities, and other groups seeking to improve the efficiency of energy use in the building sector. This report describes an estimation of energy consumption by end use based upon data from the 1989 Commercial Building Energy Consumption Survey (CBECS). The methodology used in the study combines elements of engineering simulations and statistical analysis to estimate end-use intensities for heating, cooling, ventilation, lighting, refrigeration, hot water, cooking, and miscellaneous equipment. Billing data for electricity and natural gas were first decomposed into weather and nonweather dependent loads. Subsequently, Statistical Adjusted Engineering (SAE) models were estimated by building type with annual data. The SAE models used variables such as building size, vintage, climate region, weekly operating hours, and employee density to adjust the engineering model predicted loads to the observed consumption. End-use consumption by fuel was estimated for each of the 5,876 buildings in the 1989 CBECS. The report displays the summary results for eleven separate building types as well as for the total U.S. commercial building stock.

SUMMARY

An accurate picture of how energy is used in the nation's stock of commercial buildings can serve a variety of program planning and policy needs within the U.S. Department of Energy, by utilities, and other groups seeking to improve the efficiency of energy use in the building sector. This report presents estimations of energy consumption by end use (heating, cooling, lighting, hot water, etc.) based on data from the 1989 Commercial Building Energy Consumption Survey (CBECS). This work was conducted by Pacific Northwest Laboratory for the Energy End Use and Integrated Statistics Division (EEUISD) within the Energy Information Administration (EIA).

Commercial end-use intensity (EUI), defined as energy consumption per square foot, will be used to 1) support the EIA commercial sector energy modeling and forecasting efforts as part of the National Energy Modeling System (NEMS) and 2) augment the statistical summary information from the survey as published by the EIA.

GENERAL APPROACHES

Development of EUIs for buildings can follow three general approaches: 1) direct metering, 2) statistical analysis known as Conditional Demand Analysis, and 3) engineering simulation. The approach used in this study was a combination of elements of engineering simulation and Conditional Demand Analysis. This approach, the Statistically Adjusted Engineering (SAE) model, begins by estimating end-use components with an engineering-oriented building simulation model. Predicted energy consumption for each end use in each CBECS sample building is dependent on some or all of the following factors: 1) building physical characteristics, 2) operating characteristics, and 3) weather.

The second stage of the SAE procedure uses the predicted end-use components as regressors to explain actual total building energy consumption based on billing data. The regression model coefficients are interpreted as adjustment coefficients for each of the engineering-based end-use estimates.

The adjustment coefficients are then used to generate the final end-use estimates for all buildings, including those that may not have been included in the SAE model.

The overall methodology can be divided into seven major steps:

1. Map 1989 CBECS data (and weather) into engineering model.
2. Run initial engineering model.
3. Estimate SAE models for buildings with monthly billing data, by building type.
4. Based on comparison of predicted and actual energy consumption patterns, revise engineering model. Generate second-round engineering estimates.
5. Estimate final SAE models.
6. Use SAE model coefficients to extrapolate to buildings without monthly billing data.
7. Calibrate end-use consumption to add up to EIA total energy by building.

ENGINEERING FRAMEWORK FOR EUI ESTIMATES

Over the past several years, PNL has been developing an entirely new building energy consumption estimation tool as part of the Facility Energy Decision Screening System (FEDS). This tool, the FEDS Level-1 building energy model, estimates building energy consumption for eight end uses: heating, cooling, ventilation, interior lighting, service hot water, cooking, refrigeration, and miscellaneous equipment. Information from metering studies was used to help further break out cooking and refrigeration from miscellaneous equipment in this study.

FEDS models energy use as daily average hourly profiles. These profiles are calculated for three day types (weekdays, Saturdays, and Sundays) for each month. This approach allows the model to capture the effects of the building operational schedule, as well as the average outdoor conditions, on building energy use.

DATA SOURCES

The FEDS building energy consumption model requires a fairly detailed set of input parameters. In addition to the information taken directly by the 1989 CBECS, the primary sources include the 1986 CBECS, the Regional End Use Monitoring Program (REMP)[a] commercial and residential studies, and knowledge of standard practices as documented in various construction engineering handbooks.

The characteristics data is used to inform the FEDS model of variables needed for its building-by-building energy simulations. The characteristics data is also used in the statistical adjustment regression models to better explain the cross-sectional EUIs.

Where possible, this study utilized the utility billing files developed by EIA in its own consumption estimation procedures. The files analyzed pertain to electricity and natural gas. During the development of the billing file database the following issues were considered: 1) alignment of bills to calendar months, 2) bills not specific to single buildings, and 3) imputation of missing bills. Out of a total of 5,876 buildings in the 1989 CBECS, 3,429 buildings had suitable billing data for electricity and 2,282 had suitable data for natural gas.

Along with the reported or imputed physical and operating characteristics of the buildings, the engineering model requires monthly average hourly weather profiles to predict energy consumption. National Oceanic and Atmospheric Administration's TD 3280 weather tapes provided hourly data for 102 weather stations across the U.S. Files with hourly weather profiles were assigned to each of the 5,876 buildings in the 1989 CBECS.

(a) Previously, the End Use Load and Consumer Assessment Program, a large, on-going monitoring project funded by the Bonneville Power Administration. REMP data includes both hourly time series end use consumption data and an extensive database of building characteristics, including installed capacities of energy using equipment.

FINAL FRAMEWORK FOR DEVELOPING EUI ESTIMATES

The engineering methods in FEDS incorporate thermodynamic principles to estimate end-use consumption, but are not constrained to reflect the observed total energy consumption. However, statistical methods of estimating end-use consumption reflect the observed total consumption, but do not incorporate *a priori* information on the interactions between end uses and their seasonal patterns. The SAE method combines these approaches to generate improved estimates of the end-use loads. Regression-based statistical procedures are used to adjust the engineering estimates to best represent the observed consumption.

The EUIs by fuel type and end use follow the standard convention of normalizing for building floor space. The billing data from the CBECS provides the information to calculate a whole building energy intensity which can be represented as the sum of the EUIs for the end uses present in the building.

Statistically Adjusted Engineering Models

The FEDS engineering model provides estimates of EUIs for eight major end uses. The SAE approach treats these estimates as initial values to be adjusted to best explain the observed billing data.

Based on previous work by Cambridge Systematics, Inc., for the Electric Power Research Institute, a series of sequentially more complex SAE models to analyze commercial energy data can be outlined. The first model is termed a One Period Model without Building-Specific Variables. This model generates a single parameter to adjust each EUI.

In this model, the simulated engineering EUIs enter the model as explanatory variables for each of the end-use services that the building is known to provide. The engineering EUIs vary over buildings on the basis of known or assumed building characteristics, operating schedules, and weather. For each end use and fuel, the estimated coefficient shifts the engineering-based EUI up or down.

If a particular end use is not present as indicated by the CBECS, the corresponding term in the equation is dropped. The monthly whole-building EUI (derived from the billing data) is the dependent variable.

A more complex model is the One Period Model with Building-Specific Variables. This model has the capability to adjust for biases in the EUIs generated by the engineering model that are not constant, but vary across any or all of a number of building characteristics. These dimensions may include building age, climate zone, size, and weekly operating hours.

As a simple example of this model, consider vintage effects. Three general vintages can be considered for the regression model: 1) pre-war buildings (up to 1945), 2) post-war buildings through 1979, and 3) buildings built after 1980. This model would generate different adjustment factors for each vintage.

Experience With One-Period SAE Model

Preliminary regressions with the basic SAE model by building type proved disappointing. The general performance of the monthly SAE models was not satisfactory as they did not provide realistic estimates of EUIs for all end uses. In many cases, negative signs were observed or the values of the estimated coefficients were significantly different from one. Several factors may be contributing to this result; the main factors we believe are: 1) small sample sizes, 2) end use reporting errors, 3) measurement errors of building characteristics and 4) other biases within the engineering model.

Hybrid Approach

As a result of the initial work, greater structure was imposed on the model in the form of *a priori* assumptions. The general approach was to use the monthly data to provide EUI estimates for selected end uses or combinations of end uses. This step is then followed up with SAE models that are estimated with annual data.

Electricity

For electricity, monthly consumption data is first analyzed to separate the weather-sensitive load from the non-weather sensitive load. This step

actually seeks to identify total HVAC consumption as compared to the remaining end uses. The approach used to estimate HVAC consumption is in some respects similar to the PRISM decomposition procedure often used for residential energy analysis. The monthly HVAC and non-HVAC (NHVAC) consumption estimates are then aggregated to annual values for each building in the sample with suitable billing data.

Natural Gas

For natural gas, monthly consumption data is used to distinguish between heating and non-heating consumption. To decompose the whole building gas consumption, strong assumptions are made that 1) heating requirements are zero during the summer months (June, July, and August), and 2) non-heating loads are essentially constant across the months within the year.

Annual SAE Models

The resulting values from the monthly decomposition procedures are treated as observed data, which are then used as dependent variables in a series of annual SAE regressions. For electricity, annual HVAC and NHVAC consumption values are generated for each sample building. For each building type, the cross section of "actual" HVAC consumption values (intensity) is then regressed against the FEDS values for total HVAC intensity and other building-specific demographic variables. The same SAE procedure is applied to the decomposed "actual" intensity corresponding to NHVAC end uses. In addition to vintage as an adjustment variable, we also include the following variables (measured in continuous form) in the SAE models: 1) building size (ft^2), 2) cooling degree-days, 3) employment density (employees per 1,000 ft^2), and 4) weekly operating hours. The further disaggregation of these groupings of end uses then relies almost exclusively on the FEDS engineering estimates.

The general procedure is similar for natural gas, although somewhat less symmetrical. For heating, an annual SAE regression is performed using the same specification as for the HVAC and NHVAC regressions for electricity. For non-heating end uses (primarily water heating and cooking), individual conditional demand and SAE regressions were performed without building specific or

demographic variables. Although regression models with building specific or demographic variables were preferred, it was generally the case that small sample sets (observations numbering less than 30) were observed in the buildings that used natural gas only for either water heating or cooking.

Building Types and End Uses

Eleven building types were defined for the statistical analyses. For the most part, the definitions of the building types correspond with those in the commercial sector module of the NEMS.

b	Building Type
1	Assembly
2	Education
3	Food Sales
4	Food Services
5	Hospital (in-patient health)
6	Lodging
7	Office - Large
8	Office - Small
9	Retail/Service
10	Warehouse
11	Other

The eight end uses distinguished in the study are:

	End Use
1	Space heating
2	Space cooling
3	Ventilation
4	Water heating
5	Lighting
6	Cooking
7	Refrigeration
8	Other or miscellaneous

EUI ESTIMATION: ELECTRICITY

The EUI estimation methodology for electricity involves two elements: 1) monthly bill decomposition and 2) annual SAE regressions.

Electrical Intensities by Month

In general, the seasonal variation of electricity consumption was somewhat overstated by the FEDS model. In 7 of the 11 building types, the weighted average adjustment factor for the HVAC consumption was less than 1.0.

As an example, Figure S.1 shows the monthly energy intensities (on an annualized basis)[a] for small offices, computed as simple unweighted averages for all observations with suitable billing data. The top two graphs are for electricity; the bottom two relate to natural gas.

The top left graph compares the average monthly profile from the FEDS model (dashed line) as compared to actual billing data (solid line). For this building type, the FEDS model, based strictly on engineering assumptions, comes very close to predicting the average actual level of electricity consumption. The third (small dashed) line in the graph shows the result of the billing decomposition procedure. It plots the monthly sum of the SAE-adjusted HVAC and NHVAC consumption. The adjusted HVAC and NHVAC loads track the actual monthly series quite well; however, the summer cooling load is still slightly overpredicted.

The top right graph of shows the major end uses as predicted by the FEDS model. The higher ventilation requirements during the summer reflect the assumption that demand ventilation strategies are typical. The lighting consumption in small offices is predicted by FEDS to be slightly more than double the total of the other NHVAC end uses.

(a) For annualization, we multiply the actual monthly consumption by 12. Thus, the mean value of the plotted values is equal to the annual EUI. This device helps to maintain consistency between the monthly plotted values and the annual EUI values shown elsewhere.

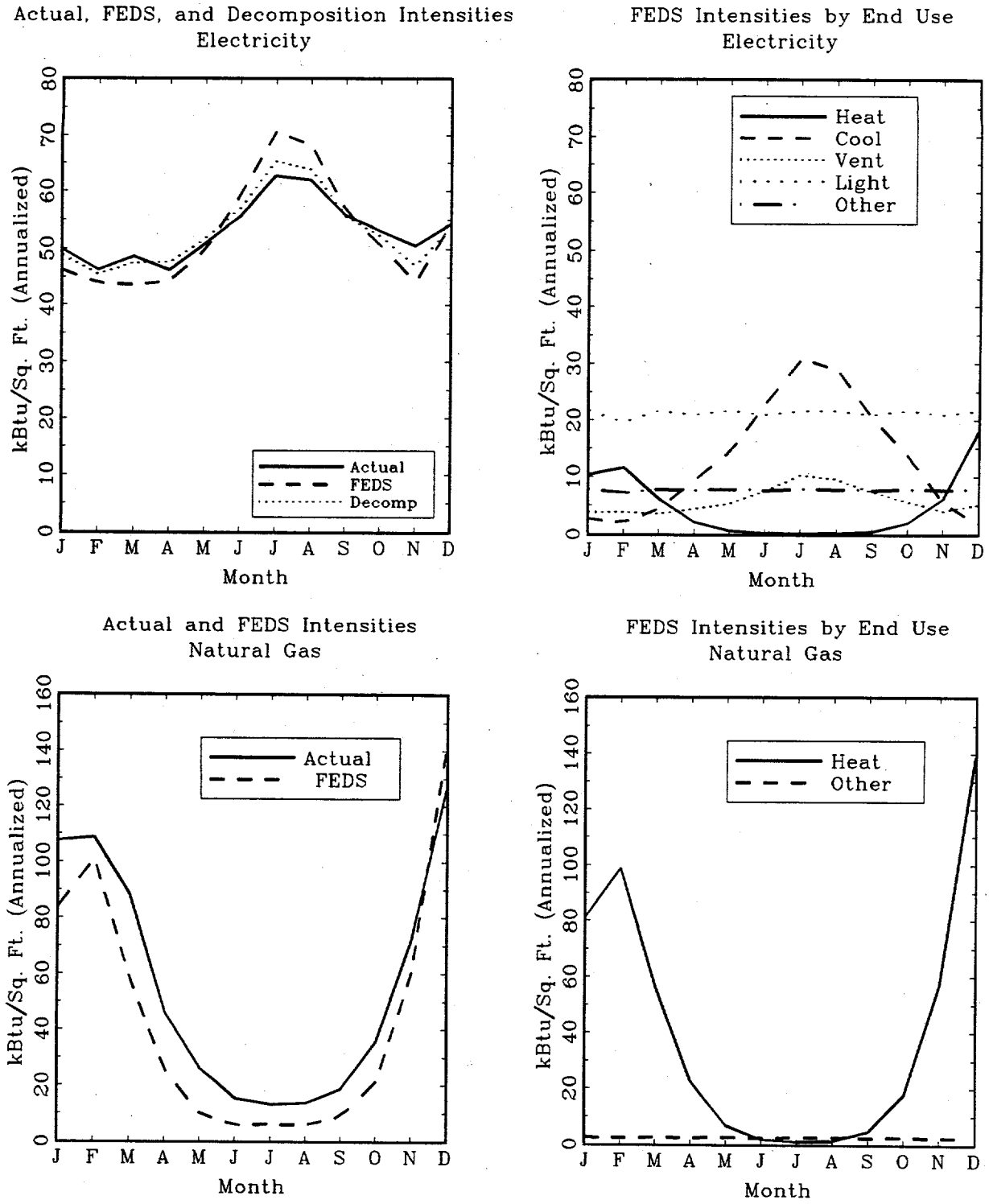

FIGURE S.1. Small Office: Monthly Average EUIs (for Building Totals, Predicted and Actual, and FEDS Major End Uses).

SAE Model Estimation Results

Since the coefficients in the SAE equations are adjustment factors, it is difficult to evaluate their magnitudes and signs. In general, the most significant variables, across the range of building types, involved vintage, weekly operating hours, and employment density.

As a partial remedy to the problem of interpretation, the variation of EUIs across key building characteristic variables was plotted. For small offices, Figures S.2 and S.3 provide examples of these plots. The graphs show the means of the actual, FEDS, and SAE intensities across two of the classification variables—vintage and building size—used in the SAE regressions.

Average EUIs by vintage for small offices are shown in Figure S.2. Although the HVAC intensities appear to minimally dependent on vintage, the top right figure clearly shows increasing electrification in new office buildings. The SAE adjustment procedure appears to modeling this trend well, especially in the post-1980 buildings.

Figure S.3 shows the effect of the building size on the predicted and actual electricity EUIs. The plots show that FEDS captures fairly well the decreasing intensity in space conditioning as building size increases. Note the SAE adjustment to non-HVAC electricity intensity for larger categories of small offices.

Goodness of Fit Measures

The results of the annual SAE models suggest that this type of specification clearly improves the cross-sectional explanation of building-level EUIs. As a simple measure of goodness of fit, linear regressions were run on the total EUI using, in turn, the FEDS and SAE EUI estimates as the explanatory variable. With the exception of lodging, the improvement in the percentage of explained variation (R^2) is large for every building type. Generally, the SAE model doubles the percentage of explained variation.

EUI Estimation for Full Sample

The results of the SAE estimations provide the basis for the final SAE estimates of EUIs for electricity EUIs. The predicted values of the total

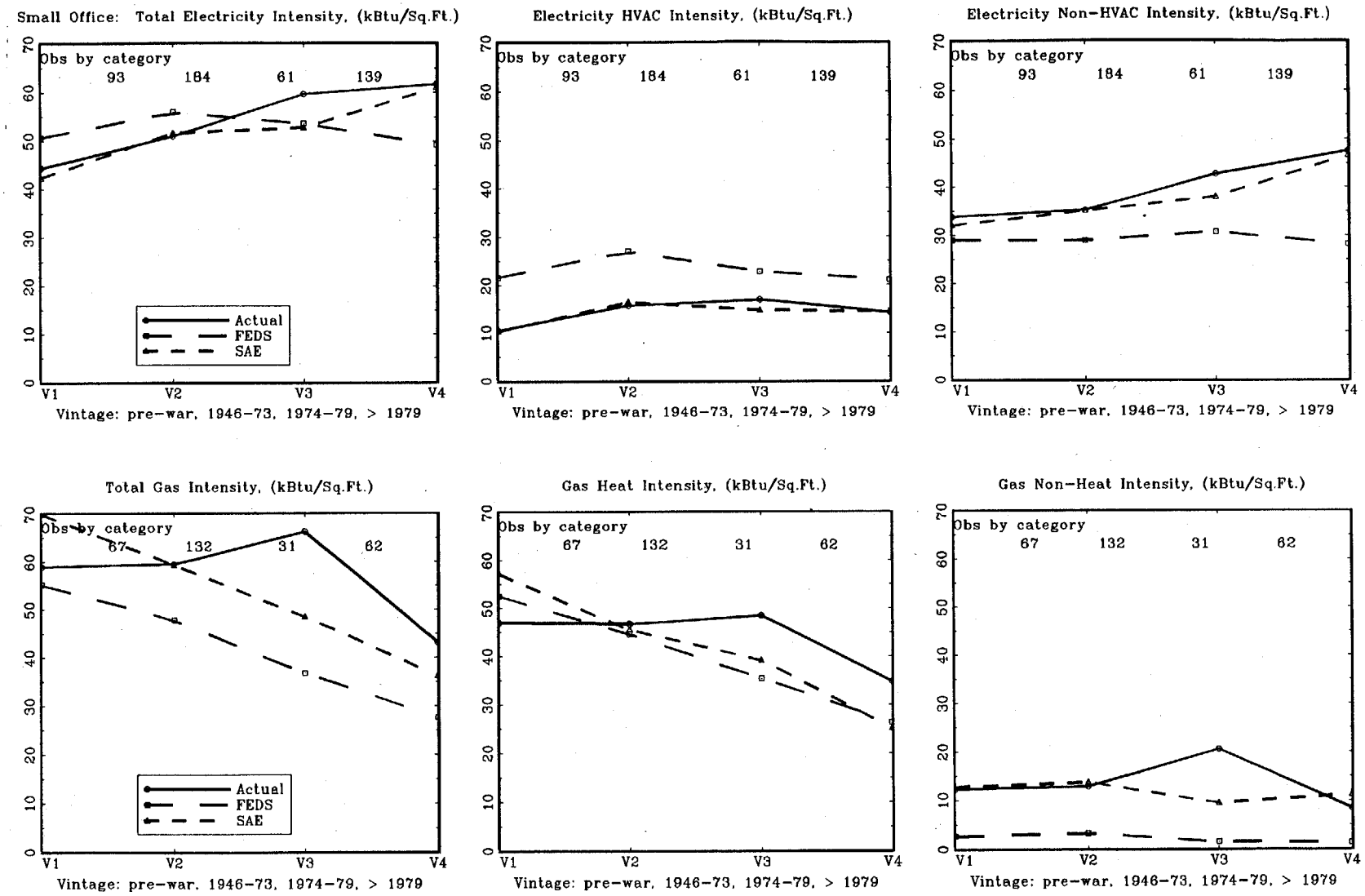

FIGURE S.2. Small Office: Average EUIs by Vintage

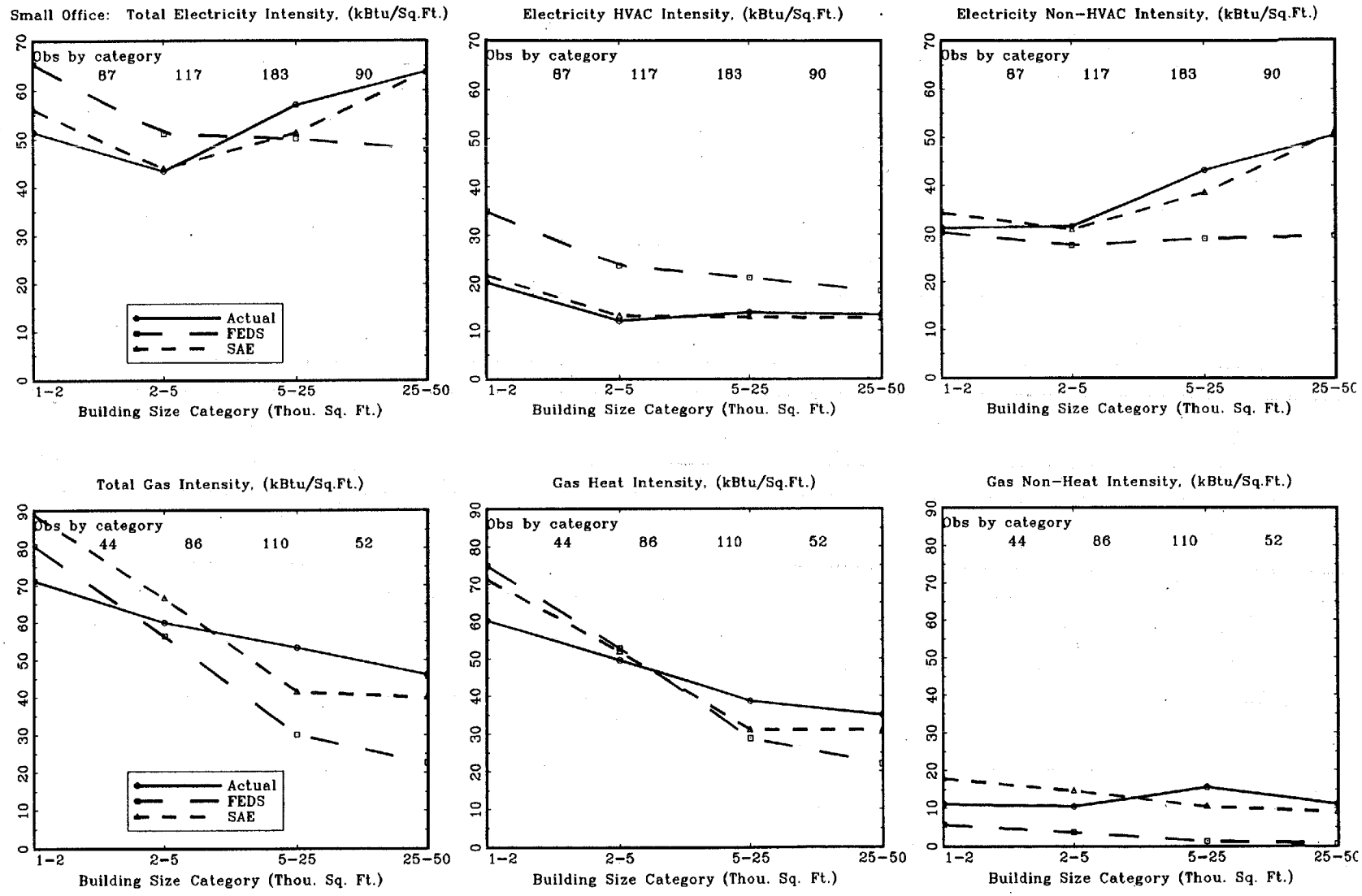

FIGURE S.3. Small Office: Effect of Building Size on Predicted and Actual Electricity EUIs

HVAC and total NHVAC consumption become control totals for the individual components from the FEDS model. Thus, for the HVAC components, the shares of the predicted FEDS end uses for heating, cooling, and ventilation are used. The same procedure is used for the NHVAC components: lighting, refrigeration, cooking, hot water, and miscellaneous electrical use.

The overall study generated three full sets of EUIs by building type. The first set was produced from FEDS without adjustment. The second set are the SAE estimates just described. The third set was termed the calibrated EUIs. The calibration was performed relative to the total building consumption as either measured from the billing data or imputed by EIA.

EUI ESTIMATION: NATURAL GAS AND OTHER FUELS

As for electricity, a methodology was developed to separate the weather-sensitive portion from the non-weather-sensitive portion of the annual energy load. The seasonal characteristics of gas use displayed in the monthly billing data provided a basis by which to distinguish between the base load (non-weather-sensitive) and non-base load (weather-sensitive) gas consumption. It was assumed that in the summer months (June, July, and August) that gas consumption was non-weather-sensitive, i.e., non-heating. A monthly average EUI was calculated from the three summer months and was used to determine a monthly baseload estimate.

Following the billing data decomposition, the next step was to explain the cross sectional variation in the base load and non-base load values within a building type. Two types of empirical models were needed to estimate the six end uses, SAE and pure statistical (conditional demand) models. Both SAE and conditional demand models were constructed and estimated individually for heating, water heating, and cooking by building type. For the manufacturing, co-generation, and cooling end uses few buildings reported gas consumption. As a result of the difficulty with small sample sizes (and other statistical problems) SAE models were not used for these end uses.

Empirical Results

It is difficult to generalize the results of conditional demand and SAE models across building types. The non-heating EUIs range widely across the building types due to the differences in intensity of these end uses (e.g., cooking in restaurants vs. warehouses). To illustrate the type of empirical results, the estimates for small office are presented and discussed briefly. For this building type, the estimated EUI (kBTU) for heating is 47.17, water heating is 11.73, cooking is 8.05, and water heating and cooking is 18.36. For this building type there appears to be an additive relationship between water heating consumption and cooking consumption (11.73+8.05=19.78) with that of the combined water heating and cooking consumption (18.36). Ideally this relationship would be desirable, but in general this additive property did not hold.

The results of the SAE model for heating indicates that the only significant coefficient was that for weekly operating hours. Although the estimated coefficient on building size was not statistically significant, Figure S.3 shows that the SAE model clearly helps to bring the variation of FEDS-generated intensities by building size in line with the observed values.

In addition to the predicted values of the SAE model, the seasonal variation of the FEDS values relative to the actual consumption was examined. In Figure S.1 the EUIs (kBtu/ft^2) are plotted against the monthly values of the actual natural gas and FEDS. For small office the FEDS model captures very well the seasonal changes in the actual EUIs of natural gas.

As in most studies summarization of the empirical results is difficult. In our report with six separate methods to estimate end use gas consumption this is, in particular, demanding. But, as heating is the primary use of natural gas we will briefly generalize the SAE annual heating model results. The goodness of fit measure (R^2) suggests a relatively good fit for grocery and retail, but low fit for warehouse and lodging. The R^2 range from 0.575 to nearly 0. Across the building types the most significant variables in the regression model are vintage and employment density, with the size variable being of less importance.

Other Fuels

The framework developed to estimate natural gas consumption by end use was applied to predict energy consumption of other energy sources. The other fuel types examined were fuel oil, district steam, and district hot water. To predict fuel oil and steam consumption for each building in the 11 building types the SAE response coefficients of the natural gas models were used as proxies.

SUMMARY OF EUI ESTIMATES

Table S.1 shows the conditional and average EUIs across the full sample of commercial buildings, based on the set of calibrated EUIs. Conditional EUIs are shown in the top panel of the table. These intensities are the average values for all buildings that are estimated to have nonzero consumption for the specific end use. Some of the disparity between the electric and gas intensities for cooking and hot water may stem from their different estimation methodologies.

TABLE S.1. EUI Estimates for All Buildings

All Buildings

Total Floorspace (bil. ft^2): 63.19

Conditional intensities for all buildings

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	6.24	6.86	4.53	16.71	3.04	0.91	1.13	13.46
Gas	36.38	33.19	0.00	0.00	0.00	15.44	12.40	8.84
Oil	35.44	1.40	0.00	0.00	0.00	31.80	12.17	8.55
D.H.	65.45	19.59	0.00	0.00	0.00	12.92	29.85	96.26

Average intensities for all buildings

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	1.52	4.46	4.40	16.18	2.96	0.88	0.38	13.10	43.88
Gas	20.63	0.07	0.00	0.00	0.00	3.54	4.92	3.62	32.78
Oil	4.84	0.00	0.00	0.00	0.00	0.07	0.41	0.32	5.65
D.H.	5.89	0.27	0.00	0.00	0.00	0.19	2.06	0.85	9.26

The second panel in Table S.1 shows the average intensities for each fuel and end use combination. The averaging is done across the entire stock of commercial building floorspace.

End Use Shares

The values of the average intensities can be used to determine the fractions of end use consumption by fuel. For electricity, lighting is the largest end use, comprising about 37% (16.184/43.881) of total consumption. Miscellaneous uses (office equipment, task lighting, task lighting, etc.) make up the next largest portion of electricity consumption at around 30%. HVAC consumption is estimated to be less than a quarter of total electric consumption.

As would be expected, heating is principal use for natural gas and oil. However, over one-third of natural gas use is estimated to be for non-heating end uses.

Figures S.4 and S.5 display the end-use shares of commercial consumption after aggregation across fuels. Figure S.4 shows the distribution as expressed in site or delivered energy. On this basis, heating is the largest use of energy in commercial buildings, accounting for nearly 36% of total consumption. Miscellaneous and lighting are the next largest categories, with a combined consumption slightly less than that for heating.

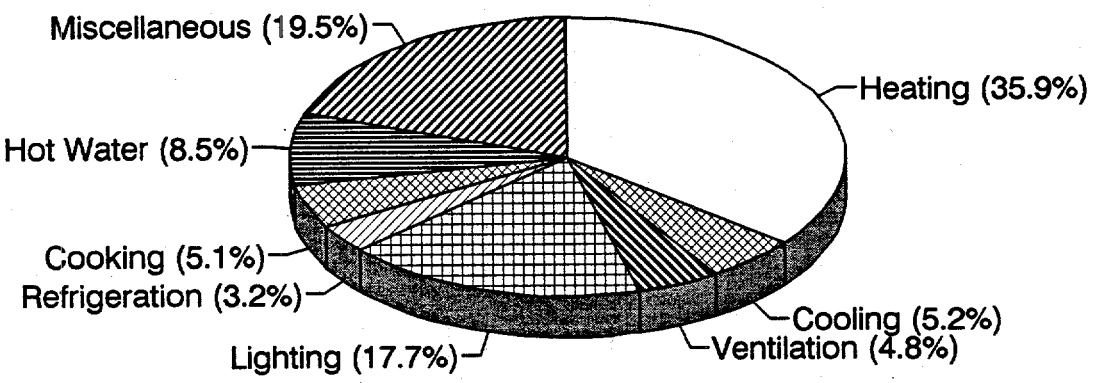

FIGURE S.4. Estimated End-Use Distribution, Delivered Energy Basis

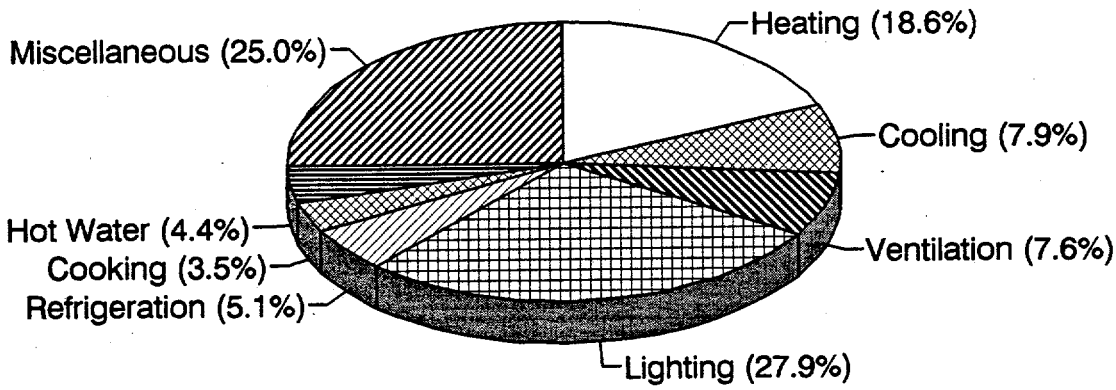

FIGURE S.5. Estimated End-Use Distribution, Primary Energy Basis

Figure S.5 shows the distribution of energy as expressed in primary energy. On this basis, electricity is converted to Btu by a factor of 11,500 Btu/kWh to account for the generation and transmission losses associated with electricity. On a primary energy basis, lighting becomes the largest single end use with 28% of total energy consumption. Miscellaneous use follows close behind with a 25% share. HVAC consumption is about a third of primary energy use, with heating comprising a little more than half of this consumption.

A comparison was made with the estimated end-use composition reported by EIA in the 1993 Annual Energy Outlook. Some significant differences exist in the end use composition of electricity currently modeled by EIA and the estimates from the current study. Space conditioning consumption is substantially lower than the AEO figure, based on the estimation procedure applied to the 1989 CBECS. Electric heating is about one-fifth of the AEO estimate, while cooling is less than half. Lighting consumption is about the same. The current study finds significantly more electricity consumption for miscellaneous (NHVAC and lighting) uses within commercial buildings.

On a strictly percentage basis, the composition of natural gas usage is roughly comparable, with the exception of space cooling. Based on the billing data provided for this study, gas consumption for absorption cooling appears to be negligible in the sample of buildings covered by the 1989 CBECS. The

current AEO estimate, suggesting nearly 8% of gas consumption is used for cooling, must be based on other information outside the CBECS or is substantially overestimated.

EXTENSIONS OF THE CURRENT ANALYSIS

Several extensions and refinements to the work described in this report are recommended. The first general area is to further develop the SAE procedures to improve the accuracy of the EUI estimates, especially for NHVAC and non-heating end uses. The second area involves additional modifications of the input assumptions in FEDS to develop an improved linkage between the model outputs and the billing data from the CBECS. Beyond the goal of contributing to improved EUI estimates, this second activity would yield other substantial benefits to energy modeling and planning activities within DOE.

Improvement of SAE Procedures

The work undertaken during this study represents one of the most ambitious attempts to utilize an building engineering model, along with monthly billing data, as a means of estimating end use consumption for a national sample of commercial buildings. Nevertheless, the study still leaves a number of unresolved issues. Some of the key issues are briefly discussed below.

More Detailed SAE models for Electricity

Perhaps the area with the highest priority for additional analysis concerns more detailed SAE models for electricity. Such models would be used to refine the individual end-use estimates within the broad HVAC and NHVAC control estimates. Two areas in which ongoing work with the FEDS model may prove beneficial are 1) improved treatment of ventilation demand, and 2) modification of assumptions for the domestic hot water model.

Non-Heating EUIs for Natural Gas

Additional study is warranted to refine the estimates for the nonheating EUIs for natural gas. The bill decomposition procedure used in this study provides a reasonable basis for separating heating consumption from these other uses, but the procedure to split the non-heating uses can be further improved. Several specific areas of work are seen as contributing to improved

EUIs: 1) better matching of reported end uses and seasonal patterns of billing data and 2) possible pooling of data from two or more CBECS.

Improved treatment of high intensity cases

An unresolved problem in analyzing the CBECS is how to treat high intensity cases. Further work is required to better understand the causes for the extremely high intensity cases. Such work may involve investigation of databases outside the CBECS.

Improve the Accuracy of the FEDS Engineering Model

A second set of potential future activities relates to modifying the input assumptions in the FEDS model to better represent the consumption behavior of the buildings in the CBECS. This activity would reduce the importance of the SAE procedures as used in this study.

One alternative approach varies strategic parameters within the building simulation model to best fit the observed total energy consumption for each building in the sample. This calibrated engineering model approach requires modifying the building simulation code so that it can be embedded within an optimization framework suitable for data fitting. The approach has the advantage that it can address envelope-HVAC interactions in a more consistent manner. This work would lay the groundwork for a powerful analytical tool to examine conservation potential in the commercial building sector.

The current study also indicates the potential for additional calibration work that could be applied on a cross-section basis. Future work could extend the engineering simulation work to yield FEDS results that better correlate with the billing data on a cross-section basis. Areas that appear promising for this type of analysis include further experimentation with various ventilation strategies and better treatment of buildings that operate on a continuous basis.

After the completion of this work, the model could be used to perform "before" and "after" simulations with various engineering parameters. As compared to using a limited number of prototypical buildings, the FEDS simulations with these buildings would start from a baseline that matches historical electricity and gas consumption levels on a national basis by building type.

ACRONYMS

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
CBECS	1989 Commercial Building Energy Consumption Survey
EIA	Energy Information Administration
EMCS	Energy Management Control System
EUI	end-use intensity
FEDS	Facility Energy Decision Screening System
FEMP	Federal Energy Management Program
HDD	heating degree-days
HID	High Intensity Discharge
HVAC	heating, air conditioning, and ventilation
IES	Illuminating Engineering Society
NEMS	National Energy Modeling System
NHVAC	non-HVAC
NOAA	National Oceanic and Atmospheric Administration
PNL	Pacific Northwest Laboratory
PRISM	Princeton Scorekeeping Method
REMP	Regional End Use Monitoring Program
SAE	Statistically Adjusted Engineering
UA	thermal conductivity of the building shell

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1.0 INTRODUCTION

Estimates of commercial building end-use energy consumption—energy consumed for a specific service such as heating, cooling, or lighting—can serve a variety of needs for building energy analysis. An accurate picture of how commercial buildings, as a whole, use energy is essential to guiding efforts to reduce energy consumption in this fast growing sector of the economy. When combined with a national survey of buildings, the end-use estimates can also indicate target markets for energy-saving technologies. These efforts often fall within a larger scope of energy modeling activities that attempt to relate commercial sector energy consumption to key economic, demographic, and policy variables.

This report presents estimations of energy consumption by end use based on data from the 1989 Commercial Building Energy Consumption Survey (CBECS) [Energy Information Administration 1991, 1992]. This work was conducted Pacific Northwest Laboratory (PNL)[a] for the Energy End Use and Integrated Statistics Division (EEUISD) within the Energy Information Administration (EIA).

Commercial end-use intensity (EUI), defined as energy consumption per square foot, will have two main roles within EIA. The first role is to serve as input to the EIA commercial sector energy modeling and forecasting efforts[b] as part of the National Energy Modeling System (NEMS) [EIA 1993]. The second role is to augment the statistical summary information published by EEUISD. The estimates are expected to be published along with the Commercial Buildings Energy Consumption and Expenditures Report series beginning with 1992 survey.

(a) PNL is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

(b) A recent description of the structure of the EIA commercial sector model is provided in "Component Design Report, Commercial Sector Energy Demand" (mimeo). Prepared by Energy Demand Analysis Branch, Energy Demand and Integration Division, Office of Integrated Analysis and Forecasting, Energy Information Administration, July 1992.

1.1 GENERAL APPROACHES

Development of end-use intensities for buildings can follow three general approaches. Direct metering provides the most accurate approach, but is expensive to implement. The metering studies that have been conducted by a few major utilities (including the Bonneville Power Administration) are not sufficient to provide a basis for end-use disaggregation of the nation's commercial building stock. Conditional Demand Analysis is another approach, but as EIA and others have noted, this approach has failed to produce satisfactory models for the commercial sector. The third approach involves engineering simulations. Two variants of this approach are described below.

1.1.1 Statistically Adjusted Engineering (SAE) Models

This approach begins by estimating end-use components with an engineering-oriented building simulation model. Predicted energy consumption for each end use j in building i can be described as

$$EUP(j, i) = f[X(i), O(i), W] \tag{1.1}$$

where $X(i)$ = the vector of building characteristics for building i
$O(i)$ = the vector of operating characteristics for building i
W = the vector of weather variables

The second stage of the procedure uses the predicted end-use components as regressors to explain actual total building energy consumption based on billing data. If the engineering model generates predictions for M end uses, then

$$E(i) = a_1 \cdot EUP(1, i) + a_2 \cdot EUP(2, i) + \ldots + a_M \cdot EUP(M, i) + e \tag{1.2}$$

where e is assumed to be a normally distributed disturbance term. If we use ordinary least squares, the sum of differences between the predicted and actual energy use across any sample will be zero. The a_i coefficients are interpreted as adjustment coefficients for each of the engineering-based end-use estimates.

1.1.2 Calibrated Engineering Models

A second approach varies strategic parameters within the building simulation model in Equation (1.1) to best fit the observed total energy consumption. This requires a building simulation code that can be embedded within an optimization framework. The end-use interactions within the building simulation models will lead to specifications requiring nonlinear optimization methods.

The calibrated engineering model approach has the advantage that it can address envelope-HVAC (heating, ventilation, air conditioning) interactions in a more consistent manner (e.g., adjusting the thermal conductivity of the shell [UA] as part of the calibration procedure will affect both heating and cooling loads). This feature is lost in the SAE models, where the estimated coefficients on the predicted heating and cooling consumption incorporate a variety of errors, including envelope characteristics, system type, and plant efficiency.

1.1.3 Approach Used

Although the calibrated engineering model has some conceptual advantages over SAE adjustment models, it is significantly more costly and complex to develop. Given time and resource constraints for this study, the SAE approach was followed. In undertaking the SAE approach, however, we remain cognizant of these interaction effects mentioned above. To the extent feasible, we pursue a limited engineering calibration as we use the regression-based adjustment factors to influence our engineering assumptions in an iterative process.

As will be discussed in detail in chapters 4 through 6, the overall methodology can be divided into seven major steps:

1. Map 1989 CBECS data (and weather) into engineering model.
2. Run initial engineering model
3. Estimate SAE models for buildings with monthly billing data, by building type

4. Based on comparison of predicted and actual consumption patterns, revise engineering model. Generate second-round engineering estimates

5. Estimated final SAE models

6. Use SAE model coefficients to extrapolate to buildings without monthly billing data

7. Calibrate end-use consumption to add up to EIA total energy by building.

1.2 ORGANIZATION OF REPORT

Chapter 2 provides an overview of the engineering simulation model used to develop end-use consumption estimates. The key model variables, derived from the CBECS, are also described briefly.

Chapter 3 discusses data issues. A considerable effort was made to extract as much information as possible from the special utility billing files that were made available for this study.

Chapter 4 lays out the SAE framework used to generate EUIs by building type. A series of increasingly more complex models that include both seasonal and building-specific adjustment factors is also laid out. The most straightforward SAE model did not produce satisfactory results in preliminary testing. The final sections of the chapter lay out some possible reasons for this result and sketch out an alternative SAE approach that was used in the study.

Chapters 5 and 6 discuss the detailed estimation methodologies and empirical results for electricity and natural gas, respectively. The empirical results for small office and the retail/service building types are highlighted.

End-use estimates on an aggregate basis are summarized in chapter 7. The distribution of energy consumption by end use derived in this study is compared to the current estimates being used by EIA. Some comparison is also made of heating and cooling EUIs by building type.

Chapter 8, the final chapter of the report, discusses extensions of the analysis undertaken for this report. Several improvements in the SAE models

are indicated that would refine the estimates made in this study. Modifications in the engineering model are also suggested.

2.0 ENGINEERING FRAMEWORK FOR EUI ESTIMATES

The approach used to estimate end-use intensities is based on a deterministic model developed using accepted engineering building energy calculation algorithms. During the past several years, PNL has been developing an entirely new building energy consumption estimation tool as part of the Facility Energy Decision Screening System (FEDS) [Dirks and Wrench 1993] for the Federal Energy Management Program (FEMP). This tool is known as the FEDS Level-1 building model and estimates building energy consumption for eight end uses: heating, cooling, ventilation, interior lighting, service hot water, refrigeration, cooking, and miscellaneous equipment.

This chapter briefly describes the engineering framework used to develop EUI estimates for the CBECS buildings. Section 2.1 provides an overview of the structure of the FEDS engineering simulation model. Section 2.2 describes in broad terms the translation of CBECS information into parameters required by the engineering model.

2.1 ENGINEERING MODEL

The engineering model used in this study is the loads calculation option of the FEDS building model.[a] The FEDS building model was designed to make a quick assessment of energy conservation potential on multi-building federal facilities. The large number of required data inputs precluded using existing hourly building energy models. However, because much energy pricing is now based on time of use, existing simpler models, such as those based on binned weather data, were not acceptable either.

FEDS models energy use as daily average hourly profiles. These profiles are calculated for three day types (weekdays, Saturdays, and Sundays) for each month. This approach allows the model to capture the effects of the building operational schedule, as well as the average outdoor conditions, on building

---

(a) A large portion of FEDS is concerned with the identification of cost-effective retrofit strategies. This capability was not used in this study.

energy use. The FEDS structures allow these effects to be captured without the significantly higher computational burden of a full-blown hourly simulation model such as DOE-2.

The FEDS building energy model requires a fairly detailed set of input parameters, but the FEDS system requires minimal information from the user (i.e., building type; floor area; vintage; occupancy schedule; fuels used for heating, cooling, and service hot water; and lighting technologies used in each building). FEDS then imputes most of the parameters required by the energy consumption model. These imputations are discussed briefly in the following section.

2.2 DEVELOPMENT OF BUILDING PARAMETERS

The development of input parameters for FEDS in this study are based on several data sources. The primary sources include the 1986 CBECS survey, the Regional End Use Monitoring Program (REMP)[a] commercial and residential studies, and knowledge of standard practices as documented in various construction engineering handbooks (e.g., information from ASHRAE and IES handbooks was used to develop many HVAC and lighting assumptions).

Information contained in the 1989 CBECS survey influences both the FEDS imputation module and the FEDS energy consumption model. The imputation module infers engineering characteristics not directly measured by the CBECS, based either on other data sources or assumptions about compliance with building standards.[b] The following sections describe, by general category of required model input, the 1989 CBECS data used, the kinds of imputations made using the data, and the types of energy calculations made using the original

---

(a) Previously, the End Use Load and Consumer Assessment Program, a large, ongoing monitoring project funded by the Bonneville Power Administration. REMP data includes both hourly time series end use consumption data and an extensive database of building characteristics, including installed capacities of energy using equipment. The key sources used in this study were Pratt et al. 1990 and Taylor and Pratt 1989.

(b) The imputations discussed should be distinguished from the imputations made by EIA in preparing the CBECS. EIA's imputations involve the estimation of values for missing responses in an otherwise complete (CBECS) questionnaire.

and imputed data. The detailed specifications of the CBECS data imputation module are contained in Appendix A. The following sections sketch the major elements of this overall process.

2.2.1 Lighting

The CBECS survey provides information about the types of lighting technologies used (fluorescent, incandescent, and HID), the percent of the building lit by each, and information about the presence or absence of high-efficiency ballasts for fluorescent and HID lighting technologies. The survey also provides the respondents' estimates of the percentage of installed lights used during occupied and unoccupied periods.

This information, plus the building type, allows imputation of both the fixtures/ft^2 and the watts per fixture for each building. This information can then be used to estimate both the lighting consumption and the contribution of the lights to the internal gains in the buildings.

2.2.2 Service Hot Water

The CBECS survey provides information on the fuel(s) used to provide service hot water. This fuel information and the information about the building type, occupant density, size, and vintage allows imputation of the service hot water system, including whether the system is distributed or central, whether or not the hot water tank is insulated, the overall capacity of the service hot water system, and the hot water consumption per occupant. The occupancy data from the survey is then used with the imputed data to estimate the service hot water consumption.

2.2.3 Miscellaneous Equipment

The survey also contains information about the fuel used for cooking and the types of refrigeration equipment in the buildings. Imputations, based on building type, can be made about the capacity densities and the consumption profiles for cooking, refrigeration and other equipment. The information on the refrigeration equipment may also be used to impute the contribution of the refrigerator rejected heat to the building internal gains. Miscellaneous equipment consumption is estimated using the building occupancy schedule and the imputed data.

2.2.4 Building Envelope Information

Information about the wall and roof construction types, whether or not the walls and roof are insulated, and the presence or absence of multiple window glazing, external shading, or tinted glass is also included in the survey. This information, along with the building vintage, allows imputation of U-values for the walls, roofs, and windows, and the imputation of a window shading coefficient. The U-values are used in the calculation of the heat transfer between the building and the outdoors.

2.2.5 Building Geometry Assumptions

Floor plans for all buildings are assumed to be rectangular. The CBECS survey specifies the total building floor area and the number of floors. This information, along with the building type, is used to impute an aspect ratio (the ratio of the length of the long side to the length of the short side) and the HVAC zoning strategy. These imputations are then used to calculate the wall and roof areas. Window areas are imputed using the 1986 CBECS data for window to gross wall area ratio.[a]

The geometry information is used in the calculation of the heating and cooling loads, including an estimate of the building solar gains. Since building orientation is not included in the survey, the model will normalize the wall and roof areas for the solar gain calculation only. This will prevent biasing the solar gain calculation toward a single orientation.

2.2.6 Heating End Use

The CBECS contains information about the primary and secondary fuels used to provide heating. The survey also describes the heating equipment and system types, as well as indicating whether or not some form of night set-back control is used for the heating. The thermostat setting(s) are then imputed for heating (based on building type) and the heating system(s) efficiency

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(a) This information was not collected in the 1989 CBECS. The imputation was made on the basis of a regression model using the 1986 CBECS relating percentage glass to size, age, climate, and building type categorical variables (See Appendix B).

(based on heating equipment, fuel, and building vintage). This information is used to calculate the heating loads and the heating consumption.

2.2.7 Cooling End Use

The CBECS also contains information about the fuel used for cooling, the cooling equipment and system types, and the vintage of some types of cooling equipment. The survey also indicates whether or not some form of night set-back control is used for the cooling. The cooling thermostat settings are imputed from the building type. The cooling system efficiency is imputed from the cooling equipment, fuel, and building or equipment vintage. This information is used to calculate both the cooling loads and the cooling consumption.

2.2.8 Ventilation End Use

The CBECS also provides information about the types of heating and cooling systems, and the presence or absence of EMCS systems. The ventilation system efficiency and static pressure are imputed from this information, as well as the heating and cooling supply temperatures. The ventilation control mode (constant ventilation or cycling on and off with the heating and cooling systems) is also imputed. These parameters are used to calculate the consumption due to building ventilation.

3.0 DATA SOURCES AND CONSTRUCTION

The principal datasets used in estimation of EUIs in the study relate to: 1) commercial building characteristics, 2) energy consumption by building, and 3) weather data. The CBECS provided the first two datasets. Weather information from the National Oceanic and Atmospheric Administration (NOAA) was combined with degree-day information from the CBECS to develop the third dataset.

As in any empirical study, data screening and assumptions about the observed data had to be made that were based on *a priori* information. The data used for this study were taken from the two sources described above. The observed responses for each building were extracted from the CBECS and the simulated engineering values were extracted from the FEDS model. It was necessary to screen the survey data for valid responses, and in some instances, impute monthly data. After the billing data were screened for valid responses, an additional screen was set to limit fuel consumption, conditional on the reported end uses, to be less than a value based upon a multiple of the FEDS engineering estimates. This screening process provided us with a subset of the sample data set used in the statistical calibration procedures. The results obtained from this analysis were used over the entire sample to develop a predictive model for electricity and natural gas consumption in commercial buildings.

3.1 BUILDING CHARACTERISTICS

Most of the building characteristics information used in the study is identical to that produced by EIA in its public use file. An ASCII version of the public use file was made available that contains data for 543 variables for 5,876 buildings for the 1989 CBECS.

Both floorspace and the number of floors are masked by the CBECS data collection contractor, and are further masked in the CBECS public use files. The versions of floorspace and number of floors made available for this study received only the first level of masking.

The characteristics data is used to inform the FEDS model of variables needed for its building-by-building energy simulations. This translation of CBECS variables into engineering inputs for FEDS is explained in detail in Appendix A. Special C (programming language) routines were developed to access the ASCII data file provided by EIA.

The second use of the characteristics data is in the statistical adjustment regression models to better explain the cross-sectional EUIs. As explained later in chapters 5 and 6, the major variables used were: 1) year constructed (vintage), 2) building size, 3) employment, 4) weekly operating hours, and 5) degree-days.

3.2 ENERGY CONSUMPTION DATA

A major objective of this study is to develop EUIs consistent with the energy consumption data published in the CBECS. The public use file contains estimates of annual energy consumption by major fuel (electricity, natural gas, fuel oil, and district heating and cooling[a]) for each of the 5,876 buildings in the 1989 survey. The majority of these estimates were based directly on billing data that was provided by utility suppliers for these buildings. Where billing data was not available, EIA performed a variety of imputation procedures to estimate fuel consumption. These procedures are explained in detail in Appendix B of the Consumption and Expenditures report for the 1989 CBECS (EIA, 1991).

This study utilized the utility billing files developed by EIA in its own consumption estimation procedures. The files analyzed pertain to electricity and natural gas. Although a fuel oil file is available, it was not used in this study. The billing file for fuel oil refers to dates in which deliveries were made to the building and as such cannot be used to reliably estimate actual consumption over a given time interval.

For statistical analysis, our goal was to construct a dataset that would accurately reflect the actual energy consumption of individual CBECS buildings

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(a) District heating and cooling includes steam, hot water, and chilled water.

on a monthly basis for 1989. This required consideration of the following issues during the development of this database: 1) alignment of bills to calendar months, 2) bills not specific to single buildings, and 3) imputation of missing bills. These topics are discussed in more detail in the succeeding sections.

3.2.1 Calendar Month Estimates

The file provided by EIA contains the consumption and expenditure information for each bill assigned to a specific building. To compare energy consumption to the FEDS model and to aggregate across buildings and fuels, it is necessary to put the consumption information in a common time frame. The most natural time frame, and one in which the FEDS model operates, is a calendar month.

The translation of the consumption data from billing period to calendar month was made in a straight forward fashion. A daily average consumption was computed for each billing period. From these daily averages, monthly consumption was computed by cumulating the estimated daily consumption over the appropriate days for a calendar month.

A more elaborate procedure might utilize spline fitting or using degree-day information as interpolators. Such procedures were not considered in this study because of resource and schedule constraints. As the monthly plots in of the aggregate EUIs suggest (chapters 5 and 6), the linear interpolation method appears to display sufficient precision to adequately assess the FEDS model output.

Months in which the electricity or gas bills covered fewer than 20 days were identified as having missing data. For months where bills cover more than 20 days, the daily average consumption was extended to the portion of the month not included in a utility bill. These cases were often in January or December (e.g., if the first bill covered the period January 5 through February 4, the daily average consumption for this period was assigned to the first four days of January).

For the statistical adjustment procedure described in chapters 5 and 6, the data set was limited to buildings that had at least six separate bills covering six months during 1989.

3.2.2 Bills Not Specific to Single Building

For various reasons, a large number of utility bills do not display a one-to-one correspondence with CBECS sample buildings. The most common situation involves bills that cover floorspace outside that in the specific CBECS sample building. In this case, an adjustment factor, termed the disaggregation ratio, was computed by EIA. The disaggregation ratio is the proportion of the square footage of all buildings covered by the fuel bill that is contained by the specific CBECS building. These ratios range from less than 1% to over 99%.

A far less common case is one in which multiple meters were present for different establishments in the same building and not all of the associated bills were collected. The adjustment ratio in this case was termed an aggregation ratio. For example, if one bill were available in a building with two (separately billed) tenants, the aggregation ratio would be 2.0 under the assumption of roughly comparable floorspace.

In examining the pattern of monthly bills and reported end uses, preliminary examination of the building-level consumption data indicated the need to restrict the statistical analysis to observations with close correspondence between the building characteristics and the consumption data. As a result, we limited the final data set to include observations where the aggregation/disaggregation ratio was between 0.9 and 1.1.[a]

(a) Another situation involved several sample buildings whose energy consumption is reported as a single aggregated quantity. EIA terms these cases as worksheet cases and prorates the bills in proportion to predicted consumption from multiple regression models. About 300 buildings were handled in this manner for the estimation of electricity in the 1989 CBECS. Worksheet cases were not included in the statistical adjustment and calibration efforts conducted in this study.

Table 3.1 shows the total number of observations available by building type after the imposition of the screens involving the number of months and aggregation/disaggregation ratios. The number of buildings using each fuel is also shown to indicate how many buildings require end use breakdowns.

3.2.3 Incomplete Series of Utility Bills

Section 3.2.1 described the procedure to develop monthly energy consumption data for electricity and natural gas. As mentioned above, our initial data set for analysis was restricted to include buildings where billing data was available for six months or more.

To retain as much information as possible, buildings with less than 12 months of billing data (and greater than six months) were used in the sample set. To retain these buildings observations, the electricity and gas consumption was imputed by regressing monthly gas consumption onto degree days (HDD) of the census region in which each building resides. Then, the missing monthly values were combined with the actual values to form 12 months of billing data for each building.

In the course of the statistical analysis described in chapter 5, we had three alternatives for handling the buildings with between 6 and 11 months of

TABLE 3.1. Number of Observations Available for Monthly Statistical Analysis

Building Type	Total Obs	Electricity		Natural Gas	
		Using Fuel[a]	Suitable for Analysis	Using Gas Fuel[a]	Suitable for Analysis
Assembly	670	667	448	433	295
Education	679	678	315	479	250
Food Sales	86	86	65	54	37
Food Service	189	189	134	147	114
Hospital	137	137	74	105	66
Lodging	271	271	114	189	95
Large Office	472	470	291	280	181
Small Office	716	716	481	417	298
Retail/Service	1,162	1,160	823	736	522
Warehouse	855	791	438	388	282
Other	639	487	246	223	142
Total	**5,876**	**5,652**	**3,429**	**3,451**	**2,282**

(a) Total buildings for which non zero fuel consumption was estimated by EIA. Includes buildings with no monthly billing data.

billing data: 1) drop the buildings from the data set, 2) develop procedures to handle different numbers of months, or 3) impute missing values. Since the majority of such buildings lack only one or two months, we did not want to lose these complete monthly billing profiles. Procedures to handle different numbers of months broke down when we wished to perform any analysis that aggregated across buildings (including plotting monthly averages). As a result, we chose to impute the missing values. The missing monthly values were combined with the actual values to form 12 months of billing data for each building.

The imputation procedure was based on a simple regression model using heating and cooling degree days. Monthly electricity intensity for a given building (e) was specified as:

$$EUI_m = a_o \, MDAYS_m + a_1 \, HDD_m + a_2 \, CDD_m + e \qquad (3.1)$$

where EUI_m = the monthly electricity intensity, $kBtu/ft^2$

$MDAYS_m$ = the days in month m (28, 30, or 31)

HDD_m = the heating degree days for applicable census division in month m

CDD_m = the cooling degree days for applicable census division in month m

To impute the monthly values for gas, the specification used only HDD:

$$EUI_m = a_o \, MDAYS_m + a_1 \, HDD_m \qquad (3.2)$$

The components of Equations 3.1 and 3.2 provide a method to estimate the weather-sensitive and non-weather-sensitive portions of the load in a straight forward manner. The non-weather-sensitive portion of the load, which is measured by a_o, is constant on a daily average for each month. The use of the MDAYS variable is designed to account for the different number of days in each month. The weather-sensitive portion of the load is captured by the coefficients on degree days.

3.3 MULTIPLE FUELS

The FEDS engineering values were estimated for each building in the survey for each end use identified above. However, problems arose when multiple fuels were used for a single end use. Primary and secondary heating represents the most complicated situation. Some buildings reported more than one energy source for primary heating or more than one energy source for secondary heating. For example, a response may include both electricity and natural gas as primary heating sources. Or, another example may be natural gas for primary heating and fuel oil and electricity for secondary heating.

The FEDS model generates values for only a single heating fuel (that includes primary and secondary). This limitation is because of the current version of FEDS models only one type of heating system (i.e., electric baseboard, forced air electric, gas furnace, etc.). This feature permits the model to readily translate the heating load into heating consumption via a set of conversion efficiencies.

The most prevalent multiple fuel combination for heating is with gas as the primary fuel and electricity as the secondary fuel. Monthly gas and electricity consumption for buildings with this combination were analyzed. Using April and October as base months, we examined the relative increase in consumption in these fuels over the winter months of 1989. The increase in electricity was quite small in comparison to gas, usually 10% or less of the increase in total consumption from the base months. Based upon this simple analysis, we set the consumption of any secondary heating fuels as 10% of the total heating energy consumption. If more than one primary (secondary) energy source was identified, then each was given an equal weight of the FEDS estimate.

Multiple fuels are also present for water heating and cooking. For these end uses, we split the fuels equally (i.e., if electricity and gas were used for cooking, we adjusted the FEDS output to reflect 50% of the consumption for each fuel). For three fuels, the shares were set to 1/3.

3.4 WEATHER DATA

Along with the reported or imputed physical and operating characteristics of the buildings, the engineering model requires hourly weather profiles (by month) to predict energy consumption. The hourly profiles contain considerably more information than the heating degree-day and cooling degree-day data contained on the standard CBECS files.

The source of the hourly weather data is the NOAA's TD 3280 weather tapes. From these tapes for calendar year 1989, we use the hourly readings for: 1) dry bulb temperature, 2) wet bulb temperature, 3) atmospheric pressure, and 4) clearness index (i.e. cloudiness). The wet bulb temperature and atmospheric pressure are used to help calculate the humidity ratio. The clearness index is used to calculate solar radiation measures. Software developed by PNL to support FEDS and other commercial building analysis work was used to develop the hourly profiles of the appropriate variables by month.

For each of the hourly weather files, annual heating and cooling degree-day values were computed for 1989. Within each census division we identified the station that matched up the most closely to the CBECS-assigned heating and cooling degree days for each CBECS building. Formally, we computed a distance metric based upon a geometric average of the heating and cooling degree days and chose the station with the minimum distance metric. For the level of precision needed to estimate end use shares by fuel, this mapping is satisfactory. Files with hourly weather profiles were assigned to each of the 5,876 buildings in the 1989 CBECS.

4.0 GENERAL FRAMEWORK FOR DEVELOPING EUI ESTIMATES

The engineering methods in FEDS incorporate thermodynamic principles to estimate end-use consumption, but are not constrained to reflect the observed total energy consumption. However, statistical methods of estimating end-use consumption reflect the observed total consumption, but do not incorporate *a priori* information on the interactions between end uses and their seasonal patterns. The SAE method combines these approaches to generate improved estimates of the end-use loads. Regression-based statistical procedures are used to adjust the engineering estimates to best represent the observed consumption.

This chapter outlines the basic methodology of the SAE approach as it applies to the CBECS sample of commercial buildings. Preliminary regressions with the basic SAE model proved unsatisfactory. Therefore, a hybrid approach (combining elements of a statistical decomposition of monthly billing data and SAE methods) was used to generate the final estimates. Chapters 5 and 6 explain how it was applied for electricity and natural gas.

4.1 NOMENCLATURE AND DISAGGREGATION

A nomenclature has been developed to track the various dimensions (i.e., building types, regions, fuels, and end uses) involved in the SAE methods discussion. To maintain consistency, the calibration procedure recognizes the levels of disaggregation that are part of the NEMS commercial sector model. Eleven building types were defined for this study. A mapping between these building types and the CBECS building types is shown in Table 4.1.[a]

(a) This mapping deviates from the NEMS commercial model in its treatment of outpatient health care. NEMS includes these buildings with hospitals under the general heading of health care. The pattern of energy consumption for these buildings is much closer to office buildings than to hospitals.

TABLE 4.1. Building Type Mapping

	Current Study	CBECS
1.	Assembly	Assembly
2.	Education	Education
3.	Food Sales	Food Sales
4.	Food Services	Food Services
5.	Hospital	Health Care (inpatient)
6.	Lodging	Lodging Skilled Nursing Care
7.	Large Office	Office Health Care (outpatient) >50,000 sq. ft.
8.	Small Office	Office Health Care (outpatient) ≤50,000 sq. ft.
9.	Retail/Service	Mercantile and Service
10.	Warehouse	Warehouse (refrigerated and nonrefrigerated)
11.	Other	Public Order and Safety Laboratory Residential Parking Garage Vacant

Four fuel types (k) are distinguished. Total consumption is represented by capital letters:

k	Fuel
1	Electricity (E)
2	Natural Gas (G)
3	Fuel oil, kerosene (O)
4	District heat (steam, hot water, chilled water) (S)

$$\text{Total energy (F)} = F_1 + F_2 + F_3 + F_4 = E + G + O + S$$

Building floor space, in terms of square footage, is represented by ft^2.

Energy intensities by fuel are expressed as EUIs. Thus

$$EUIe = E/ft^2$$
$$EUIg = G/ft^2$$
$$EUIo = O/ft^2$$
$$EUIs = S/ft^2$$

The eight end uses (u) are distinguished as

u	End Use
1	Space heating (sh)
2	Space cooling (sc)
3	Ventilation (v)
4	Water heating (wh)
5	Lighting (li)
6	Cooking (ck)
7	Refrigeration (rf)
8	Other or miscellaneous (ms)

Table 4.2 presents a schematic of a end use by fuel matrix. Oil use is shown for space cooling and cooking, although only about a half dozen buildings in the sample identified oil being used for these uses.

4.1.1 Identities

From these definitions, several of the key identities used to motivate the discussion dealing with the statistical calibration procedure can be laid out. The data available from the CBECS provide building level consumption by

TABLE 4.2. Schematic End Use by Fuel Matrix

	Electricity	Natural Gas	Fuel Oil	District Heat
Space heating	X	X	X	X
Space cooling	X	X	X	X
Ventilation	X			
Water heating	X	X	X	X
Lighting	X			
Cooking	X	X	X	X
Refrigeration	X			
Misc.	X	X	X	X

fuel. Total fuel consumption is the sum of the unmeasured consumption by end use. Therefore, for each building i, the sum of total consumption by fuel k, F_k, can be expressed as

$$F_{ik} = \sum_u F_{iku} \cdot D_{iku} \tag{4.1}$$

where F_{iku} = (non zero) fuel use in building i for fuel k by end use u

D_{iku} = a dummy variable that equals one if building i uses fuel k for end use u.[a]

The EUIs by fuel type EUI_{ku} follow the standard convention of normalizing for building floor space. Thus, for each building i

$$EUI_{iku} = F_{iku}/ft_i^2 \tag{4.2}$$

The billing data from the CBECS provides the information to calculate a whole building energy intensity, EUI_{ik}, which can be represented as the sum of the EUIs for the end uses present in the building:

$$EUI_{ik} = \sum_u EUI_{iku} \cdot D_{iku} \tag{4.3}$$

4.2 STATISTICALLY ADJUSTED ENGINEERING MODELS

The FEDS engineering model, described in Chapter 2, provides estimates of EUIs for eight major end uses. The SAE approach treats these estimates as initial values to be adjusted to best explain the observed billing data.

Cambridge Systematics, Inc., developed a series of sequentially more complex SAE models to analyze residential end-use load shapes for the Electric Power Research Institute in 1985 (Cambridge Systematics 1985). Section 4.2.1

(a) D_{iku} can equal one for more than one fuel for a given end use. The empirical treatment of multiple fuels is discussed in Section 3.3.

modifies the general framework presented by Cambridge Systematics, Inc., to apply it to the estimation of EUIs for commercial buildings.

4.2.1 One Period Model without Building-Specific Variables

The simplest SAE model generates a single parameter to adjust each EUI. From Equation 4.3, the following relationship was specified between the unobserved EUIs and the engineering EUIs:

$$EUI_{iku} = a_{ku} \cdot EUIR_{iku} + w_{iku} \tag{4.4}$$

where $EUIR_{iku}$ = engineering estimate of load for building i for fuel k for end use u

a_{ku} = parameter that adjusts the engineering EUI for end use u for fuel k

w_{iku} = an error term.

Substituting Equation 4.4 for EUI_{iku} in Equation 4.3, gives a regression model that can be estimated with the monthly whole-building EUI (derived from the billing data) as the dependent variable.

$$EUI_{ik} = \sum_{u} a_{ku} \cdot EUIR_{iku} \cdot D_{iku} + e_{ik} \tag{4.5}$$

where $e_{ik} = \sum_{u} w_{iku} \cdot D_{iku}$.

In this model, the simulated engineering EUIs enter the model as explanatory variables for each of the end-use services that the building is known to provide. The engineering EUIs vary over buildings on the bases of known or assumed building characteristics, operating schedules, and weather. For each end use and fuel, the estimated coefficient, a_{ku}, shifts the engineering-based EUI up or down.

If each estimated value of a_{ku} is equal to one, the EUIs are the same as those calculated in the engineering model. A value other than one can reflect

a variety of factors. For instance, for heating and cooling EUIs, the engineering-based estimates depend on several categories of information: 1) the envelope characteristics of the building including u-values for the walls, roof, and glazing; 2) the level of internal gains from lights, equipment, and occupants; 3) operational factors including thermostat settings and HVAC control strategies; and 4) HVAC system efficiency. While the CBECS provides information to specify a number of these variables, the discussion in Chapter 2 suggests that a number of variables are specified on the basis of a typical or average building. If the characteristics within the sample buildings differ on average from the assumed values, then the actual EUIs will diverge from the engineering EUIs. Thus, the a_{ku} parameters will capture the average difference between the EUIs from the actual building to buildings that, in part, are specified as "typical" buildings.

4.2.2 Multiperiod Adjustment with no Building-Specific Variables

In the model described in the previous section, the same adjustment factor is applied to each month of the year. For some end uses, it may be desirable to have adjustment factors that vary by month (or possibly season).

The end uses that the SAE estimates are most likely to be improved for, with this more flexible model, are heating and cooling. A variety of factors within the engineering model determine the balance points within the building (i.e., the outside temperature at which heating or cooling is required). During the "shoulder" months in the spring or fall, the engineering model may or may not estimate a non-zero level of heating or cooling energy use. If the engineering model does not adequately capture these factors, it may not properly represent the change in heating or cooling energy consumption that occurs from these time periods to the winter or summer peak space conditioning periods. This nonlinearity would not be accounted for in the single adjustment model discussed in Section 4.2.1.

Of the remaining end uses, water heating and lighting are the most likely to display some seasonal effects, especially in northern areas of the U.S. Water heating consumption varies as the temperatures of the ground supply water rises and falls during the year. Lighting varies with the amount of

daylighting used. Seasonal variations have been observed for both of these end uses for metered buildings in the Northwest. However, these effects are not large.

One specification issue is whether to employ individual adjustments by months or to collapse the months into seasons. Again, in the interest of minimizing the number of estimated coefficients, a seasonal model may be satisfactory. Four periods were chosen, using the following classification scheme:

s	Season
1	Spring (March-May)
2	Summer (June-August)
3	Fall (September-November)
4	Winter (December-February)

By adding the subscript s to represent seasons, the resulting SAE model can be specified, with seasonal effects applied to heating and cooling only, as

$$EUI_{ik} = \sum_{s=1}^{4} a_{k1s} \cdot EUIR_{ik1s} \cdot D_{ik1} + \sum_{s=1}^{4} a_{k2s} \cdot EUIR_{ik2s} \cdot D_{ik2} + \sum_{u=3}^{U} a_{ku} \cdot EUIR_{iku} \cdot D_{iku} + e_{iku} \tag{4.6}$$

4.2.3 One Period Model with Building-Specific Variables

The one period model described in Section 4.2.1 will generate different estimates of EUIs for each building in the sample. These differences stem from the variation of building-specific characteristics and weather used in the building engineering model.

The potential of systematic biases in the engineering EUI estimates, stemming from using what was judged as "typical" engineering or operational

assumptions in areas where the CBECS does not provide specific information, was also discussed. The one-period model provides an estimate of the overall average difference between the engineering EUI and the true EUI.

However, the assumption of constant bias in the engineering estimates may be overly restrictive. Clearly, there may be a number of dimensions along which this bias may vary. Building age, climate zone, size, and operating hours are possible candidate variables to explore the patterns of bias. Energy prices, if available, would also be a logical candidate variable to investigate. Operational characteristics and the general energy efficiency of building envelope and equipment would be expected to be linked to energy prices.

A danger in trying to incorporate too many building-specific conditioning variables is the risk of generating implausible EUI estimates—from an engineering perspective—in overly ambitious attempts to match the sample data. A balance must be struck between preserving the benefits of the *a priori* engineering estimates and finding the optimal fit to the sample data. Unfortunately, there is no clear answer to this dilemma; we need to let our best engineering and technical judgement guide the final model.

At the outset of the study we focused the building-specific conditioning variables upon vintage and climate effects. Considering the first of these effects, the overall whole building intensities published for the 1989 CBECS clearly indicate a strong dependence upon the age of the building. The intensities for electricity and natural gas are shown in Table 4.2. For electricity, the intensities increase in a steady pattern up through 1983, after which they fall by nearly 25 percent. The natural gas intensities increase in the post-war period, and then remain fairly constant through 1983. Like electricity, gas intensities then decline sharply in buildings built in the latter half of the 1980s.

A wide variety of imputations in the engineering model depend on the age of the building. The engineering model is likely to indicate that newer buildings are less energy intensive than older buildings. Moreover, the growing penetration of air conditioning over the historical period will also be automatically captured by the model. However, it is problematic that our

knowledge of historical construction practices and HVAC system types, coupled with penetration rates from the CBECS, will be sufficient to yield the patterns shown in Table 4.3. Another strong motivation for including vintage effects is that one of the required outputs of the overall study is to produce separate sets of EUIs for new versus existing buildings.

TABLE 4.3. Whole Building EUIs by Vintage

Year Constructed	Electricity kWh/ft^2	Natural Gas CF/ft^2
1899 or before	4.7	50.8
1900 to 1919	5.7	39.1
1920 to 1945	7.8	41.3
1946 to 1959	10.9	55.2
1960 to 1969	14.5	52.5
1970 to 1979	16.2	52.9
1980 to 1983	20.5	52.1
1984 to 1986	15.8	39.7
1987 to 1989	15.5	44.1

Source: EIA 1992, Tables 21 and 38.

To operationalize vintage effects, we need to collapse the number of vintage "dummy" variables from the number shown in Table 4.3. Three general vintages are proposed for the regression analysis: 1) pre-war buildings (up to 1945), 2) post-war buildings through 1979, and 3) buildings built after 1980.

Starting from Equation 4.4, the expression for the adjusted EUI after the incorporation of vintage effects (v) becomes

$$EUI_{iku} = a_{ku1} \cdot EUIR_{iku} + a_{ku2} \cdot EUIR_{iku} \cdot V_2 + a_{ku3} \cdot EUIR_{iku} \cdot V_3 + w_{iku} \tag{4.7}$$

where V_2 = 1 if building i was built between 1945 and 1979, 0 otherwise
V_3 = 1 if building i was built after 1979
all other variables are defined in Equation 4.4.

An estimable regression specification is obtained when Equation 4.7 is substituted into Equation 4.3, as before. Note that in this specification, the interpretation of the a_{ku} coefficients is slightly different than in the model with no vintage effects. The coefficient a_{ku1} is the adjustment factor for the pre-war buildings. Coefficients a_{ku2} and a_{ku3} are the incremental values added to a_{ku1} to yield the adjustment factors for the two vintages of post-war buildings.

Climate Zone

The engineering simulations indicate a strong dependence of space-conditioning energy use on weather. Energy intensities, however, do not vary as widely as weather conditions, since building codes and practices also reflect climatic variations. For instance, the envelope requirements in the ASHRAE 90-1975 and 90A-1980 building standards have a great deal of variation depending on the location of the building.

Although differences in envelope requirements by climate region are built into the engineering model, little empirical evidence exists regarding commercial building construction practices in various regions of the country. Most building energy-related studies used the ASHRAE codes to guide their choice of assumptions regarding the building component efficiencies. Two unavoidable shortcomings of this approach are: 1) that little is known about buildings built prior to the energy standards of the 1970s, and 2) that little evidence exists about compliance with the existing codes.

Given these uncertainties, a second set of categorical variables could adjust the heating and cooling energy intensities by the EIA climate zones (EIA 1992).

$$EUI_{iku} = a_{ku1} \cdot EUIR_{iku} + \sum_{j=2}^{5} c_{kuj} \cdot EUIR_{iku} \cdot CL_j + w_{iku} \qquad (4.8)$$

where CL_j = 1 if i is in climate zone j, 0 otherwise.

Other Candidate Variables

As mentioned above, at the outset of the study we prepared to focus upon vintage and climate zone as the most fruitful areas to consider building-specific variables, although the CBECS does contain some other building-specific information that may improve the SAE model. Some of these variables are the result of "yes-no" questions in the survey; it is difficult to make any informed guesses as to the magnitude of their energy impacts within the engineering model. These variables include

1. building size
2. weekly operating hours
3. employment density
4. percentage of space vacant
5. "activity" variables: # students, # beds, # seats, # rooms
6. computer room with separate A/C system

Some of the variables influence nearly all of the EUIs for a sample building; others would affect primarily heating or cooling. The general approach was to test the statistical power of these variables in the model development process. The variables derived from "yes-no" questions in the survey were specified as dummy variables for the appropriate end uses. The continuous variables were transformed as deviations from sample means before inclusion in the model. In all cases, the coefficients on these variables are interpreted as an incremental values to the sample average adjustment factors.

4.3 EXPERIENCE WITH ONE-PERIOD SAE MODEL

The development of a final SAE specification began with the estimation of the one-period adjustment model discussed in Section 4.2.1. The regression data sets consisted of monthly observations on electricity or natural gas intensity as the dependent variables and the FEDS-simulated consumption (converted to intensities) by end use as the independent variables. The general performance of the monthly SAE models was not satisfactory as they did not provide realistic estimates of EUIs for all end uses. In many cases, negative

signs were observed or the values of the estimated coefficients were significantly different from one. This implied considerable disagreement of the SAE-based intensities with those generated by the engineering model.

Without presenting a full range of results of the preliminary specifications that were tested, Figures 4.1 and Figure 4.2 illustrate some the problems encountered with this general approach. Figure 4.1 shows the regressions results for an SAE electricity model that used six major end-use categories from FEDS as independent variables. Although the percentage of explained variation is high for a cross-section model, the estimated coefficients on ventilation and hot water were both negative (and statistically significant).

Valid cases:	5514	Dependent variable:	Elec-EUI
Missing cases:	0	Deletion method:	None
Total SS:	65519462.289	Degrees of freedom:	5508
R-squared:	0.369	Rbar-squared:	0.368
Residual SS:	41339328.871	Std error of est:	86.633
F(6,5508):	536.955	Probability of F:	0.000
Durbin-Watson:	0.232		

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
Heat	0.903437	0.063296	14.27	0.000	0.188	0.1611
Cool	0.541845	0.113968	4.75	0.000	0.102	0.0593
H. Wtr	-4.764012	0.879689	-5.42	0.000	-0.070	-0.0321
Vent	-1.498594	0.454821	-3.29	0.001	-0.071	0.0739
Light	1.562044	0.096619	16.17	0.000	0.221	0.2467
Misc	3.891099	0.368406	10.56	0.000	0.022	0.3402

FIGURE 4.1. Small Office: Monthly SAE Electricity Regression Results

Valid cases:	3355	Dependent variable:	Gas-EUI
Missing cases:	0	Deletion method:	None
Total SS:	22683785.185	Degrees of freedom:	3352
R-squared:	0.626	Rbar-squared:	0.626
Residual SS:	8476980.215	Std error of est:	50.288
F(3,3352):	1872.570	Probability of F:	0.000
Durbin-Watson:	0.744		

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
Heat	0.602799	0.011091	54.35	0.000	0.626	0.6521
Cool	-1.311449	0.429725	-3.05	0.002	-0.038	-0.0473
H. Wtr	7.213891	0.333247	21.65	0.000	0.259	0.3586

FIGURE 4.2. Assembly: Monthly SAE Gas Regression Results

The heating and cooling coefficients are plausible, but the cooling coefficient suggests a substantial overprediction from the FEDS model. The coefficient on miscellaneous end use (misc) is nearly four.

Figure 4.2 presents the regression results for a natural gas SAE model applied to assembly buildings. The constant adjustment model contains terms for heating, cooling, and water heating. In this case, a negative coefficient was obtained for cooling. More disturbing, however, is the very low coefficient on heating at 0.60, a factor that would apply to nearly all assembly buildings using natural gas. Finally, the water heating coefficient suggests a severe problem with the FEDS engineering results for this end use.

An investigation to provide a complete explanation of the causes for the type of results illustrated by these examples was not possible within the time frame of this study. In general, we believe the following general factors are responsible.

Small Sample Sizes

We have strong *a priori* convictions that the proper way to conduct the SAE regression analysis is by building type. The different activities within different building types generate different internal loads that, in turn, influence heating and cooling consumption. After data cleaning to ensure adequate numbers of monthly consumption observations, we can end up with only a very few buildings within a specific building type that contain a particular end use. As Table 3.1 indicates, this becomes a particularly severe problem for building types such as food sales, food service, and hospitals. Moreover, even for building types with greater numbers of observations, heterogeneity of activities can lead to statistically unreliable coefficient estimates (e.g., various service activities in the retail/service sector).

End Use Reporting Errors

End use reporting errors were identified by comparing the monthly intensity plots and reported end uses. The more severe cases appear to associated with natural gas more than electricity. As an example, we plotted the monthly consumption for each of the 104 buildings reporting natural gas for cooling that met our criteria for inclusion in the SAE models. Of this total, we

could detect only about a dozen buildings for which natural gas consumption was higher in the summer than during the fall or spring. Although this is not a rigorous test of whether these buildings, in fact, used gas for cooling it suggests why the regression coefficients on the FEDS-generated gas cooling variables were seldom close to unity. Another reporting problem appears for buildings that report no gas consumption for heating, but the monthly consumption profiles indicates very high usage in the winter as compared to the summer and shoulder months.

Errors in the Engineering Model Predictions

In one sense, one would think that errors from the engineering model would not be of great concern, since the entire point of the SAE procedure is to account for this problem. The SAE model in Equation 4.1, however, can only account for errors that cause the predicted end use consumption to be a constant ratio of the actual consumption. Clearly the pattern of biases may be much more complicated than this simple specification.

One source of this error may involve a statistical concept termed "errors in variables." Given that the FEDS predictions are based on variables from CBECS, any measurement errors of the building characteristics from CBECS will be translated into errors in the intensity predictions from the model. This in turn will produce estimated coefficients that are biased downward within the SAE model (for example, see Johnston 1972).

Whether or not the errors from FEDS stem from CBECS reporting errors or from the internal construction of the engineering model, they tended to have differential impacts by end use on the estimated SAE coefficients. Consistent with an errors-in-variables model, the coefficients on the FEDS end uses with relatively high cross-sectional variances were nearly always less than one, sometimes significantly so. In the same equation, the coefficients on end uses where the FEDS model produced more uniform intensities were often greater than one. The results in Figure 4.2 follow this pattern. The coefficient on gas heating is much less than one, while the water heating adjustment coefficient is very high. The cross sectional variance of the FEDS heating predictions is much higher than for water heating. A major problem with this result

4.4.1 Electricity Decomposition Procedure

For electricity, monthly consumption data is first analyzed to separate the weather-sensitive load from the non-weather sensitive load. In the context of the EUI estimation work, this step actually seeks to identify total HVAC consumption as compared to the remaining end uses.

The approach used to estimate HVAC consumption is in some respects similar to the PRISM decomposition procedure that is often used for residential energy analysis (Fels 1986). However, instead of testing heating and cooling degree days (to various base temperature) as explanatory variables for the weather sensitive consumption, we use the simulated FEDS HVAC consumption. As compared to degree days, this has the advantage of automatically incorporating the FEDS assumptions involving the thermal integrity of the building directly into estimation procedure.

The decomposition procedure is conducted for each building in the sample that contains monthly electricity billing data (including buildings with imputed data, see Section 3.). The monthly HVAC and non-HVAC consumption estimates are then aggregated to annual values.

4.4.2 Natural Gas Decomposition

For natural gas, monthly consumption data is used to distinguish between heating and non-heating consumption. To decompose the whole building gas consumption we make the strong assumptions that 1) heating requirements are zero during the summer months (June, July, and August), and 2) non-heating loads are essentially constant across the months within the year. The first assumption, no heating load in the summer months, is consistent with FEDS predictions for gas heating; only a handful of buildings showed any heating load during June, July, or August. The second assumption is more problematic; the limited amount of metered data suggested somewhat higher consumption for water heating in the non-summer months. Nevertheless, we believed that a decomposition using this assumption as a first approximation was preferable to the pure SAE approach described above.

The combination of these assumptions implies that sum of non-heating end uses can be identified from observed gas consumption during the summer. In

is that the FEDS model actually modeled the mean heating intensity for assembly buildings fairly closely (see Appendix D, Figure D.1). Naively applying the adjustment factor of 0.6 to the FEDS heating intensity would not be appropriate.

Conclusion

The preliminary results with the monthly cross-section time series SAE model suggested that a credible set of EUIs could not be obtained from such an approach without considerable experimentation with specification and further data cleaning. A thorough investigation of the errors-in-variables hypothesis would require a building-by-building comparison of predicted and actual intensities, an effort well beyond the scope of this study. Moreover, the monthly SAE model makes very difficult to investigate to compare the cross-sectional performance of the FEDS model versus the seasonal performance.[a]

As a result of this work, we decided to impose greater structure on the model in the form of *a priori* assumptions. The general approach was to use the monthly data to provide EUI estimates for selected end uses or combinations of end uses. This step is then followed up with SAE models that are estimated with annual data. This procedure is discussed in general in the following section.

4.4 SAE APPROACH USING MONTHLY BILL DECOMPOSITION

As indicated above, the final methodology to estimate EUIs for electricity and gas involves decomposing monthly bills prior to a SAE modeling effort. Given the conventional uses for electricity as compared to gas, the decomposition procedures differ slightly. The following sections provide an overview of the procedures finally used in the study.

(a) This last consideration also was a factor in our decision not to try to add building-specific and demographic variables to the monthly specification. Our judgement was that expanding the model in this form (e.g., as illustrated in Equation 4.7) would not have solved the problems described above.

the empirical analysis discussed in Chapter 6 we explain in detail how the non-heating consumption was estimated from summer consumption. As for electricity, this step is conducted for each building in the sample.

4.4.3 Annual SAE Models

The resulting values from the monthly decomposition procedures are then treated as observed data, which then are used as dependent variables in a series of annual SAE regressions. For electricity, we have a cross section of annual HVAC and non-HVAC consumption for each building type. The "actual" HVAC consumption (intensity) is then regressed against the FEDS values for total HVAC intensity and other building-specific demographic variables. This model is similar to that discussed in section 4.2.3, with the exception that only one end use (actually, the sum of heating, cooling and ventilation) is being explained. The same SAE procedure is applied to the decomposed "actual" intensity corresponding to non-HVAC end uses.

The further disaggregation of these combined end uses then relies almost exclusively on the FEDS engineering estimates. As described in the next chapter, separate adjustments were made for electric heating for several building types.

The general procedure is similar for natural gas, although somewhat less symmetrical. For heating, an annual SAE regression is performed using the same specification as for the HVAC and NHVAC regressions for electricity. For non-heating end uses (primarily water heating and cooking), individual SAE regressions were performed without building specific or demographic variables. These regressions were done for various subsets of the individual building samples in order to generate the most credible EUI estimates for these two separate end uses. Given there was extremely small number of observations which we believed actually used natural gas for cooling, we relied on the FEDS-generated estimate for this end use.

The next two chapters provide details of the decomposition procedure and SAE models. Chapter 5 discusses the EUI estimation procedure and selected empirical results for electricity and Chapter 6 does the same for natural gas.

5.0 EUI ESTIMATION: ELECTRICITY

This chapter presents the detailed methodology used to generate the EUIs for electricity. Section 5.1 discusses the methodology and section 5.2 discusses the empirical results of the SAE regressions, with particular emphasis on the small office and retail/service building types. Section 5.3 covers several issues with regard to the generation of the final EUI estimates.

5.1 METHODOLOGY FOR ELECTRICITY EUIs

As discussed in the previous chapter, the EUI methodology involves two elements: 1) monthly bill decomposition and 2) annual SAE regressions. These topics are the subject of the following two subsections.

5.1.1 Monthly Bill Decomposition

The objective of the monthly bill decomposition is to separate the weather-sensitive electricity consumption from the non-weather-sensitive consumption. The results from this step are used to generate individual adjustment factors for the HVAC and non-HVAC (NHVAC) categories of electrical end use.

Formally, the HVAC and NHVAC loads comprise the end uses shown in Equations 5.1 and 5.2, as generated by the FEDS building model:

$$\text{EUIFEDS}^{\text{HVAC}},\ \text{HVAC} = \text{Heating} + \text{Cooling} + \text{Ventilation} \tag{5.1}$$

$$\text{EUIFEDS}^{\text{NHVAC}},\ \text{NHVAC} = \text{Lighting} + \text{Refrigeration} + \text{Cooking} + \text{Hot Water} + \text{Miscellaneous} \tag{5.2}$$

The HVAC load itself is further divided into two components: 1) a weather-sensitive component ($\text{EUIFEDS}^{\text{HVACW}}$) and 2) a non-weather-sensitive component ($\text{EUIFEDS}^{\text{HVACNW}}$). $\text{EUIFEDS}^{\text{HVACNW}}$ is defined as the month with the minimum total HVAC consumption ($\text{EUIFEDS}^{\text{HVACNW}} = \min[\text{EUIFEDS}^{\text{HVAC}}]$). The weather-sensitive component is defined as the consumption exceeding this level. Expressed as intensities (i.e., divided by square footage), we have

$$EUIFEDS^{HVACW} = EUIFEDS^{HVAC} - EUIFEDS^{HVACNW} \quad (5.3)$$

The second step in this procedure is to estimate the response of the actual electricity consumption to HVACW. A coefficient of unity suggests that the FEDS model is properly accounting for the factors contributing to the HVAC energy consumption. These factors are primarily the thermal integrity of the structure (UA-value) and the efficiency of the heating and cooling equipment.

The response coefficient is estimated with the monthly data for 1989 (Equation 5.4).

$$EUI_m = b_1 EUIFEDS_m^{HVACW} + b_2 MDAYS_m \quad (5.4)$$

where EUI_m = the electricity consumption/ft^2 in month m

$EUIFEDS_m^{HVACW}$ = the weather-sensitive portion of predicted HVAC consumption in the month

$MDAYS_m$ = days in month m (28, 30, or 31).

Equation 5.4 posits that the non-weather sensitive portion of the load is constant on a daily average for each month. Using the MDAYS variable accounts for the different numbers of days in each month.

The coefficient on $EUIFEDS_m^{HVACW}$ (b_1) is the starting point for an adjustment factor to be applied to the non-weather-sensitive loads. Equation (5.5) is used to convert to an annual basis.

$$R = (EUI - b_1 EUIFEDS^{HVACW})/(EUIFEDS - b_1 EUIFEDS^{HVACW}) \quad (5.5)$$

where EUI = the annual electricity consumption/ft^2, actual

$EUIFEDS^{HVACW}$ = the weather-sensitive portion of predicted HVAC consumption, totaled over the year

EUIFEDS = total annual electricity consumption/ft^2, FEDS predicted

The numerator in equation 5.5 is the estimate of total "actual" non-weather-sensitive electricity consumption, computed as the difference between

the actual total consumption (EUI) and the regression-based estimate of weather-sensitive consumption. The denominator in Equation 5.5 is a FEDS-based estimate of non-weather-sensitive load (lighting, hot water, refrigeration, cooking, miscellaneous) and the non-weather sensitive portion of the HVAC load.

The results of this procedure are estimates of total HVAC consumption and NHVAC consumption for each building with a full set of monthly billing data. These "quasi" actual values are designated as $\tilde{EUI}^{HVAC}$ and $\tilde{EUI}^{NHVAC}$. These levels of consumption are then considered as actual data in a Statistically Adjusted Engineering (SAE) regression model. Based on the adjustment factor, R, in Equation (5.5), the estimates of HVAC and NHVAC consumption are defined as

$$\tilde{EUI}^{HVAC} = b_1 \cdot EUIFEDS^{HVACW} + R \cdot EUIFEDS^{HVACNW} \tag{5.6}$$

$$\tilde{EUI}^{NHVAC} = EUI - \tilde{EUI}^{HVAC} \tag{5.7}$$

Note that the computation of NHVAC consumption as residual forces the sum of $\tilde{EUI}^{HVAC}$ and $\tilde{EUI}^{NHVAC}$ to equal the actual total annual electricity intensity. In the SAE procedure described below, separate equations were developed to explain both $\tilde{EUI}^{HVAC}$ and $\tilde{EUI}^{NHVAC}$.

Finally, adjustment factors are computed that relate to the FEDS-generated end-use predictions.

$$r1 = \tilde{EUI}^{HVAC}/(EUIFEDS^{SH} + EUIFEDS^{SC} + EUIFEDS^{V}) \tag{5.8}$$

$$r2 = \tilde{EUI}^{NHVAC}/(EUIFEDS^{RF} + EUIFEDS^{LI} + EUIFEDS^{CK} + EUIFEDS^{WH} + EUIFEDS^{MS}) \tag{5.9}$$

Special Cases

The procedure described above works well for the majority of buildings in the 1989 CBECS. However, in some buildings the FEDS-generated total energy intensity deviates significantly from the actual billing data. Therefore, in some circumstances the procedure described earlier fails.

The first rule imposed on the estimation procedure is that the response coefficient, b_1, in Equation (5.4) be greater than or equal to 0.1. This ensures that the final model will generate at least a modest level of HVAC consumption for the sample building.

Very high or low values of b_1 can lead to a negative adjustment factor, R, in equation (5.5). If this happens, the first course of action is to set the adjustment factor equal to 1.0. This step removes the scaling of the non-weather-sensitive portion of the HVAC load.[a]

With or without the scaling, other cases exist for which the computed value of $\tilde{EUI}^{NHVAC}$ is negative in Equation (5.7). This occurs when FEDS substantially understates the weather sensitivity of the HVAC loads and there appears to be a very small "base" (non-weather-sensitive) load. In such cases, regression analysis is not used to try separating the "actual" HVAC load from the NHVAC load. Rather, the NHVAC load is defined as the minimum observed monthly consumption (on an annualized basis). Thus, the separation into HVAC and NHVAC components is made independent of the FEDS-generated results.[b]

$$\tilde{EUI}^{NHVAC} = \min(EUIFEDS_m) \tag{5.10}$$

$$\tilde{EUI}^{HVAC} = EUI - \tilde{EUI}^{NHVAC} \tag{5.11}$$

(a) Out of a total of 3,429 cases, 91 (2.7%) had the adjustment factor R set to 1.0.

(b) This case occurred for 58 buildings in the total sample. Nineteen of these cases had a positive adjustment factor R and thus did not have the scaling previously removed.

Adjustment Coefficients for Electric Heating

The model in Equation (5.4) assumes that adjustment to the HVAC loads applies equally to electric heating and cooling. A procedure was developed to estimate an approximate adjustment factor that could be uniformly applied to the FEDS heating consumption predictions for buildings with electric space heating.

The first step in this procedure was to decompose the predicted FEDS ventilation consumption. For most building types, the ventilation strategy is assumed to be demand driven. This strategy indicates that a portion of the ventilation requirements will vary as monthly heating and cooling loads. To estimate the portion of ventilation that is seasonally or weather dependent (VW), the following regression is used:

$$\tilde{EUIFEDS}_m^{VW} = a_1\ EUIFEDS_m^{SH} + a_2\ EUIFEDS_m^{SC} + a_3\ MDAYS_m + e \qquad (5.12)$$

If no electric cooling is present, $EUIFEDS^{SC}$ is dropped in Equation (5.12). The non-weather-sensitive portion of the ventilation load $\tilde{EUIFEDS}^{VNW}$ is then estimated as a residual:

$$\tilde{EUIFEDS}_m^{VNW} = EUIFEDS_m^{V} - \tilde{EUIFEDS}_m^{VW} \qquad (5.13)$$

Next, augmented heating and cooling loads were defined based on the regression in Equation (5.12). Thus

$$EUIFEDS_m^{SH^*} = EUIFEDS_m^{SH} + a_1\ EUIFEDS_m^{SH} \qquad (5.14)$$

$$EUIFEDS_m^{SC^*} = EUIFEDS_m^{SC} + a_2\ EUIFEDS_m^{SC} \qquad (5.15)$$

The non-weather-sensitive electricity demand is defined as the sum of the non-weather sensitive ventilation demand plus other non-HVAC end uses:

$$EUIFEDS_m^{NHVAC^*} = EUI\tilde{F}EDS_m^{VNW} + EUIFEDS_m^{NHVAC} \tag{5.16}$$

Separate response coefficients for heating and cooling are estimated with the monthly data for 1989 in Equation (5.13):

$$EUI_m = b_1\ EUIFEDS_m^{SH^*} + b_2\ EUIFEDS_m^{SC^*} + b_3\ EUIFEDS_m^{NHVAC^*} \tag{5.17}$$

where EUI_m = the electricity consumption/ft^2 in month m

Using buildings within each building type, the weighted average of the b_1 and b_2 coefficients is computed (Equation 5.17). The weights are based upon the annual values of $EUIFEDS^{SH^*}$ and $EUIFEDS^{SC^*}$.

At this point, any separate adjustment to the FEDS-generated heating consumption is still primarily judgmental. The relative magnitudes of the overall heating and cooling loads are examined, along with the monthly plots of the actual versus the FEDS-adjusted consumption. Based on this information, electric heating values were uniformly reduced by 30% in restaurants and large offices.[a] These two building types have greater-than-average internal loads that may be offsetting winter heating loads to a greater extent than is modeled in FEDS. Several other building types also suggested a small reduction in heating loads, but the evidence was not as clear cut.

5.1.2 Statistically Adjusted Engineering Models

Following the billing data decomposition, the next step is developing a model that can explain the cross sectional variation in the estimated HVAC and NHVAC loads. This step employs the SAE model approach as described in Chapter 4.

(a) The procedure described in this section was applied independently of the overall decomposition procedure. The adjustments to the FEDS electric heating predictions, based upon Equation (5.14), were applied prior to the decomposition methodology described in Equations (5.3) through (5.9).

The SAE models focus on six major variables:[a]

1. Vintage
2. Building size
3. Climate
4. Weekly operating hours
5. Employment density
6. Presence of manufacturing activity

A variety of specifications were tested with variations of these variables. For variables 2 through 5, specifications using dummy (categorical) variables or continuous variables were tested. In the dummy variable specification, for example, building size would be modeled as three or four separate dummy variables depending on the size category of the building. The continuous specification would simply enter the square footage of the building as a single, independent variable.

The continuous form of variables 2 through 5 generated higher percentages of explained variance, with the added advantage of minimizing the total number of variables. Moreover, since the regressions were performed for each building type, many of the boundaries for the categorical variables had to be adjusted for each building type (e.g., small, medium, and large buildings are different for restaurants as compared to educational buildings).

The final form of the SAE specification was almost identical for both $\tilde{EUI}^{HVAC}$ and $\tilde{EUI}^{NHVAC}$.

$$\tilde{EUI}^{HVAC} = (\alpha_0 + \alpha_1 D_{V1} + \alpha_2 D_{V2} + \alpha_3 SQFT + \alpha_4 CDD + \alpha_5 HRS + \alpha_6 EMP)\ EUIFEDS^{HVAC} + u \tag{5.18}$$

(a) For the warehouse building type, a separate dummy variable was added for a refrigerated warehouse. The value of the coefficient was interpreted as a refrigeration intensity.

$$\tilde{EUI}^{NHVAC} = (\beta_0 + \beta_1 D_{V1} + \beta_2 D_{V2} + \beta_3 SQFT + \beta_4 CDD + \beta_5 HRS + \beta_6 EMP) EUIFEDS^{NHVAC} + \beta_7 ElcMan + u \tag{5.19}$$

where $EUIFEDS^{HVAC}$ = FEDS predicted intensity, HVAC

$EUIFEDS^{NHVAC}$ = FEDS predicted intensity, non-HVAC

V1 = 1 if the year built is between 1946 and 1979; 0 otherwise

V2 = 1 if the year built is between 1980 and 1989; 0 otherwise

SQFT = building size, thousand square feet

CDD = Cooling degree days, base 65°F

HRS = Weekly operating hours

EMP = Employment density, employees per 100 ft^2

ElcMan = 1 if electricity used for manufacturing; 0 otherwise

In the estimation procedure for electricity, all of the modifier variables (V1, V2, SQFT, CDD, HRS, and EMP) are taken as deviations from their individual sample means. Although this step does not change the predictive quality of the regression equation, it does help interpret the coefficient of $EUIFEDS^{HVAC}$ and $EUIFEDS^{NHVAC}$.

The data sets used in the SAE regression omitted "high intensity" observations that would distort the usefulness of the adjustment procedure. In preliminary estimation work, we experimented with statistically-based criteria, primarily using the studentized t-statistic. Further experience lead to using an upper limit based on the results of the engineering model. For each building type, the building with the maximum total electricity and natural gas intensity was identified. The cut-off intensity was then computed as 3.0 times this FEDS intensity. Table 5.1 shows the intensities used for this screening procedure.

Several additional steps complete the estimation process. Equations (5.18) and (5.19) are estimated without an intercept. This specification stems from the discussion in Section 4.4 and ensures that changes in FEDS-generated estimates of EUIS are translated into proportional changes in the final EUIs. One difficulty with this specification is that it does not require that the mean of the predicted values match the mean of the actual dependent variable. A more accurate estimator of the EUIs for the full sample

TABLE 5.1. Maximum Annual EUIs for Calibration Procedure (kBtu/ft^2)

Building Type	Electricity	Gas
Assembly	491	807
Education	670	700
Food Sales	511	632
Restaurants	1153	1316
Hospitals	433	343
Lodging	511	647
Large Office	833	308
Small Office	593	686
Retail	664	840
Warehouse	500	421
Other	447	849

should make an adjustment for this discrepancy. As such, final scaling factors were applied to the estimated coefficients in Equations (5.18) and (5.19) to force the mean of the predicted values to match the actual mean.

The linear specification in Equations (5.18) and (5.19) does not ensure that the predicted values of the HVAC or non-HVAC intensities are globally positive. Thus, even if all of the predicted values within the estimation sample are positive, negative values could be generated upon extrapolation of the equation to buildings that did not have monthly billing data. Typically, up to a half dozen cases for a single building type would be observed with negative predictions. Because the overall methodology needs to extrapolate to buildings that are not included in the estimation sample, there is no satisfactory way to avoid this problem without going to a logarithmic or other specification. Since the principal aim of this study is to generate EUIs for some aggregation of buildings (e.g., building type and region), the solution was to fix the predicted EUIs of such buildings at a uniform value of 1.0 (kBtu/ft^2).

5.2 EMPIRICAL RESULTS

This section presents the results of the monthly decomposition and annual SAE models as applied to electricity. The adjustment coefficients shown apply to the final version of the FEDS building model used in the study.

As indicated in Chapter 1, these represent the second-round engineering estimates upon which the final adjustment parameters were estimated. A number of changes were made to the FEDS model based upon preliminary data analysis, primarily stemming from the results of the monthly bill decomposition. These all involved electricity end uses. The major changes were concerned with ventilation, refrigeration, and lighting. Details of these changes are discussed at the end of Appendix A.

5.2.1 Decomposition of HVAC and NHVAC Consumption

Table 5.2 presents the weighted average adjustment factors related to the FEDS generated HVAC and NHVAC consumption. The adjustment factors are the r1 and r2 values in Equations (5.8) and (5.9). The weights are the predicted values of HVAC and NHVAC EUI values from FEDS.[a]

TABLE 5.2. Monthly Bill Decomposition Results: Adjustment Ratios, Weighted Average Ratios

Building Type	HVAC (r1)	NHVAC (r2)
Assembly	0.699	1.365
Education	0.792	1.801
Food Sales	0.639	1.012
Restaurants	1.008	0.911
Hospital	1.637	1.299
Lodging	0.695	1.092
Large Office	1.289	1.459
Small Office	0.608	1.293
Retail	0.825	1.964
Warehouse	1.307	1.997
Other	0.592	1.491

(a) In essence, the weighting generates a fraction in which the numerator is the mean actual intensity and the denominator is the mean FEDS intensity. In contrast, an unweighted mean of the adjustment factors can be distorted by individual cases with very high values (Actual/FEDS), but which have very small intensities. Note, however, that we do not account for building size or sampling weights in deriving this statistic.

In general, the seasonal variation of electricity consumption was somewhat overstated by the FEDS model. As shown in the first column of the table, in seven of the 11 building types the weighted average adjustment factor was less than 1.0.

Figure 5.1 shows the energy intensities for small offices, computed as simple unweighted averages for all observations with suitable billing data. The top two graphs are for electricity; the bottom two relate to natural gas (see following chapter for discussion).

The top left graph compares the average monthly profile from the FEDS model (dashed line) as compared to actual billing data (solid line). The most encouraging feature of the graph is that the FEDS model, based strictly on engineering assumptions, comes very close to predicting the average actual level of electricity consumption. As previously discussed, the small office sector displays a common trait of the model at this stage of development and slightly overpredicts the seasonal variation in electricity loads.

The third (small dashed) line in the graph shows the result of the billing decomposition procedure. It plots the monthly sum of $E\tilde{U}I^{HVAC}$ and $E\tilde{U}I^{NHVAC}$ as computed in Equations (5.5) and (5.6). By the nature of its construction the annual average value of this sum equals the annual average actual intensity, but the accuracy over any particular month may vary. The adjusted HVAC and NHVAC loads track the actual monthly series quite well; however, the summer cooling load is still slightly overpredicted.

The top right graph of shows the major end uses as predicted by the FEDS model. Note the shape of the monthly ventilation curve. The higher ventilation requirements during the summer reflect the assumption that demand ventilation strategies are typical. The averages shown in the graph indicate that heating and cooling are both conducted during the winter months across the nation. Even though this result stems primarily from buildings in different climate regions, the zoning feature built into the FEDS model can also generate simultaneous heating and cooling within a single building for winter months. The lighting consumption in small offices is predicted, by FEDS, to be slightly more than double the total of the other NHVAC end uses.

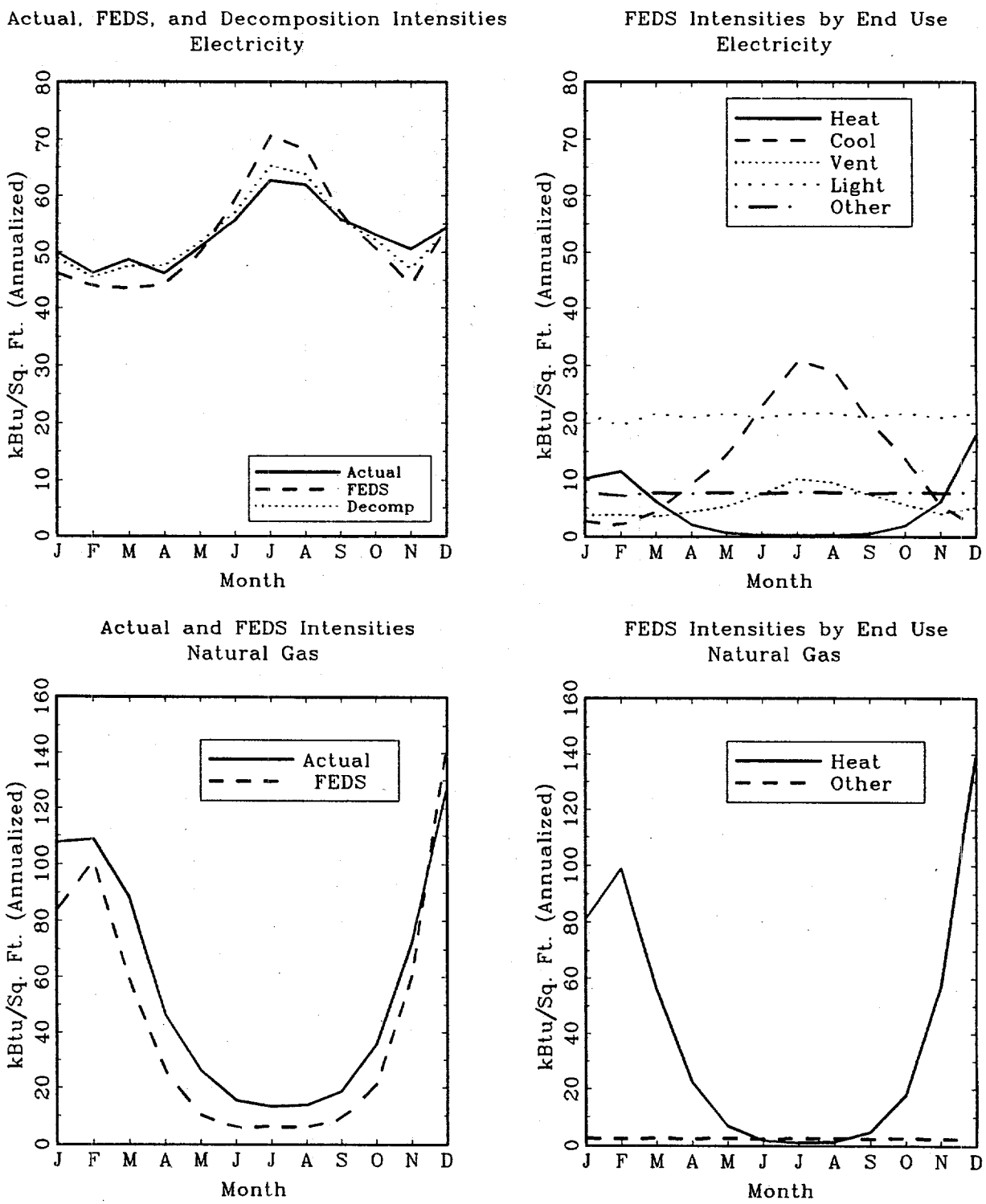

FIGURE 5.1. Small Office: Monthly Average EUIs (for Building Totals, Predicted and Actual, and FEDS Major End Uses).

Figure 5.2 shows the same monthly information for the retail/service building type. As compared to small offices, the simulated electricity intensity from FEDS is somewhat lower than the actual values. Again, however, the seasonal variation is slightly greater than what is observed for the average monthly intensity.

In two building types (hospitals and warehouses) the FEDS model understates the seasonal variability of the electricity (cooling) loads. In hospitals, the assumptions concerning ventilation strategies and internal loads in FEDS understated the variation in cooling requirements over the year. In warehouses, the adjustment procedure indicates lower temperature setpoints and more cooling than was assumed as typical for this building type. Future work will be devoted to modifying the FEDS model to better handle these cases.

Appendix D shows the set of monthly plots for each of the building types.

5.2.2 SAE Model Estimation Results

The following sections describe the results of the SAE model estimations. As above, the focus is on small office and retail/service building types.

Small Office

Figure 5.3 shows the results of the SAE regressions for HVAC and NHVAC electricity intensities for small office, as described in equation 5.10. To simplify the notation, the independent variable $EUIFEDS^{HVAC}$ is shortened to HVf (HVAC, FEDS). Similarly, $EUIFEDS^{NHVAC}$ becomes NHVf.

The top part of the figure shows the estimated coefficients for the HVAC portion of consumption. As expected the most statistically significant variable is the predicted value of HVAC consumption from the FEDS model.

The remaining variables are all entered multiplicatively with HVf to ensure that they only adjust the value from FEDS (chapter 4). The vintage variables are positive, with the coefficient on only the post-1980 dummy variable being greater than its standard error. A positive coefficient indicates

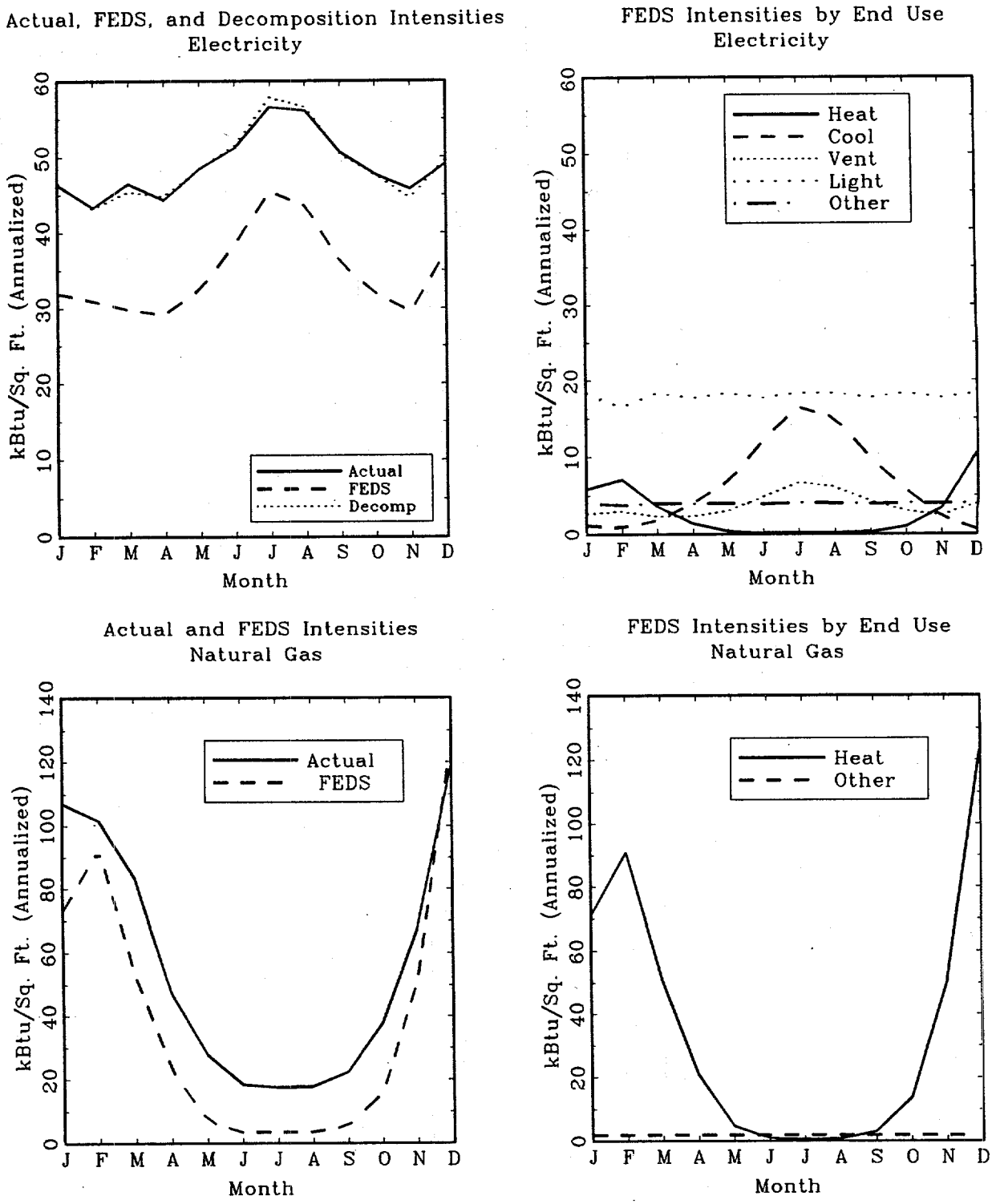

FIGURE 5.2. Retail/Service: Monthly Average EUIs

HVAC

Valid cases:	476	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	155608.728	Degrees of freedom:	469
R-squared:	0.189	Rbar-squared:	0.178
Residual SS:	126263.419	Std error of est:	16.408
F(7,469):	15.572	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.481883	0.029563	16.300367	0.000	0.610023	0.666688
V1*HVf	0.054800	0.072694	0.753843	0.451	0.034491	0.141552
V2*HVf	0.124530	0.085819	1.451087	0.147	0.066417	-0.064502
SQFT*HVf	0.001665	0.002509	0.663525	0.507	0.023867	-0.212634
CDD*HVf	0.000081	0.000023	3.546999	0.000	0.125182	0.349712
HRS*HVf	0.002994	0.001278	2.343485	0.020	0.078080	0.085571
EMP*HVf	0.067129	0.012520	5.361666	0.000	0.178373	0.281829

NHVAC

Valid cases:	476	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	945132.526	Degrees of freedom:	468
R-squared:	0.103	Rbar-squared:	0.089
Residual SS:	847948.123	Std error of est:	42.566
F(8,468):	6.705	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.172897	0.066124	17.737968	0.000	0.620325	0.650853
V1*NHVf	-0.068373	0.169145	-0.404226	0.686	-0.018065	-0.044836
V2*NHVf	0.343288	0.187812	1.827829	0.068	0.081787	0.093471
SQFT*NHVf	0.016118	0.005027	3.206473	0.001	0.110007	0.128229
CDD*NHVf	-0.000074	0.000074	-0.995271	0.320	-0.033659	-0.054595
HRS*NHVf	0.002859	0.001884	1.517394	0.130	0.053406	0.271865
EMP*NHVf	0.180610	0.033448	5.399748	0.000	0.181510	0.224121
ElcMan	9.913276	11.696186	0.847565	0.397	0.028835	0.146559

FIGURE 5.3. Small Office: SAE Regression Results for Electricity

that an incremental adjustment to the FEDS-generated HVAC consumption for new buildings is called for, after taking into account the influence of the remaining variables in the equation.

Keeping in mind that the coefficients of the SAE regressions are used as adjustment factors of the FEDS predictions, the figure indicates statistically significant effects for three of the remaining four variables. The regression results suggest that cross-sectionally, the FEDS model is underpredicting HVAC intensities for buildings with relatively higher levels of cooling degree days, weekly operating hours, and employment densities.

The interpretation of the lower portion of the figure, with coefficients for the NHVAC regression, is similar. The sum of NHVAC loads in the post-1980 buildings appears to still be underpredicted by FEDS. Building size appears to require some adjustment, as compared to the HVAC results. Larger buildings within the small office category (up to 50,000 ft^2) appear to have higher loads than predicted by FEDS. The only other significant modifying variable in the NHVAC regression is employment density. This influence is quite strong, with a t-value exceeding 5.

The final variable in the regression is a dummy variable that indicates whether electricity was used for manufacturing activity within the building. Although the value for the small office sector is positive, adding an estimated 10 kBtu to the average annual intensity, the statistical significance of the variable is low.

Since the coefficients in the SAE equations are adjustment factors, it is difficult to evaluate their magnitudes and signs. As a partial remedy to this problem, the implementation of plotting software to examine the patterns of EUIs across key building characteristic variables was developed as a diagnostic tool. For small offices, Figures 5.4 through 5.8 provide an example of one set of these plots. The graphs show the means of the actual, FEDS, and SAE intensities across different categories of five variables identical or similar to those used in the SAE regressions: vintage, building size, climate zone, operating hours and employment density. As in Figures 5.1 and 5.2, we will restrict the discussion the top portion of the figures which relate to electricity.

Variation of EUIs by vintage is shown in Figure 5.4. Although the HVAC intensities appear to minimally dependent upon vintage, the top right figure

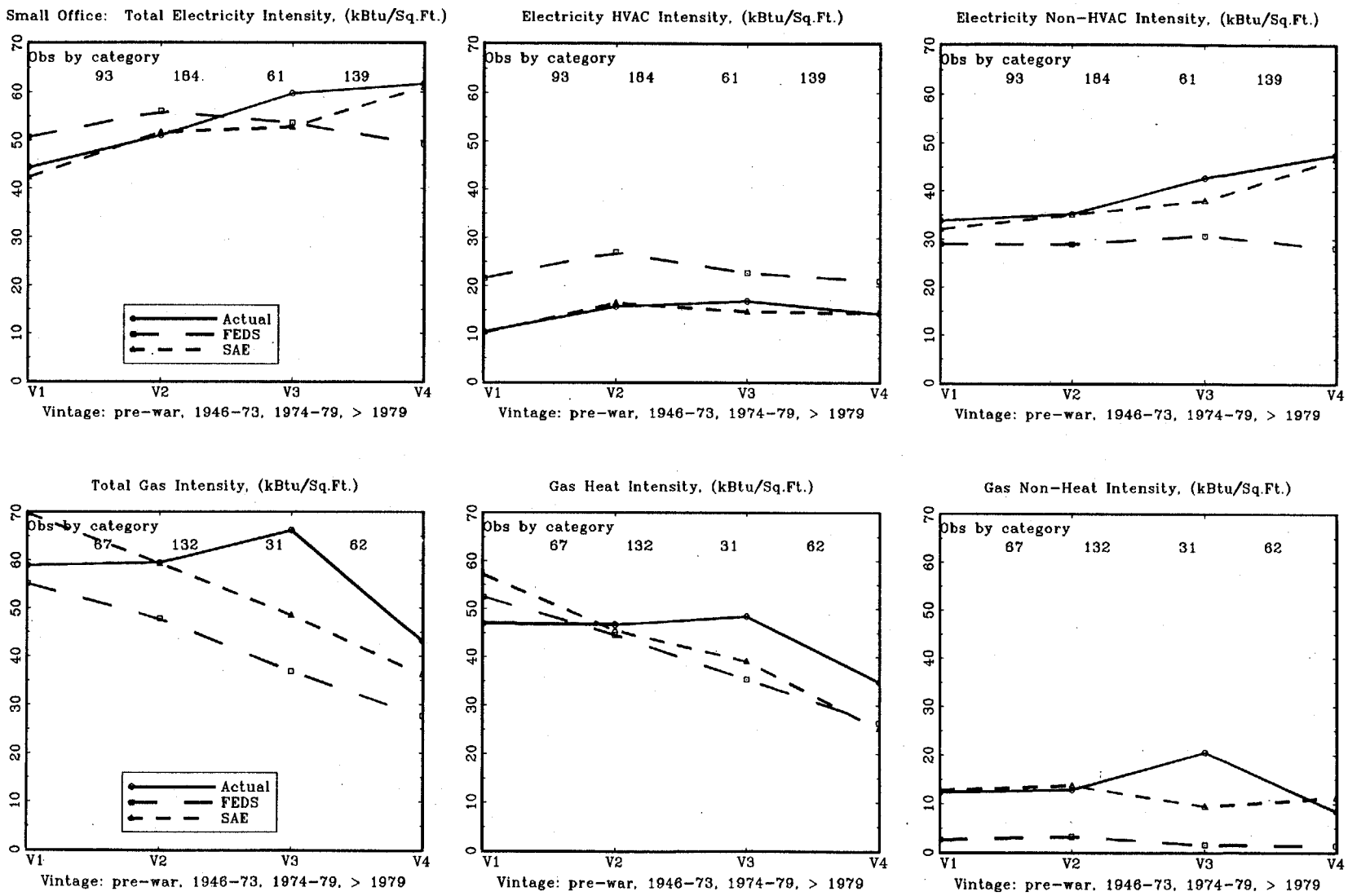

FIGURE 5.4. Small Office: Actual, FEDS, and SAE Intensities By Vintage

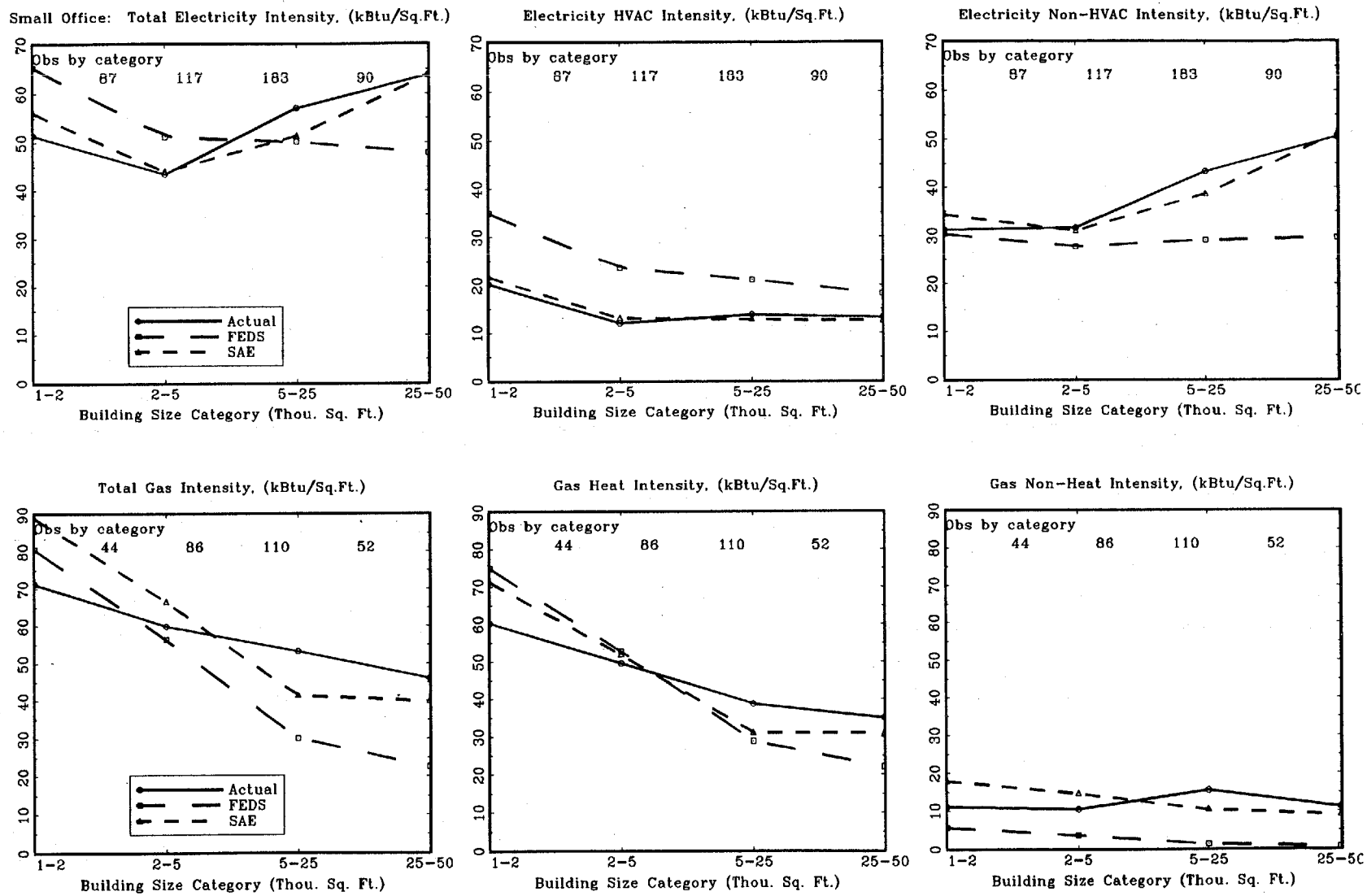

FIGURE 5.5. Small Office: Actual, FEDS, and SAE Intensities By Building Size Category

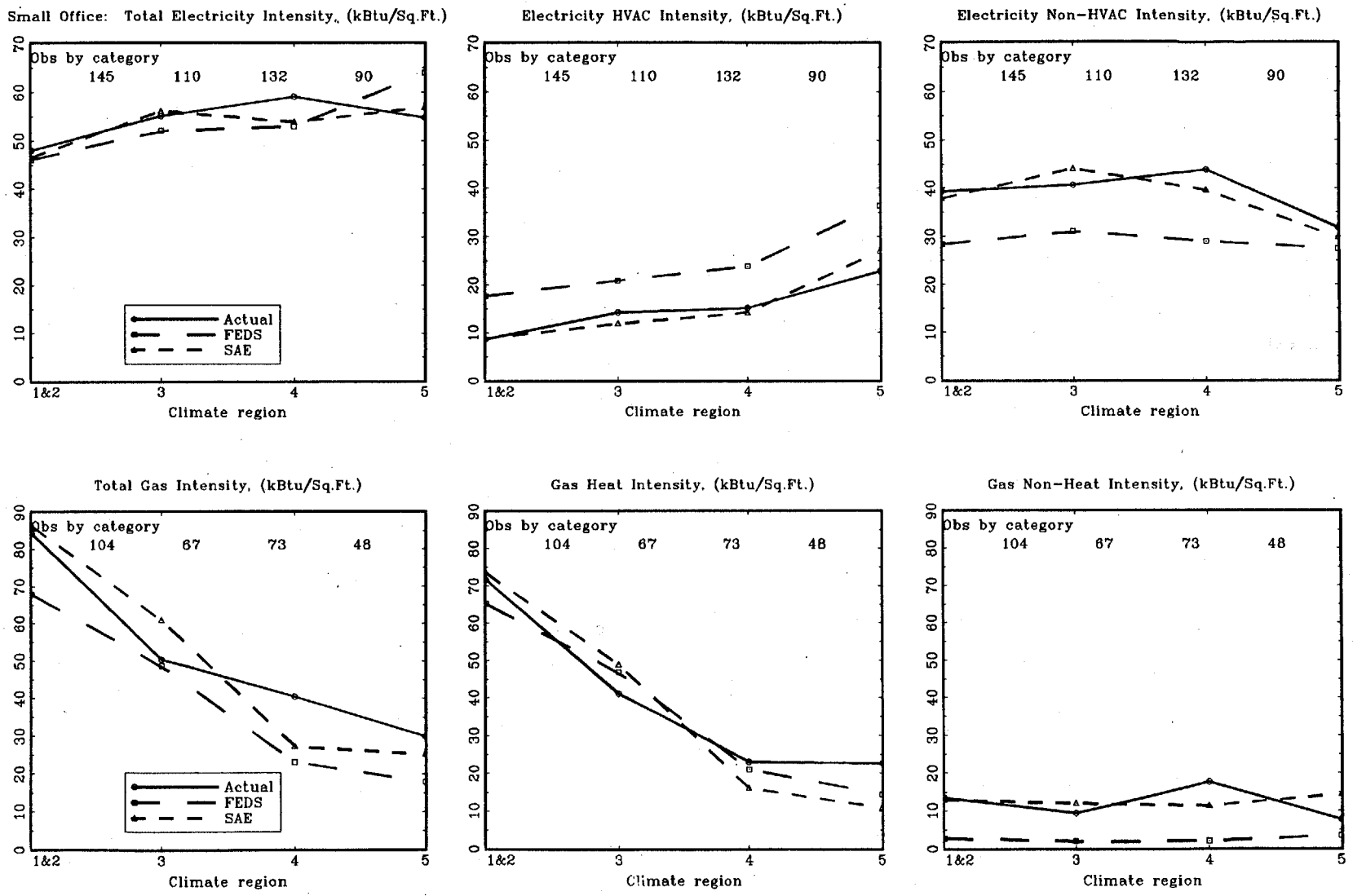

FIGURE 5.6. Small Office: Actual, FEDS, and SAE Intensities By Climate Region

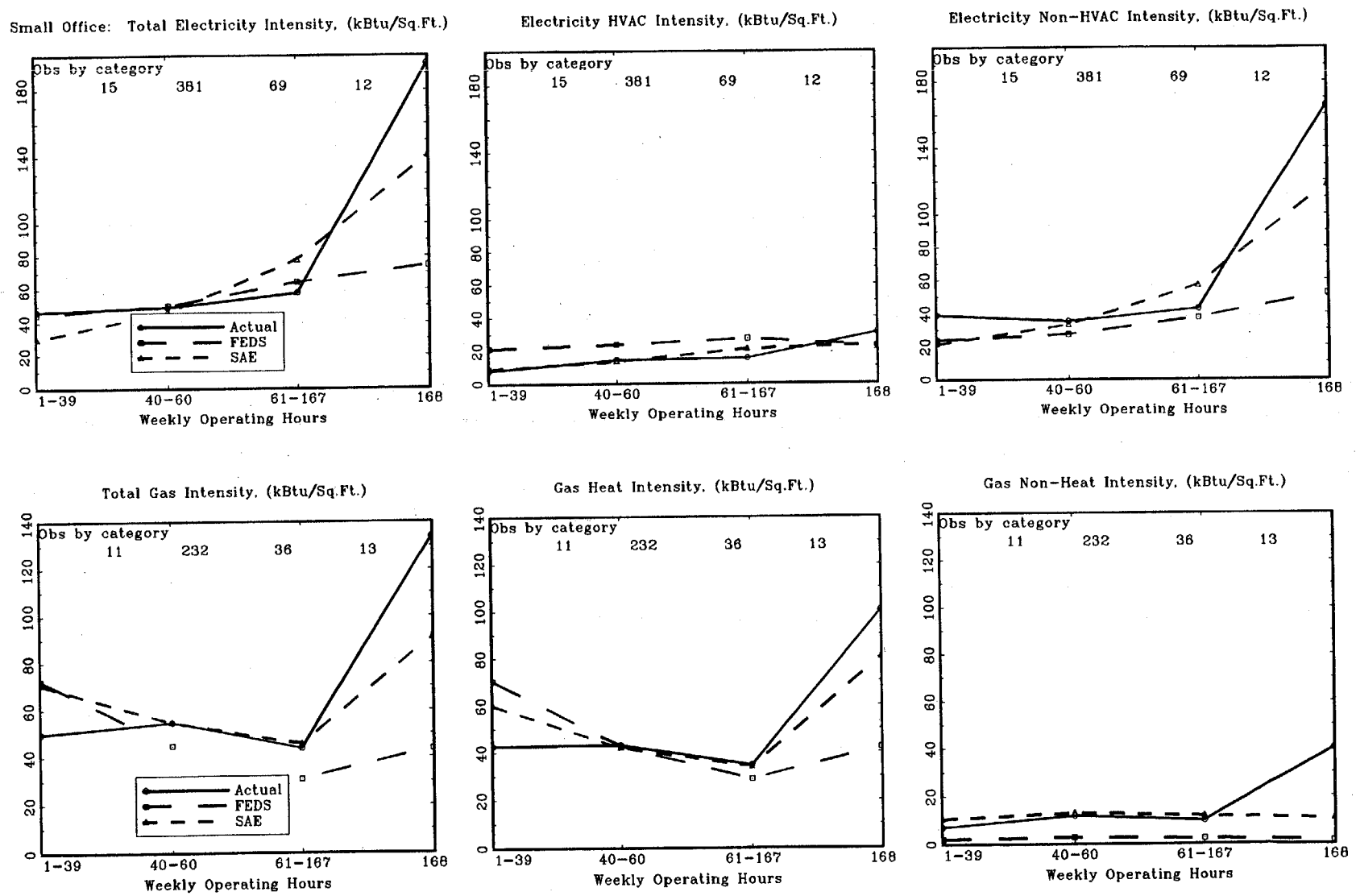

FIGURE 5.7. Small Office: Actual, FEDS, and SAE Intensities By Weekly Hours Category

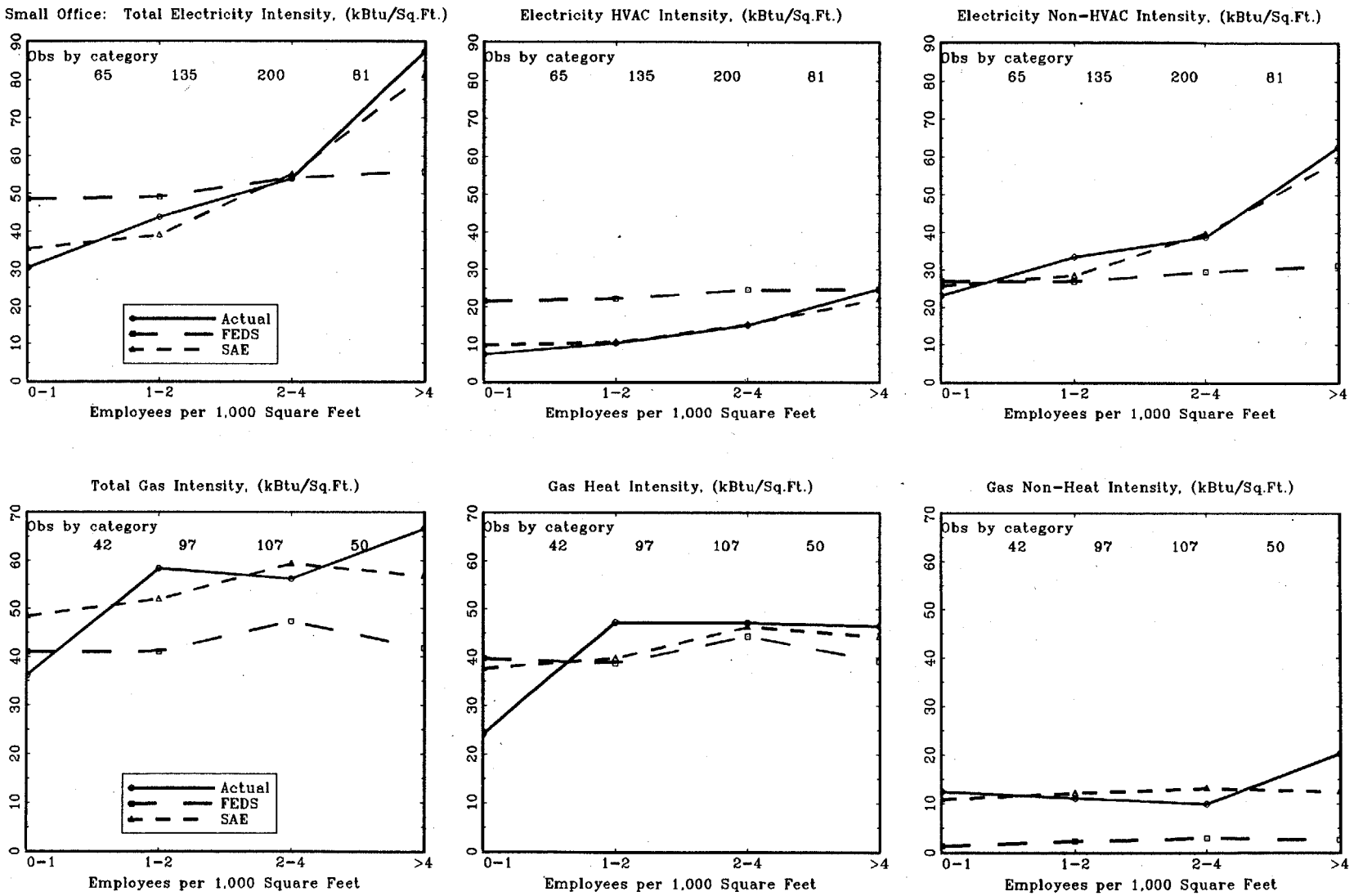

FIGURE 5.8. Small Office: Actual, FEDS, and SAE Intensities By Employment Density Category

clearly shows increasing electrification in new office buildings. The SAE adjustment procedure appears to modeling this trend very well, especially in the post-1980 buildings.[a]

The top middle graph in Figure 5.5 clearly shows how heating and cooling requirements per square foot (HVAC) are significantly higher in very small buildings. This general phenomenon is generally captured by the engineering simulations, although the level is somewhat higher the actual data. Note that the SAE model brings this relationship closely in line with the observed average intensities. In interpreting figures, note that the number of observations in each category is shown at the top of the graph.

The top right graph shows how the non-HVAC intensities as a whole increase with larger buildings (up to 50,000 ft^2 in small office). The SAE predictions match this pattern, consistent with the high statistical significance of SQFT in SAE regression shown in Figure 5.3.

Figure 5.6 shows the various EUI measures by EIA climate zone.[b] Climate zone one has relatively few observations and so has been combined with climate zone 2.

In general, the FEDS model does a satisfactory job in tracking the increase air conditioning loads associated with warmer climates. The middle top figure shows all three lines rising. The SAE procedure adjusts for the

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(a) The multivariate nature of the SAE regression approach makes it difficult to rigidly interpret this result in light of the estimated vintage coefficients in Figure 5.3. The coefficient on the post-1980 buildings is positive, but the coefficient on the 1946-1979 dummy variable (V1*NHVf) is slightly negative. Clearly, other variables are also contributing to the positive adjustment that is shown for all of the post-war buildings in Figure 5.4.

(b) The EIA climate zones are defined as follows:

Zone #	HDD	CDD
1	< 7,000	< 2,000
2	5,500-7,000	< 2,000
3	4,000-5,500	< 2,000
4	2,000-4,000	< 2,000
5	2,000-4,000	< 2,000

somewhat constant overprediction of cooling from the FEDS model. As expected, there is little dependency of the non-HVAC loads with respect to climate zone.

Figure 5.7 shows the effect of weekly operating hours upon the predicted and actual electricity EUIs. The most striking element of the figure is the jump in non-HVAC intensity for the small offices reporting continuous operations (168 hours/week). The SAE model employs hours as a continuous variable and, thus, the adjusted (dashed line) intensity rises monotonically as operating hours increase. Note that there are only 12 buildings in the sample that reported a continuous schedule and met the criteria for inclusion in the SAE estimation.

Employee density is the classifying variable in Figure 5.8. In this case, both HVAC and non-HVAC loads appears to be strongly dependent upon this variable. Although the FEDS model shows some dependence upon density, it is weak compared to the relationship exhibited by the actual intensities. The close tracking of the adjusted EUIs to the actual EUIs is consistent with the high statistical significance of the employee density variables (EMP) in SAE regressions (Figure 5.3).

Retail/Service

Figure 5.9 displays the SAE regression results for the retail/service building type. As before, the top panel shows the adjustment coefficients for the HVAC portion of the total intensity. The lower panels shows the coefficients on the same variables as applied to the NHVAC end uses.

In contrast to the results for small offices, the vintage coefficients are very strong for both SAE regressions for the retail/service building type. The positive coefficient on the post-1980 buildings is particularly significant; this result is consistent with the FEDS underprediction as shown in Figure 5.2.

Similar to the results for small offices, the adjustment coefficient for building size is not statistically significant. This result suggests that the FEDS model is performing an adequate job of accounting for the greater envelope thermal losses (or gains) in smaller buildings. For non-HVAC use, the coefficient is negative, a turnaround from the result obtained for small

HVAC

Valid cases:	822	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	731061.739	Degrees of freedom:	815
R-squared:	0.369	Rbar-squared:	0.364
Residual SS:	461606.303	Std error of est:	23.799
F(7,815):	67.963	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.641651	0.050813	12.627577	0.000	0.382477	0.516339
V1*HVf	0.220975	0.132608	1.666382	0.096	0.063083	-0.034129
V2*HVf	0.873499	0.155872	5.603942	0.000	0.210835	0.228690
SQFT*HVf	0.000113	0.000412	0.273098	0.785	0.007843	-0.209140
CDD*HVf	0.000327	0.000040	8.079922	0.000	0.221481	0.361101
HRS*HVf	0.006385	0.001150	5.554611	0.000	0.158021	0.316967
EMP*HVf	0.270039	0.040351	6.692288	0.000	0.187355	0.364280

NHVAC

Valid cases:	822	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	4117986.090	Degrees of freedom:	814
R-squared:	0.341	Rbar-squared:	0.336
Residual SS:	2712684.786	Std error of est:	57.728
F(8,814):	52.711	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.561651	0.090108	17.330914	0.000	0.463837	0.553476
V1*NHVf	0.758534	0.217646	3.485178	0.000	0.108274	0.062594
V2*NHVf	1.566301	0.285709	5.482148	0.000	0.172768	0.103263
SQFT*NHVf	-0.001088	0.000296	-3.674593	0.000	-0.091527	-0.007305
CDD*NHVf	0.000228	0.000102	2.221833	0.027	0.056644	0.007598
HRS*NHVf	0.017705	0.002084	8.494870	0.000	0.225340	0.420213
EMP*NHVf	0.960403	0.070459	13.630705	0.000	0.335866	0.407253
ElcMan	15.557902	10.064778	1.545777	0.123	0.038242	0.105209

FIGURE 5.9. Retail/Service: SAE Regression Results for Electricity

offices. Here the adjustment may be picking up a compositional effect of relatively smaller service-related buildings (e.g., laundromats, dry cleaners) that have high internal loads.

The FEDS models again appears to be understating the cross-sectional variation with regard to cooling degree days. The positive coefficient on CDD for the HVAC adjustment regression exceeds eight.

Finally, the hours and employment density coefficients are positive and statistically significant. The employment density adjustment is strong for both the HVAC and non-HVAC SAE regressions.

As might be expected, the magnitude of the coefficient for the manufacturing dummy variable is somewhat greater in the retail/service than for small offices. Although the statistical significance is greater for the retail/service sector, it is still not a powerful explanatory variable relative to the factors discussed above.

Figures 5.10 through 5.14 display the EUIs across each of the variables used in the SAE regression results. As for the small office building type, the plots clearly indicate the role of weekly hours and employment density in adjusting the FEDS model results.

Goodness of Fit Measures

The figures displaying the results of the annual SAE models (Figures 5.4-5.8 and 5.10-5.14) suggest that this type of specification clearly improves the cross-sectional explanation of building-level EUIs. As a simple measure of goodness of fit, we ran simple linear regressions on the total EUI, using the FEDS and SAE EUI estimates as the independent variable (Equations 5.16 and 5.17).

$$EUI = a_0 + a_1 \, EUIFEDS + e \tag{5.20}$$

$$EUI = b_0 + b_1 \, EUISAE + e \tag{5.21}$$

The results of these regressions are shown in Table 5.3. With the exception of lodging, the improvement in the percentage of explained variation is large for every building type. One of the largest improvements is for restaurants, where the R^2 increases from 0.038 to 0.502. The pattern of coefficients is also consistent with this result. In the SAE regression, the slope coefficient (b_1) is much closer to unity and the intercept is smaller.

Although we can take some satisfaction that the SAE models improve the measures of explained cross-sectional variation, the ultimate objective is to provide an engineering-based explanation of total EUI by building type that directly incorporate the general building characteristics and demographic variables discussed above. Although some modifications were made to the FEDS

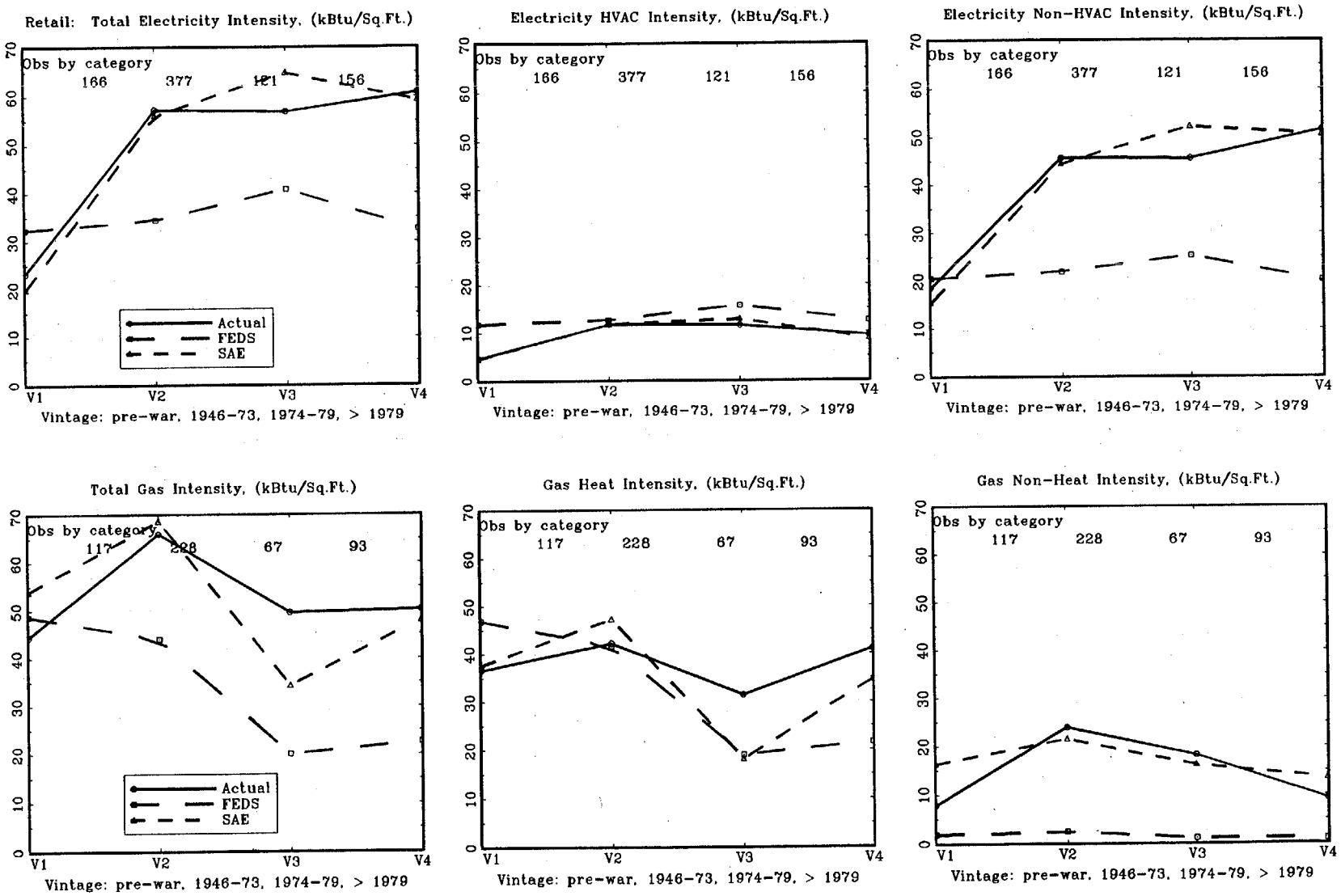

FIGURE 5.10. Retail/Service: Actual, FEDS, and SAE Intensities By Vintage

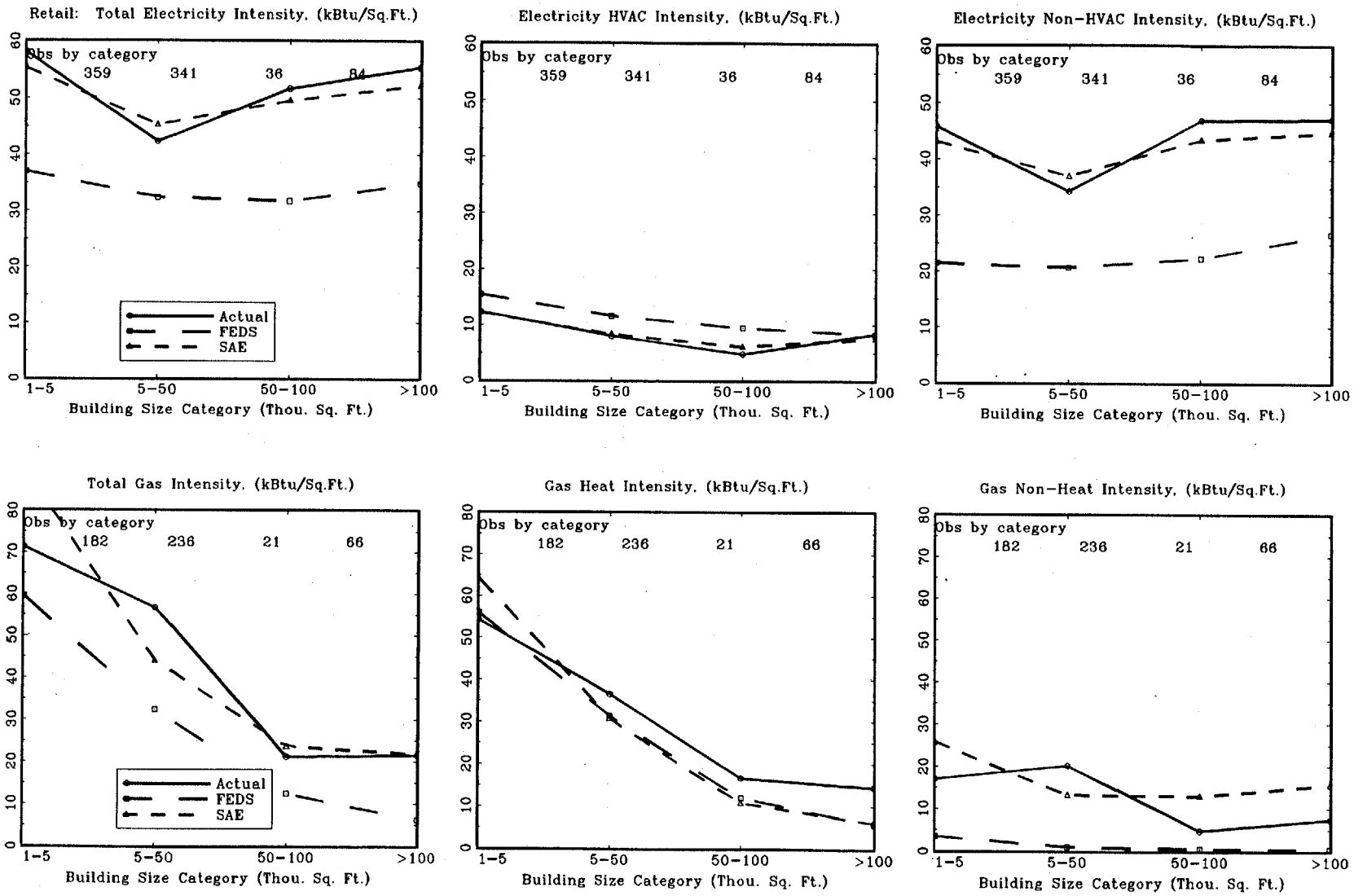

FIGURE 5.11. Retail/Service: Actual, FEDS, and SAE Intensities By Building Size Category

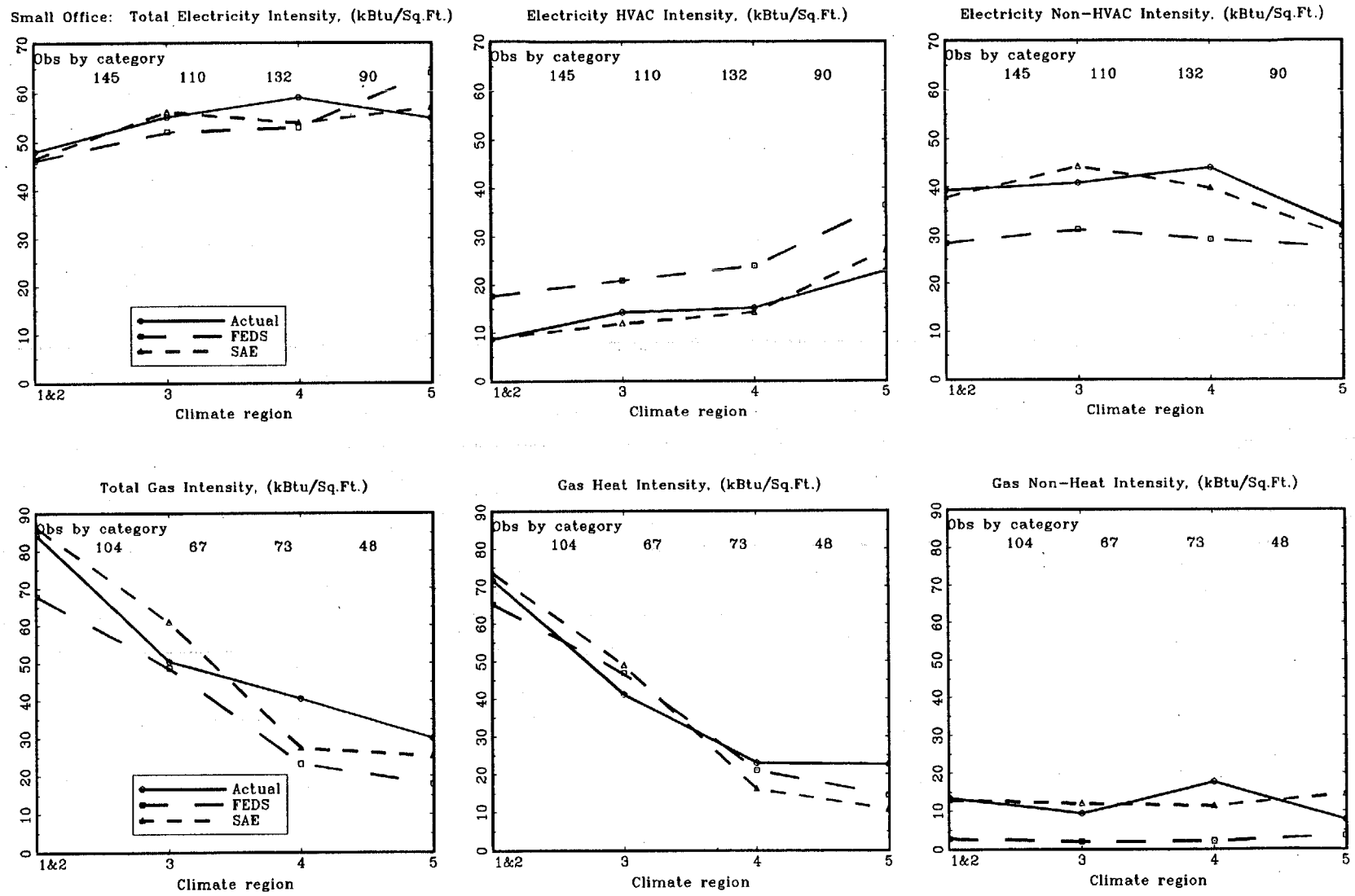

FIGURE 5.12. Retail/Service: Actual, FEDS, and SAE Intensities By Climate Region

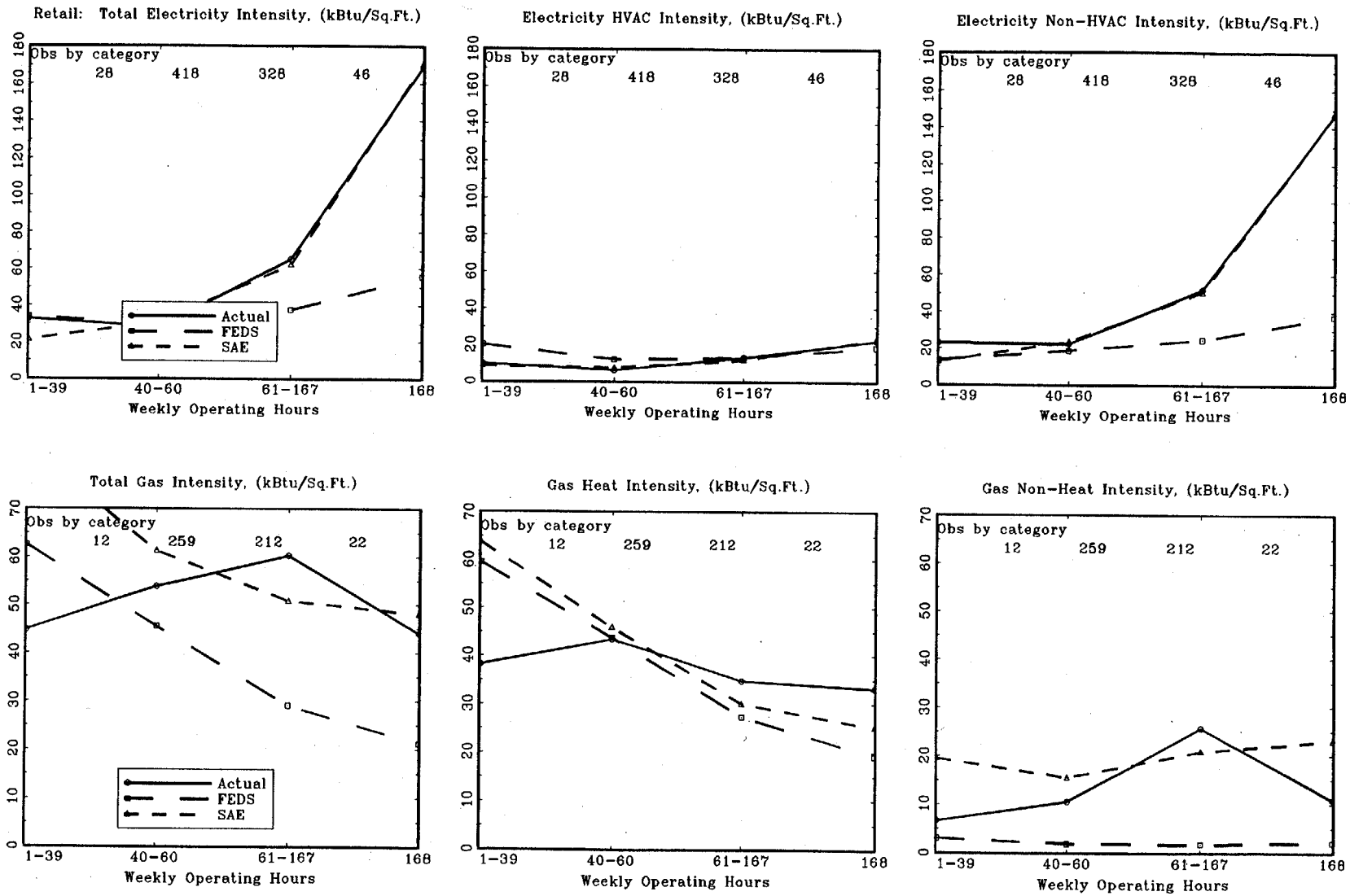

FIGURE 5.13. Retail/Service: Actual, FEDS, and SAE Intensities By Weekly Hours Category

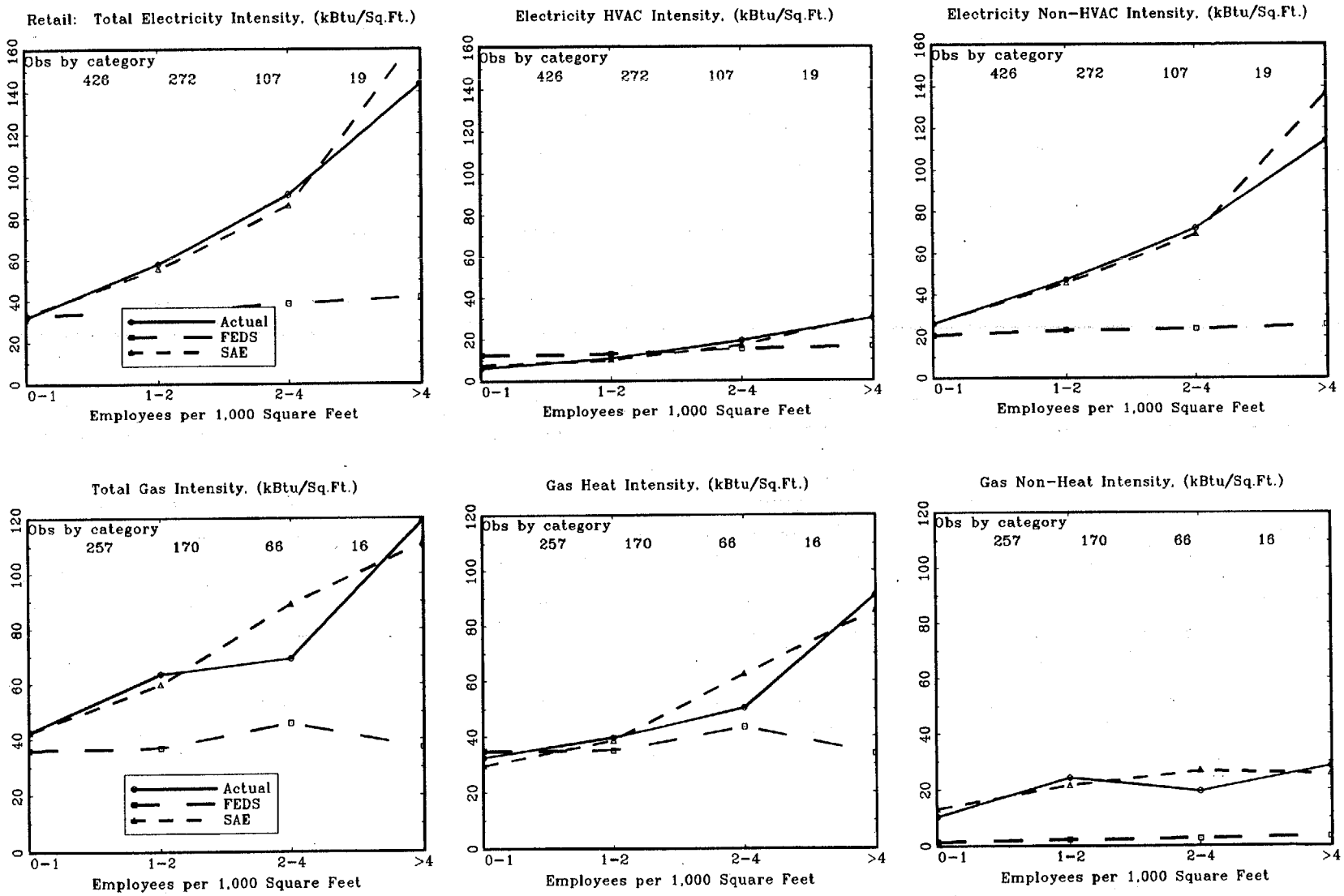

FIGURE 5.14. Retail/Service: Actual, FEDS, and SAE Intensities By Employment Density Category

TABLE 5.3. Overall Goodness of Fit Measures by Building Type, Electricity EUIs

	FEDS				SAE		
Building Type	N	α_0	α_1	R^2	β_0	β_1	R^2
Assembly	445	9.04	0.603	0.084	4.72	0.813	0.216
Education	314	13.93	0.656	0.055	8.085	0.768	0.208
Food Sales	65	-42.21	1.178	0.110	-0.49	1.003	0.344
Restaurant	129	43.53	0.627	0.038	8.67	0.926	0.502
Hospital	70	214.72	-0.110	0.000	18.23	0.837	0.182
Lodging	114	31.49	0.283	0.072	29.49	0.360	0.085
Large Office	281	52.15	0.437	0.020	35.70	0.530	0.056
Small Office	476	36.25	0.318	0.017	18.65	0.648	0.135
Retail	822	-6.10	1.715	0.133	3.69	0.918	0.394
Warehouse	436	16.72	0.620	0.019	6.93	0.713	0.169
Other	245	20.83	0.496	0.039	10.08	0.718	0.147

model and input assumptions on the basis of preliminary simulation results, this process clearly can be extended and improved. To reach this goal will require a longer-range effort than was afforded to this particular study.

The full set of estimation results for the SAE regressions is shown in Appendix D.

5.3 EUI ESTIMATION FOR FULL SAMPLE

The results of the estimation in Equations (5.18) and (5.19) provide the basis for the final SAE estimates of EUIs for electricity EUIs. The *predicted* values of the HVAC and non-HVAC intensities, $\hat{EUI}^{HVAC}$ and $\hat{EUI}^{NHVAC}$, become control totals for the HVAC and NHVAC components from the FEDS model. Thus, for the HVAC components, the shares of the predicted FEDS end uses for heating, cooling, and ventilation are used. Denoting these shares as gsh, gcl, and gvt, the SAE estimates of the HVAC end-uses are defined as

$$EUISAE^{SH} = gsh \cdot E\hat{U}I^{HVAC} \tag{5.22}$$

$$EUISAE^{SC} = gsc \cdot E\hat{U}I^{HVAC} \tag{5.23}$$

$$EUISAE^{VN} = gvt \cdot E\hat{U}I^{HVAC} \tag{5.24}$$

The same procedure is used for the NHVAC components: lighting, refrigeration, cooking, hot water, and miscellaneous electrical use.

The overall study generated three full sets of EUIs by building type. The first set was produced from FEDS without adjustment. The second set are the SAE estimates just described. The third set was termed the calibrated EUIs. The calibration was performed relative to the total building consumption as either measured from the billing data or imputed by EIA.

5.3.1 Scaling Procedure

The basic procedure to generate the calibrated EUIs was to proportionally scale the SAE estimates by end use to ensure that the total EUI matched the EIA estimate. Application of the same scaling factor for every end use follows the method used by EIA in its estimation of end-use consumption for the residential sector. Although it cannot be recommended as the best procedure for estimating the end use breakdown for individual CBECS sample buildings, it reflects the aggregate end-use proportions estimated via the SAE approach.

In the course of developing the final calibrated EUIs, instances where a strict proportional scaling procedure generated implausible results were encountered. This occurred when there was only a small number of available observations for particular building types in a specific census division. The presence of buildings with very large consumption tended to push all of the EUIs for some building types much higher than the national average.

To help overcome this problem, we limited the magnitude of the scaling in certain high intensity cases. Proportional scaling of each of the EUIs was performed only up to a given prescribed maximum (total) intensity. The residual consumption (again, expressed as an intensity) was then assigned to the miscellaneous end use category. The values for the maximum intensities used

were identical to those employed for the screening of the SAE regression observations. As discussed in section 5.2, these intensities were calculated as a multiple of 3.0 times the maximum FEDS-generated intensity for any single CBECS sample building within a building category (Table 5.3).

5.3.2 Use of HVAC and NHVAC Decomposition Estimates

The monthly bill decomposition work generates a reasonable estimate of the HVAC and NHVAC consumption for a large share of the overall CBECS sample [i.e., the $E\tilde{U}I^{HVAC}$ and $E\tilde{U}I^{NHVAC}$ from Equations (5.6) and (5.7)]. For these buildings in the final calibrated dataset, these values were used as control totals for the two categories of end uses. Within these categories the end use breakdown was generated from the engineering model as described above. For the remaining buildings, the *predicted* (SAE) values from Equations (5.18) and (5.19) were used as control totals for the separate categories of HVAC and non-HVAC end uses.

6.0 EUI ESTIMATION: NATURAL GAS AND OTHER FUELS

This chapter examines natural gas EUI of six specific end uses for 11 commercial building types identified in the CBECS. We have two primary objectives to accomplish. The first objective is to estimate natural gas use for each building type across the various end uses: heating, cooling, water heating, cooking, manufacturing, and electricity generation. The second objective is to develop a model that predicts consumption for natural gas and other fuels. Overall, the natural gas model is used to predict annual fuel consumption by end use for every building reported in the CBECS.

6.1 METHODOLOGY

Our preferred approach to estimate natural gas EUI was to combine statistical methods and engineering simulations into single SAE model for each of the 11 building types. Such a model conditions the estimates of natural gas consumption to end-use specific characteristics and to the individual commercial building characteristics. Instead, SAE models were constructed and estimated individually for heating, water heating, and cooking by building type. In addition, limited observations of cooling, manufacturing, and cogeneration in certain building types (one of many statistical problems) restricted the estimation procedures feasible for these end uses. Consequently, pure statistical methods were used to capture manufacturing and cogeneration EUIs. And, cooling estimates were based solely on the simulated engineering estimates. As a result, to calculate the annual consumption for a specific building type, the consumption of each end use is summed to estimate the total consumption.

Section 6.1.1 discusses how we separated the weather-sensitive portion from the non-weather-sensitive portion of the annual energy load. Section 6.1.2 describes our empirical estimation procedure. Section 6.2 discusses the results for two familiar building types, small office and retail. Section 6.3 describes how the other fuels were estimated using the framework of the natural gas model.

6.1.1 Weather-Sensitive vs. Non-Weather-Sensitive Loads

The objective of this subsection is to describe how the weather-sensitive load was separated from the non-weather-sensitive load for each building. The seasonal characteristics of gas use displayed in the monthly billing data provided us with a basis by which to distinguish between the base load (non-weather-sensitive) and non-base load (weather-sensitive) gas consumption. It was assumed that in the summer months (June, July, and August) that gas consumption was non-heating. Thus, we calculated an average consumption that incorporated the EUIs of these three months to form an annual base load estimate. The annual base load (BL) estimate was the minimum two month average of the annualized actual energy use during the summer months. The non-base load (NBL) was then calculated by subtracting the base load from the actual gas consumption.[a] As a result the actual EUI is decomposed into the two components, BL and NBL (Equation 6.1).

$$EUI = E\tilde{U}I^{BL} + E\tilde{U}I^{NBL} \tag{6.1}$$

where EUI = the "actual" total natural gas consumption

EUI^{NBL} = our estimate of total "actual" weather-sensitive (NBL) natural gas consumption

EUI^{BL} = our estimate of "actual" non-weather-sensitive (BL) consumption.

Note that EUI^{NBL} is only a proxy for the proportion of the actual natural gas consumption used for heating , and EUI^{BL} is a proxy for the amount of actual consumption used for water heating, cooking, and cooling, miscellaneous. Natural gas consumption used for cooling was included in the EUI^{BL}

(a) In all, 54 cases were observed in which the annualized base load estimate was greater than the annualized non-summer consumption. These observations were not included in the SAE regression models described in the next section.

estimate as only 14 buildings within the entire regression sample set reported using gas for cooling and had a consumption profile that indicated cooling use.[a]

The result of this process generates estimates of the base load and the non-base load for each building in the regression data set. These values are then utilized as actual data in the empirical models discussed in section 6.1.2.

6.1.2 Empirical Models

Following the billing data decomposition, the next step is develop a set of models that can explain the cross sectional variation in the base load and non-base load values within a building type. As indicated previously, both pure statistical and SAE approaches were used to complete our modeling effort. The pure statistical and/or conditional demand models are described in this section, along with a discussion of the SAE models.

Heating, water heating, and cooking coefficients were each estimated individually in conditional demand models. In addition, because numerous sample buildings included gas end use for both water heating and cooking, it was necessary to estimate water heating and cooking observations in a separate model. These models are represented in Equations 6.2 and 6.3.

$$EUI^{NBL} = \alpha_{sh} D_{sh} + e_{sh} \tag{6.2}$$

$$EUI^{BL} = \alpha_i D_i + e_i \qquad i = wh, ck, whck \tag{6.3}$$

(a) Of the 14 buildings with observed cooling use of natural gas, 10 had higher monthly intensities during the summer than the annual average and thus, were excluded from the regression analysis. The other four buildings with cooling were included in the regression analysis, but are judged to have negligible effect on the estimated SAE models (see Section 6.1.2). See page 6.7 for additional discussion related to gas cooling.

where D_{sh}, D_{wh}, D_{ck}, and D_{whck} are categorical variables (1 indicating the presence of an end use, 0 otherwise) for heating, water heating, cooking, and the combination of water heating and cooking, respectively; and e_i is the estimated error terms. The models in Equation 6.3 were estimated with only water heating, only cooking, and only the combination of water heating and cooking present (over any of the seven end uses) in the regression subsets. Then, observations that included heating were added to the individual subsets of data and the models were re-estimated. Thus, we have two sets of regression coefficients for each model within each of the 11 building types; one set dependent only on the buildings that reported consumption of that end use and no other consumption; and another set dependent on each end use alone or each end use with only heating. The former set is presented in a table containing the conditional demand coefficients in Appendix D.

Again, the initial approach examined was to jointly estimate water heating consumption, cooking consumption, and water heating and cooking consumption, rather than individually estimate the levels of consumption as indicated in Equation 6.3. Ideally, in the initial model the sum of the water heating coefficient and the cooking coefficient should be equal to the water heating and cooking coefficient (i.e., one may expect an additive relationship between water heating consumption and cooking consumption, and that of water heating and cooking consumption). The results of the initial model estimates did not confirm this relationship and were inconclusive overall. Consequently, each end use was estimated individually as specified in Equation 6.3.

The models and coefficients generated in Equations 6.2 and 6.3 provide preliminary information regarding the EUIs. To further refine these estimates, SAE models were defined for heating, water heating, cooking, and water heating and cooking. The SAE models for water heating, cooking, and water heating and cooking (Equation 6.4) are defined by simply replacing the categorical variables with FEDS engineering estimates.

$$EUI^{BL} = \beta_i EUIFEDS_i + e_i \qquad i = wh, ck, whck \tag{6.4}$$

where the $EUIFEDS_i$ are the simulated engineering estimates for water heating, cooking, and the combination of water heating and cooking, respectively, and e_i is the estimated error terms. For all building types, these estimates included each end use alone or each end use combined with observations of heating. In addition, for the building type Retail we also estimated each end use alone (e.g., water heating and no other end use observed). For this building type we had sufficient observations to estimate the end uses with and without heating present. Furthermore, we observed that there were significant differences between the two sets of water heating coefficients. After examining a wide variety of model specifications for heating, we settled on a final heating model. This model is significantly different than Equation 6.2. A detailed description of the heating model is provided below.

Similar to the SAE model for HVAC electricity consumption, the adjustment of the engineering-based heating EUI was hypothesized to depend upon the vintage of the building, square footage, heating degree days, weekly operating hours, and employment density. This model is shown in Equation 6.5.

$$\tilde{EUI}^{NBL} = (\beta_0 + \beta_1 D_{v1} + \beta_2 D_{v2} + \beta_3 SQFT + \beta_4 HDD + \beta_5 HRS + \beta_6 EMP) EUIFEDS^{sh} + e \qquad (6.5)$$

where $EUIFEDS^{sh}$ = the engineering heating values

D_{v1} = 1 if the year built was between 1946 and 1979, 0 otherwise

D_{v2} = 1 if the year built was between 1980 and 1989, 0 otherwise

SQFT = building size (thousands of ft^2)

HDD = heating degree days

HRS = weekly operating hours

EMP = employment density (employees/100 ft^2).

A variety of specifications were tested with variations of these major variables. For the SQFT, HDD, HRS, and EMP variables, specifications using

either dummy (categorical) variables or continuous variables were tested. As for electricity, the continuous form of the variables generated higher percentages of explained variance.

As previously indicated, many buildings in the CBECS reported natural gas end use for both water heating and cooking. To report separate water heating and cooking EUIs it was necessary to establish a reliable methodology that prorates water heating and cooking shares. To accomplish this task, a conditional demand model (Equation 6.6) was constructed.

$$E\tilde{U}I^{BL} = \alpha_{sh}D_{sh} + \alpha_{sc}D_{sc} + \alpha_{wh}D_{wh} + \alpha_{ck}D_{ck} + \alpha_{whck}D_{whck} + \alpha_{ot}D_{ot} + e \qquad (6.6)$$

where D_{sh}, D_{sc} D_{wh}, D_{ck}, D_{whck}, D_{ot} are categorical variables for heating, cooling, water heating, cooking, water heating and cooking, and other, respectively. D_{ot} consists of manufacturing or co-generation. The water heating share is then approximated by $\alpha_{wh}/(\alpha_{wh}+\alpha_{ck})$, while the cooking share is approximated by $\alpha_{ck}/(\alpha_{wh}+\alpha_{ck})$[(a)]. Each of these shares are multiplied by the coefficient β_{whck}, estimated in the SAE version of Equation 6.4, to create the coefficients that share out water heating from cooking use:

$$\beta^{wh}_{whck} = \frac{\alpha_{wh}}{(\alpha_{wh} + \alpha_{ck})} \times \beta_{whck} \qquad (6.7)$$

$$\beta^{ck}_{whck} = \frac{\alpha_{ck}}{(\alpha_{wh} + \alpha_{ck})} \times \beta_{whck} \qquad (6.8)$$

Manufacturing and co-generation were estimated by conditional demand models. This is because engineering estimates were not simulated for these two end uses. The model is presented in Equation 6.9.

(a) Because of limited observations the coefficients for this share ratio were taken from Equation 6.4 for Hospitals and Lodging.

$$EUI = \alpha_{NBL} EUIFEDS^{NBL} + \alpha_{BL} EUIFEDS^{BL} + \beta_{mn} D^{mn} + \beta_{cg} D^{cg} + e \qquad (6.9)$$

where $EUIFEDS^{NBL}$ is heating and cooling, and $EUIFEDS^{BL}$ is water heating and cooking. Given this model specification, the resulting coefficients are conditional average values of manufacturing and co-generation that account for both base load and non-base load EUIs.

Cooling was estimated directly from the FEDS simulated estimates. We decided to use FEDS estimates because only 14 sample observations suggested any measurable cooling with natural gas, based on inspection of the monthly profiles of gas usage.[a]

Energy consumption for an individual building was allocated to the miscellaneous category in several cases. One common case occurred when no end use was reported, but positive natural gas consumption was recorded. Another case transpired when the only end use that was reported was heating, and there was non-zero base (i.e., summer) consumption. In Equation (6.6), the base load EUIs are regressed on a set of end uses that include heating. The heating categorical variable, D_{sh}, identifies buildings with heating as the *only* end use requiring natural gas. Because the base load is defined on the basis of summer consumption, it is expected that the conditional coefficient α_{sh} should be insignificant and near zero for the base load EUI. However, this was not necessarily the case and, consequently, this average value was allocated to miscellaneous (ms). In addition to miscellaneous allocations, Table 6.1 provides a summary of the EUI allocations to specific end uses.

A natural gas model is estimated for each of the 11 building types. Within each building type, the annual consumption of natural gas is the sum of the predicted values from each of the end use models (i.e., the coefficients for heating (sh), water heating (wh), cooking (ck), and water heating and

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(a) 102 buildings with suitable natural gas billing data reported gas used for cooling. However, except for the 14 buildings cited above, these cases revealed either no increase in natural gas use during the summer months or gas usage was negligible during these months.

TABLE 6.1. Summary of EUI Allocations to Specific End Uses

	End Uses Effected				Allocation Process
	sh	wh	ck	ms	
Gas consumption reported but no end uses reported.				x	Consumption assigned to miscellaneous.
Base load heating use estimated in Equation 6.6.	x			x	Consumption assigned to miscellaneous.
Adjust the wh only coefficients for seasonality (from base load to non-base load)	x	x			The wh only coefficient was adjusted for seasonality such that $EUI^{NBL}/EUI^{BL}<1.5$. The residual EUIs were then assigned to heating.
Adjust the ck only coefficients for seasonality (from base load to non-base load)	x		x		The ck only coefficient was adjusted for seasonality such that $EUI^{NBL}/EUI^{BL}<1.5$. The residual EUIs were then assigned to heating.
Decompose whck use into wh consumption and ck consumption.		x	x		The whck coefficient is prorated to share out wh from ck as shown in (6.7) and (6.8).

cooking (whck) are multiplied by the FEDS engineering values and/or continuous structural variables to forecast EUIs). In the case of cooling (sc), the FEDS value were not statistically adjusted so the adjustment coefficient is identically one. For manufacturing (mf) and co-generation (cg), the coefficients are conditional average values which, when multiplied by the appropriate categorical variables, provide the desired estimate. The final model for each of the building types is shown in Equation 6.10.

$$\hat{EUI} = \hat{EUI}^{sh} + EUIFEDS^{sc} + \hat{EUI}^{wh} + \hat{EUI}^{ck} + \hat{EUI}^{mf} + \hat{EUI}^{cg} + \hat{EUI}^{ms} \quad (6.10)$$

where $\hat{EUI}^{sh}$, $\hat{EUI}^{wh}$, $\hat{EUI}^{ck}$, $\hat{EUI}^{mf}$, $\hat{EUI}^{cg}$, and $\hat{EUI}^{ms}$ are predicted EUIs for heating, water heating, cooking, manufacturing, and miscellaneous, respectively.

Following the procedure used for the electricity estimation, any negative value which occurred as a result of a negative regression coefficient was set to one. Assignment of the positive value makes it possible to scale the end uses to the total consumption in the CBECS public use files. A final calibrated set of EUI estimates were gleaned from the SAE estimates in the

same manner as described in Chapter 5. A complete list of the coefficients generated from the conditional demand and SAE models for each building type are presented in Appendix D.

6.2 EMPIRICAL RESULTS

The results presented in the following figures contain the coefficients resulting from the conditional demand models and the SAE models for Small Office and Retail building types.

6.2.1 Small Office

The top table in Figure 6.1 contains the coefficients of the conditional demand model for buildings classified in the Small Office category. These values are conditional (i.e., the average EUIs of each end use given consumption of that end use is observed in a building). The conditional EUI (kBtu/ft^2) for heating (sh) is 47.17, water heating (wh) is 11.73, cooking (ck) is 8.05, and water heating and cooking (whck) is 18.36. For Small Office note that the coefficients among water heating consumption and cooking consumption and that of water heating and cooking consumption are nearly additive. This additive relationship was an exception, not a rule, as it did not hold consistently for all the other building types. Manufacturing (mf) is assigned the value 1.00, as the regression coefficient was negative. The conditional average co-generation (cg) load was estimated at 39.35 and miscellaneous (ms) load at 8.40.

The second table in Figure 6.1 shows the coefficients that adjust the FEDS engineering estimates to the observed responses. Two sets of coefficients are reported for each end use. The two end uses separated base load coefficients from non-base load coefficients. Water heating shows a larger coefficient for non-base load consumption relative to base load consumption. There is no change in cooking.

The bottom table presents a detailed description of the coefficients and test statistics of the SAE heating model. In particular, notice that the only significant coefficient is HRS (weekly operating hours) with a t-statistic of 2.77. Referring to Figures 5.4-5.8, the plots presenting total

Small Office	sh	wh	ck	whck	mf	cg	ms
Conditional Demand Coefficients	47.17	11.73	8.05	18.36	1.00	39.35	8.40

Small Office	sc	wh	ck	whck	
Adjustment Coefficients				wh	ck
Baseload	1.00	1.74	1.74	1.42	2.31
Non-Baseload	1.00	1.92	1.74	1.42	2.31

Valid cases:	293	Dependent variable:	EUI^{NBL}
Missing cases:	0	Deletion method:	None
Total SS:	875082.801	Degrees of freedom:	286
R-squared:	0.135	Rbar-squared:	0.117
Residual SS:	757073.672	Std error of est:	51.450
F(7,286):	6.369	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.154883	0.256940	0.602796	0.547	0.132741	0.674119
V1*SHf	-0.099061	0.112960	-0.876958	0.381	-0.064254	0.509373
V2*SHf	-0.165530	0.181919	-0.909913	0.364	-0.048885	0.206668
SQFT*SHf	0.000009	0.000006	1.407646	0.160	0.073224	0.432345
HDD*SHf	0.000051	0.000033	1.543854	0.124	0.288402	0.669252
HRS*SHf	0.005704	0.002057	2.772820	0.006	0.283858	0.660317
EMP*SHf	0.012550	0.027093	0.463219	0.644	0.037024	0.558383

FIGURE 6.1. Small Office: SAE Regression Results for Natural Gas

gas intensity and gas heat intensity exhibit relatively little sensitivity to any of the building characteristics except for weekly operating hours. The cross-sectional graph of gas heat to weekly operating hours shows that the SAE model adjusts the FEDS heating values significantly for buildings operating on a continuous schedule (168 hrs/week).

In addition to observing the predicted values of the SAE model, we examined the seasonal variations of the FEDS values to the actual consumption. In Figure 5.1 the EUIs (kBtu/Sq. Ft.) are plotted against the monthly values of the actual natural gas and FEDS. We see that the FEDS model captures the seasonal changes in the actual EUIs of natural gas. Of particular interest is the sharp increase in EUIs exhibited in February apparent across the building

types. This a direct result of mild January weather and a severe cold spell in February. To put this phenomena into perspective the 56-year average heating degree days (HDD) for January and February are 943 and 734 respectively. The HDD for January and February in 1989 are 808 and 857 respectively.

6.2.2 Retail

The top table in Figure 6.2 contains the coefficients of the conditional demand model for buildings classified in the Retail category. The conditional EUI (kBtu/ft^2) for heating (sh) is 44.53. The EUIs for water heating, cooking, and water heating and cooking (including heating end use) are 28.10, 7.83, and 21.09, respectively. Likewise, the EUIs for water heating, cooking, and water heating and cooking alone are 51.55, 6.92, and 13.21, respectively. We speculate that the differences between the two water heating EUIs are due to the presence of laundromats in the sample. These laundromats used natural gas primarily for water heating with no discernable heating use present. For Retail, note that the coefficients among water heating consumption and cooking consumption and that of water heating and cooking consumption are not additive. As previously indicated, this can be attributed to, among other factors, the heterogeneity of buildings within a building type. The conditional average EUI for manufacturing (mf) is 35.51, co-generation (cg) is 45.63 and miscellaneous (ms) is 9.97.

The second table in Figure 6.2 shows the coefficients that adjust the FEDS engineering estimates to the observed responses. Three sets of coefficients are reported for each end use. These end uses separate base load coefficients from non-base load coefficients. In addition, for the base load adjustment, coefficients with and without heating present are reported. Note that without heating present, the water heating coefficient is larger.

The bottom table presents a detailed description of the coefficients and test statistics of the SAE heating model. In contrast to Small Office, notice that the weekly operating hours (HRS) coefficient is insignificant and the three coefficients for D_{v1}, D_{v2}, and EMP (vintage, and employment density variables) are significant. Referring to Figures 5.10-5.14 in Chapter 5, the plots presenting gas heat intensity show that the SAE predicted values are very sensitive to the vintage and employment density variables.

Retail/Service	sh	wh	ck	whck	mf	cg	ms
Conditional Demand Coefficients							
Baseload (w/Heating)	44.53	28.10	7.83	21.09	35.51	45.63	9.97
Baseload (w/o Heating)	NA	51.55	6.92	13.21	35.51	45.63	9.97

Retail/Service	sc	wh	ck	whck	
				wh	ck
Baseload (w/Heating)	1.00	4.15	20.57	13.07	5.08
Baseload (wo/Heating)	1.00	9.71	19.52	14.61	5.68
Non-Baseload	1.00	8.05	10.45	4.17	1.62

Valid cases:	508	Dependent variable:	EUI^{NBL}
Missing cases:	0	Deletion method:	None
Total SS:	1459387.762	Degrees of freedom:	501
R-squared:	0.243	Rbar-squared:	0.234
Residual SS:	1105163.083	Std error of est:	46.967
F(7,501):	22.940	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.218748	0.216493	1.010417	0.313	0.173743	0.656822
V1*SHf	0.212348	0.086758	2.447599	0.015	0.129710	0.533204
V2*SHf	0.404799	0.157539	2.569507	0.010	0.090709	0.279104
SQFT*SHf	0.000000	0.000000	0.296563	0.767	0.009388	0.120057
HDD*SHf	0.000007	0.000028	0.270558	0.787	0.040597	0.651140
HRS*SHf	0.000661	0.001640	0.403292	0.687	0.034329	0.627732
EMP*SHf	0.228649	0.028192	8.110453	0.000	0.383855	0.667624

FIGURE 6.2. Retail/Service: SAE Regression Results for Natural Gas

A comparison of the monthly EUIs (kBtu/Sq. Ft.) of FEDS and the actual consumption is presented in Figure 5.2. As in the Small Office category, the FEDS model appears to capture the seasonal changes natural gas consumption. In fact, for all the building categories except Hospitals the FEDS model appears to have sufficiently captured the seasonal patterns of natural gas consumption.

6.3 OTHER FUELS

We used the framework established from estimating natural gas consumption to predict energy consumption of other energy sources. The other fuel types examined were fuel oil, district steam, and district hot water. District steam and district hot water were combined into a single energy source and will be referred to as steam. To predict fuel oil and steam consumption for each building in the 11 building types the response coefficients of the natural gas models were used as proxies. This model is displayed in Equation 6.11.

$$\hat{EUI} = \hat{EUI}^{sh} + EUIFEDS^{sc} + \hat{EUI}^{wk} + \hat{EUI}^{ck} + \hat{EUI}^{mf} + \hat{EUI}^{cg} + \hat{EUI}^{ms} \tag{6.11}$$

where $\hat{EUI}^{sh}$, $\hat{EUI}^{wh}$, $\hat{EUI}^{ck}$, $\hat{EUI}^{mf}$, $\hat{EUI}^{cg}$, and $\hat{EUI}^{ms}$ are predicted fuel oil or steam EUIs for heating, water heating, cooking, manufacturing, co-generation and miscellaneous, respectively.

It is recognized that using natural gas coefficients for proxies in the estimation process for fuel oil and steam EUIs was not the ideal method by which one should predict energy consumption. However, time constraints and data difficulties made this approach the most feasible.

7.0 SUMMARY OF EUI ESTIMATES

This chapter provides a summary of the EUI estimates from the methodology discussed in the previous two chapters. We first focus on the overall end use disaggregation for all buildings. Subsequently, we provide the national average EUI estimates by building type.

7.1 RESULTS FOR ALL BUILDINGS

Table 7.1 shows the standard presentational format for the EUI estimation results. The table applies to an aggregation of the full 1989 CBECS sample. The top of the table shows the calculated floorspace from the database used in the estimation methodology, 63.19 billion square feet.[a]

The top panel of Table 7.1 shows the fuel shares for the various end uses in terms of floorspace. Thus, for example, buildings containing about 24 percent of commercial floorspace use electricity for space heating. The fuel shares in this table differ to some degree from those derived from the CBECS publications. For this table, only the floorspace that was modeled by FEDS as having a positive consumption is entered as part of the fuel share calculation. In the CBECS, buildings report whether a fuel is used for heating or cooling; according to the FEDS model some of these buildings may not have actually consumed the fuel for this purpose during 1989.

With the caveat that only nonzero consumption is considered, the fuel shares for heating, cooling, gas cooking, and water heating are based on the responses from the CBECS. For the other end uses, the EUIs were based on average values that were used in or modeled by the FEDS model for all but a few CBECS sample buildings.

(a) This total differs slightly from the published value of 63.184 billion (EIA 1992). For a small number of buildings, we used the floorspace from EIA's public use file, rather than the original data used by EIA. EIA masks the floorspace values to a small degree to reduce the likelihood that any single building can be identified by a user of the public use file.

TABLE 7.1. Standard Presentational Format for EUI Estimation Results

All Buildings

Total Floorspace (Billion ft^2): 63.19

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.24	0.65	0.97	0.97	0.97	0.97	0.34	0.97
Gas	0.57	0.00	0.00	0.00	0.00	0.23	0.40	0.41
Oil	0.14	0.00	0.00	0.00	0.00	0.00	0.03	0.04
D.H.	0.09	0.01	0.00	0.00	0.00	0.01	0.07	0.00

Conditional Intensities for All Buildings

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	6.24	6.86	4.53	16.71	3.04	0.91	1.13	13.46
Gas	36.38	33.19	0.00	0.00	0.00	15.44	12.40	8.84
Oil	35.44	1.40	0.00	0.00	0.00	31.80	12.17	8.55
D.H.	65.45	19.59	0.00	0.00	0.00	12.92	29.85	96.26

Average Intensities for All Buildings

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	1.52	4.46	4.40	16.18	2.96	0.88	0.38	13.10	43.88
Gas	20.63	0.07	0.00	0.00	0.00	3.54	4.92	3.62	32.78
Oil	4.84	0.00	0.00	0.00	0.00	0.07	0.41	0.32	5.65
D.H.	5.89	0.27	0.00	0.00	0.00	0.19	2.06	0.85	9.26

The end uses for which we did not use the specific CBECS information on end use are refrigeration and electric cooking. As discussed in Appendix A, these end uses (together with miscellaneous) are modeled basically as average intensities that apply to all buildings within a given building type.[a]

Accordingly, since these end uses are assumed to be present in nearly every building, the fuel shares (saturations) are near 1.0. This treatment causes no difficulty if the EUIs are used as building averages, although it will lead to some error for specific buildings.

(a) Lighting and ventilation are also assumed to be present in nearly all buildings and depend upon a number of CBECS variables to determine their intensity.

Conditional EUIs are shown in the second panel of the table. These intensities are the average values for all buildings that contain the specific end use. When examining these intensities by fuel, one should keep in mind that the EUIs cannot be expected to represent amount of fuel to deliver an equivalent level of service to a given building. For example, the conditional EUI for electricity is significantly lower than gas or oil. Electrically heated buildings are generally in warmer areas of the country. Note, too, that electricity is expressed on a site basis (3412 Btu/kWh), and that electric heat pumps would deliver more heat per Btu of input energy than gas or oil systems.

Some of the disparity between the electric and gas intensities for cooking and hot water may stem from their different estimation methodologies as described in the previous two chapters. However, the data strongly suggest that the intensities are greater for gas as compared to electricity. For buildings with high demands for these end uses (e.g., restaurants, laundromats, hospitals) gas is the less expensive fuel to utilize. Nevertheless, as we discuss in the next chapter, additional work may be required to better rationalize the differences in EUIs found in this study.

The third panel in Table 7.1 shows the average intensities for each fuel and end use combination. The averaging is done across the entire stock of floorspace. Thus, the values in this panel are simply the conditional EUIs multiplied by the fuel shares in the top panel.

7.1.1 End Use Shares

The values of the average intensities can be used to determine the fractions of end use consumption by fuel. For electricity, lighting is largest end use, comprising about 37% (16.184/43.881) of total consumption. Miscellaneous uses (office equipment, task lighting, etc.) make up the next largest portion of electricity consumption at around 30%. HVAC consumption is estimated to be less than a quarter of total electric consumption.

As would be expected, heating is principal use for natural gas and oil. However, over one-third of natural gas use is estimated to be for non-heating end uses.

Figures 7.1 and 7.2 display the end use shares of commercial consumption after aggregation across fuels. Figure 7.1 shows the distribution as expressed in site or delivered energy. On this basis, heating is the largest use of energy in commercial buildings, accounting for nearly 36% of total consumption. Miscellaneous and lighting are the next largest categories, with a combined consumption slightly more than that for heating.

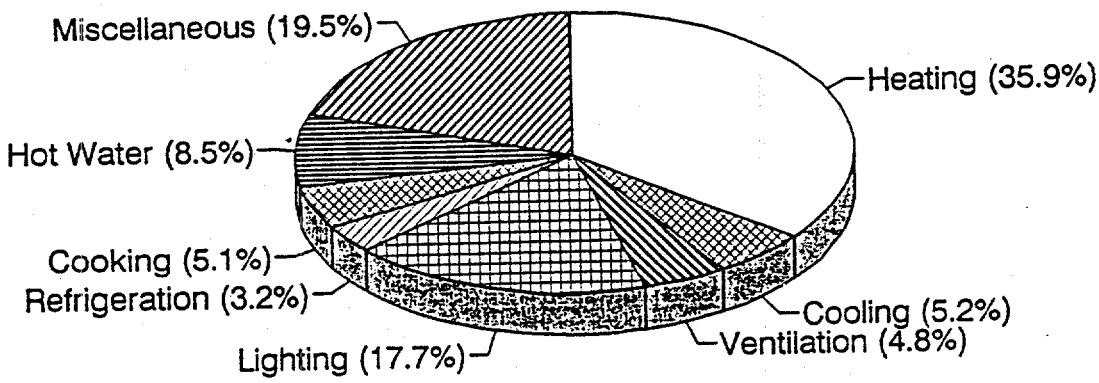

FIGURE 7.1. Estimated Distribution of End-Use Energy Consumption in U.S. Commercial Buildings, Delivered Energy Basis

Figure 7.2 shows the composition of energy as expressed in primary energy. On this basis, electricity is converted to Btu by a factor of 11,500 Btu/kWh to account for the generation and transmission losses associated with electricity. On a primary energy basis, lighting becomes the largest single end use with 28% of total energy consumption. Miscellaneous equipment use follows close behind with a 25% share. HVAC consumption is about a third of primary energy use, with heating comprising a little more than half of this consumption.

7.1.2 Comparison with Current EIA Estimates

A natural question is how the new EUI estimates and resulting end use distribution compare with the values currently being used by EIA. At a broad level, Table 7.2 compares the current composition of end uses by fuel with those published by EIA in the Annual Energy Outlook 1993 (EIA 1993).

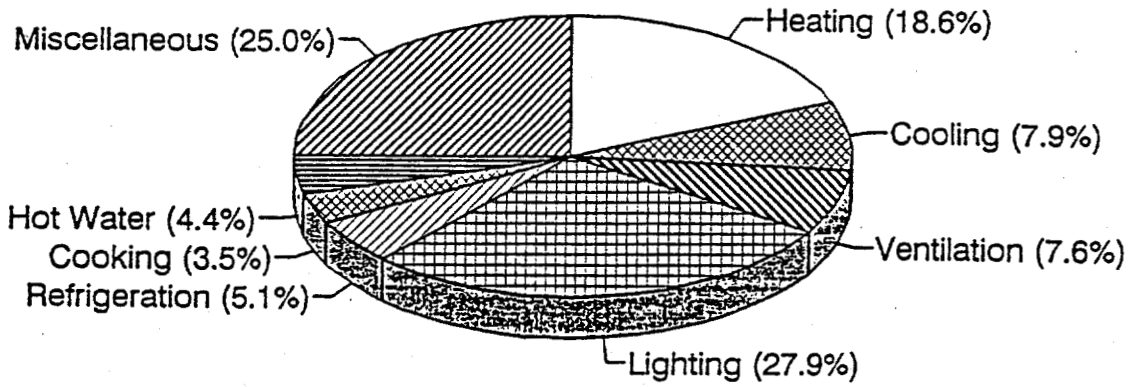

FIGURE 7.2. Estimated Distribution of End-Use Energy Consumption in U.S. Commercial Buildings, Primary Energy Basis

TABLE 7.2. Comparison of EUIs: Current Study Versus 1993 Annual Energy Outlook

	Current Study (for 1989)		AEO 1993 (for 1990)	
	QBtu	(%)	QBtu	(%)
Electricity				
Space Heating	0.10	3.5%	0.52	18.1%
Cooling	0.28	10.2%	0.73	25.4%
Lighting	1.02	36.9%	1.14	39.7%
Other	1.37	49.5%	0.48	16.7%
Total	2.77	100.0%	2.87	100.0%
Natural Gas				
Space Heating	1.30	62.9%	1.80	65.2%
Cooling	0.00	0.2%	0.21	7.6%
Other	0.76	36.9%	0.75	27.2%
Total	2.07	100.0%	2.76	100.0%
Oil (distillate)				
Space Heating	0.31	85.8%	0.45	91.8%
Other	0.05	14.2%	0.04	8.2%
Total	0.36	17.2%	0.49	17.8%

In looking at the table, emphasis should be placed upon the percentage distribution of end uses rather than the absolute consumption figures. The Annual Energy Outlook (AEO) estimates for 1990 are shown in column three of Table 7.2. Besides the one year difference in comparison years, the AEO estimates for total consumption by fuel are calibrated to a different source

(State Energy Data Report) and would not match CBECS in any event. The discrepancy is particularly high for gas and oil. Some reasons for the differences between these sources are discussed in Appendix C of the consumption and expenditures report for the 1989 CBECS (EIA 1992).

The table clearly shows some significant differences in the end use composition of electricity currently modeled by EIA and the estimates from the current study. Space conditioning consumption is substantially lower than the AEO figure, based on the estimation procedure applied to the 1989 CBECS. Heating is about one-fifth of the AEO estimate, while cooling is less than half. Lighting consumption is about the same. The current study finds significantly more electricity consumption for miscellaneous (non-HVAC and lighting) uses within commercial buildings.

On a strictly percentage basis, the composition of natural gas usage is roughly comparable, with the exception of space cooling. This may be somewhat misleading since the AEO estimate for "other" incorporates gas usage classified under commercial sales but not consumed within commercial buildings. On the other hand, the estimate shown in column one of Table 7.2 does not include gas used by central physical plants providing district heating or cooling to commercial complexes.

As discussed in chapter 6, gas consumption for absorption cooling appears to insignificant in the sample of buildings covered by the 1989 CBECS. The current AEO estimate, suggesting nearly 8% of gas consumption is used for cooling must be based on other information outside the CBECS or is substantially overestimated.

Other than fuel differences in total consumption, the end use composition in for distillate fuel oil is comparable between the two sources. Space heating is the dominant use of oil within commercial buildings.

7.2 RESULTS BY BUILDING TYPE

Table 7.3 shows the calibrated EUIs for each building type. The format is identical to that discussed for Table 7.1.

TABLE 7.3. Calibrated EUIs for Building Types 1 through 11

Building Type 1: Assembly

Total Floorspace (Billion ft^2): 6.91

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.25	0.66	0.99	0.99	0.99	0.99	0.27	0.99
Gas	0.59	0.00	0.00	0.00	0.00	0.19	0.45	0.40
Oil	0.14	0.00	0.00	0.00	0.00	0.00	0.05	0.00
D.H.	0.12	0.00	0.00	0.00	0.00	0.00	0.09	0.00

Conditional Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	11.19	5.46	3.69	9.20	1.64	0.11	0.77	5.92
Gas	32.93	12.93	0.00	0.00	0.00	13.85	4.24	2.81
Oil	30.79	0.00	0.00	0.00	0.00	0.00	5.79	3.92
D.H.	54.23	23.07	0.00	0.00	0.00	0.56	6.57	107.50

Average Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	2.77	3.62	3.66	9.11	1.62	0.11	0.21	5.86	26.95
Gas	19.46	0.00	0.00	0.00	0.00	2.63	1.92	1.13	25.15
Oil	4.21	0.00	0.00	0.00	0.00	0.00	0.30	0.03	4.55
D.H.	6.31	0.05	0.00	0.00	0.00	0.00	0.60	0.17	7.13

TABLE 7.3. (contd)

Building Type 2: Education

Total Floorspace (Billion ft^2): 8.08

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.13	0.51	1.00	1.00	1.00	1.00	0.19	1.00
Gas	0.69	0.00	0.00	0.00	0.00	0.42	0.61	0.48
Oil	0.20	0.00	0.00	0.00	0.00	0.00	0.07	0.01
D.H.	0.12	0.06	0.00	0.00	0.00	0.00	0.12	0.00

Conditional Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	9.35	4.24	3.00	14.15	1.28	0.09	1.10	4.71
Gas	42.30	0.00	0.00	0.00	0.00	15.40	3.02	5.17
Oil	41.87	0.00	0.00	0.00	0.00	0.45	3.95	5.96
D.H.	62.63	17.94	0.00	0.00	0.00	2.28	21.68	108.19

Average Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	1.25	2.17	2.99	14.14	1.28	0.09	0.20	4.71	26.83
Gas	29.30	0.00	0.00	0.00	0.00	6.41	1.85	2.49	40.04
Oil	8.42	0.00	0.00	0.00	0.00	0.00	0.29	0.07	8.78
D.H.	7.68	1.04	0.00	0.00	0.00	0.00	2.65	0.11	11.50

Building Type 3: Food Sales

Total Floorspace (Billion ft^2): 0.79

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.14	0.85	1.00	1.00	1.00	1.00	0.60	1.00
Gas	0.60	0.00	0.00	0.00	0.00	0.26	0.33	0.32
Oil	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D.H.	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00

TABLE 7.3. (contd)

Conditional Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	2.27	23.58	10.12	23.42	56.46	11.39	2.84	9.59
Gas	28.48	0.00	0.00	0.00	0.00	59.96	3.28	2.11
Oil	30.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D.H.	94.70	0.00	0.00	0.00	0.00	0.00	0.86	0.00

Average Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	0.31	19.95	10.12	23.42	56.46	11.39	1.69	9.59	132.92
Gas	17.01	0.00	0.00	0.00	0.00	15.68	1.07	0.68	34.44
Oil	6.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.99
D.H.	1.12	0.00	0.00	0.00	0.00	0.00	0.01	0.00	1.13

Building Type 4: Food Service

Total Floorspace (Billion ft^2): 1.17

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.25	0.87	1.00	1.00	1.00	1.00	0.29	1.00
Gas	0.65	0.00	0.00	0.00	0.00	0.64	0.52	0.54
Oil	0.14	0.00	0.00	0.00	0.00	0.00	0.03	0.00
D.H.	0.03	0.00	0.00	0.00	0.00	0.01	0.03	0.00

Conditional Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	4.94	18.87	11.01	23.05	13.67	14.87	8.03	13.99
Gas	44.69	64.60	0.00	0.00	0.00	79.68	41.78	13.15
Oil	60.62	0.00	0.00	0.00	0.00	21.42	68.03	0.00
D.H.	31.52	0.00	0.00	0.00	0.00	16.88	8.09	0.00

Average Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	1.24	16.36	11.01	23.05	13.67	14.87	2.36	13.99	96.54
Gas	29.27	0.16	0.00	0.00	0.00	51.28	21.89	7.07	109.67
Oil	8.40	0.00	0.00	0.00	0.00	0.17	2.19	0.00	10.77
D.H.	1.00	0.00	0.00	0.00	0.00	0.19	0.26	0.00	1.45

TABLE 7.3. (contd)

Building Type 5: Hospital

Total Floorspace (Billion ft^2): 1.62

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.13	0.89	1.00	1.00	1.00	1.00	0.10	1.00
Gas	0.72	0.00	0.00	0.00	0.00	0.51	0.50	0.54
Oil	0.56	0.02	0.00	0.00	0.00	0.05	0.05	0.38
D.H.	0.16	0.01	0.00	0.00	0.00	0.25	0.29	0.06

Conditional Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	8.82	20.20	11.39	38.48	3.27	2.89	14.12	8.06
Gas	33.87	37.17	0.00	0.00	0.00	34.82	86.34	38.04
Oil	6.96	0.41	0.00	0.00	0.00	53.47	33.88	4.86
D.H.	82.52	12.76	0.00	0.00	0.00	16.97	94.35	156.58

Average Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	1.11	17.88	11.39	38.48	3.27	2.89	1.39	8.06	84.47
Gas	24.25	0.23	0.00	0.00	0.00	17.88	43.00	20.45	105.80
Oil	3.89	0.00	0.00	0.00	0.00	2.63	1.66	1.82	10.01
D.H.	12.93	0.13	0.00	0.00	0.00	4.28	27.40	8.93	53.67

Building Type 6: Lodging

Total Floorspace (Billion ft^2): 3.48

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.38	0.71	1.00	1.00	1.00	1.00	0.16	1.00
Gas	0.58	0.00	0.00	0.00	0.00	0.45	0.58	0.40
Oil	0.07	0.00	0.00	0.00	0.00	0.00	0.05	0.03
D.H.	0.17	0.02	0.00	0.00	0.00	0.07	0.15	0.03

TABLE 7.3. (contd)

Conditional Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	8.66	6.88	5.83	13.49	4.53	3.96	9.62	2.20
Gas	40.17	0.00	0.00	0.00	0.00	14.49	36.84	7.02
Oil	25.58	0.00	0.00	0.00	0.00	0.00	22.21	2.84
D.H.	81.14	4.30	0.00	0.00	0.00	5.21	60.70	73.47

Average Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	3.29	4.86	5.83	13.49	4.53	3.96	1.52	2.20	39.67
Gas	23.23	0.00	0.00	0.00	0.00	6.49	21.32	2.83	53.87
Oil	1.69	0.00	0.00	0.00	0.00	0.00	1.09	0.09	2.87
D.H.	13.83	0.08	0.00	0.00	0.00	0.39	9.21	2.42	25.93

Building Type 7: Large Office

Total Floorspace (Billion ft^2): 6.96

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.31	0.86	1.00	1.00	1.00	1.00	0.42	1.00
Gas	0.54	0.00	0.00	0.00	0.00	0.32	0.34	0.44
Oil	0.15	0.00	0.00	0.00	0.00	0.00	0.03	0.13
D.H.	0.29	0.04	0.00	0.00	0.00	0.02	0.17	0.02

Conditional Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	5.69	6.96	16.43	21.71	2.52	0.21	0.37	19.48
Gas	13.22	47.78	0.00	0.00	0.00	1.96	7.43	4.75
Oil	13.17	0.64	0.00	0.00	0.00	0.00	7.65	1.98
D.H.	42.77	21.45	0.00	0.00	0.00	5.29	12.76	74.47

Average Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	1.74	6.00	16.39	21.66	2.51	0.21	0.16	19.43	68.09
Gas	7.20	0.23	0.00	0.00	0.00	0.62	2.55	2.08	12.68
Oil	2.01	0.00	0.00	0.00	0.00	0.00	0.20	0.25	2.47
D.H.	12.20	0.87	0.00	0.00	0.00	0.12	2.21	1.52	16.92

TABLE 7.3. (contd)

Building Type 8: Small Office

Total Floorspace (Billion ft^2): 5.28

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.46	0.90	1.00	1.00	1.00	1.00	0.52	1.00
Gas	0.55	0.00	0.00	0.00	0.00	0.02	0.32	0.38
Oil	0.06	0.00	0.00	0.00	0.00	0.00	0.02	0.01
D.H.	0.04	0.00	0.00	0.00	0.00	0.00	0.02	0.00

Conditional Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	6.50	8.77	4.11	24.13	3.43	0.28	0.97	18.18
Gas	45.96	37.53	0.00	0.00	0.00	1.97	7.10	9.40
Oil	73.49	3.94	0.00	0.00	0.00	0.00	9.95	12.98
D.H.	221.66	23.24	0.00	0.00	0.00	6.34	14.24	222.03

Average Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	2.99	7.92	4.11	24.13	3.43	0.28	0.51	18.18	61.55
Gas	25.19	0.21	0.00	0.00	0.00	0.05	2.27	3.54	31.25
Oil	4.71	0.00	0.00	0.00	0.00	0.00	0.19	0.19	5.09
D.H.	9.23	0.05	0.00	0.00	0.00	0.01	0.33	0.64	10.27

Building Type 9: Retail/Service

Total Floorspace (Billion ft^2): 12.37

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.29	0.76	1.00	1.00	1.00	1.00	0.47	1.00
Gas	0.60	0.00	0.00	0.00	0.00	0.23	0.35	0.43
Oil	0.11	0.00	0.00	0.00	0.00	0.00	0.02	0.02
D.H.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 7.3. (contd)

Conditional Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	3.51	5.38	2.11	16.25	1.00	0.35	0.68	19.34
Gas	38.70	21.62	0.00	0.00	0.00	7.17	13.36	9.38
Oil	50.17	4.35	0.00	0.00	0.00	0.00	16.65	15.77
D.H.	23.03	135.96	0.00	0.00	0.00	0.00	3.62	63.23

Average Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	1.00	4.11	2.11	16.23	1.00	0.35	0.32	19.32	44.44
Gas	23.21	0.10	0.00	0.00	0.00	1.66	4.67	4.02	33.67
Oil	5.49	0.00	0.00	0.00	0.00	0.00	0.36	0.24	6.10
D.H.	0.18	0.08	0.00	0.00	0.00	0.00	0.03	0.23	0.52

Building Type 10: Warehouse

Total Floorspace (Billion ft^2): 9.26

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.16	0.34	0.94	0.95	0.95	0.95	0.34	0.95
Gas	0.49	0.00	0.00	0.00	0.00	0.01	0.31	0.36
Oil	0.13	0.00	0.00	0.00	0.00	0.00	0.01	0.02
D.H.	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Conditional Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	5.27	1.89	0.40	11.67	2.74	0.15	0.34	10.98
Gas	36.02	0.00	0.00	0.00	0.00	0.36	1.49	11.81
Oil	37.33	0.00	0.00	0.00	0.00	0.00	11.88	50.74
D.H.	131.44	0.00	0.00	0.00	0.00	0.00	0.87	127.19

Average Energy Intensities (kBtu/ft^2)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	0.82	0.64	0.37	11.06	2.61	0.14	0.12	10.46	26.23
Gas	17.62	0.00	0.00	0.00	0.00	0.00	0.47	4.19	22.28
Oil	4.76	0.00	0.00	0.00	0.00	0.00	0.13	0.87	5.76
D.H.	2.68	0.00	0.00	0.00	0.00	0.00	0.00	0.88	3.57

TABLE 7.3. (contd)

Building Type 11: Misc. Buildings

Total Floorspace (Billion ft^2): 7.29

Fuel Shares by End Use
(fraction of floorspace with usage > 0)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	0.15	0.48	0.84	0.81	0.84	0.84	0.26	0.84
Gas	0.43	0.00	0.00	0.00	0.00	0.16	0.28	0.33
Oil	0.09	0.00	0.00	0.00	0.00	0.00	0.03	0.03
D.H.	0.07	0.00	0.00	0.00	0.00	0.00	0.03	0.00

Conditional Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc
Elec	3.32	5.22	0.61	18.68	1.91	0.15	0.38	22.45
Gas	42.19	0.00	0.00	0.00	0.00	4.36	10.28	11.26
Oil	47.07	0.00	0.00	0.00	0.00	0.00	19.02	12.07
D.H.	68.39	67.93	0.00	0.00	0.00	80.58	48.77	59.00

Average Energy Intensities ($kBtu/ft^2$)

	Heat	Cool	Vent	Light	Refr	Cook	H Wtr	Misc	Total
Elec	0.49	2.51	0.51	15.07	1.61	0.13	0.10	18.87	39.28
Gas	18.04	0.00	0.00	0.00	0.00	0.69	2.87	3.76	25.36
Oil	4.19	0.00	0.00	0.00	0.00	0.00	0.57	0.36	5.12
D.H.	4.79	0.08	0.00	0.00	0.00	0.32	1.42	0.54	7.15

TABLE 7.4. Cooling EUIs by Building Type

Bldg. Type	ft^2 (bil.)	%	Conditional Cooling EUI (kBtu/Sq.Ft)	Average Cooling EUI (kBtu/Sq.Ft)	Elec Consmp. (TBtu)	%
Assembly	6.91	10.9%	5.46	3.62	25.0	8.9%
Education	8.08	12.8%	4.24	2.17	17.5	6.2%
Food Sales	0.79	1.2%	23.58	19.95	15.8	5.6%
Food Serv.	1.17	1.9%	18.87	16.36	19.1	6.8%
Hospital	1.62	2.6%	20.2	17.88	29.0	10.3%
Lodging	3.48	5.5%	6.88	4.86	16.9	6.0%
Lrg. Office	6.96	11.0%	6.96	6.00	41.8	14.8%
Sml. Office	5.28	8.4%	8.77	7.92	41.8	14.8%
Retail/Serv	12.37	19.6%	5.38	4.11	50.8	18.0%
Warehouse	9.26	14.6%	1.89	0.64	5.9	2.1%
Misc. Bldgs	7.29	11.5%	5.22	2.51	18.3	6.5%
All Buildings	63.21	100.0%	6.86	4.46	281.9	100.0%

Although any number of comparative examinations of EUIs at the building type level can be performed, we focus here on (electric) cooling and natural gas heating. Table 7.4 summarizes the intensities for electric cooling by building type. The conditional intensities are shown in column three and the average intensities are shown in column four.

Table 7.4 clearly indicates that as far as cooling is concerned, there are substantial differences in intensity across building types. Space cooling intensities are very high in three building types: food sales, food service, and hospitals. These three building types account for just over 5% of the total floorspace in the commercial sector, but contribute to over 20% of the cooling consumption.

The picture is somewhat different for gas heating. With the exception of large offices, Table 7.5 shows that natural gas heating intensities are generally within 20 to 40% from one another.

The right most column in Table 7.5 shows the total intensities for buildings using gas as published by EIA (Table 38, EIA 1992).[(a)] Although

TABLE 7.5. Natural Gas Intensities by Building Type

Bldg. Type	ft^2 (bil.)	%	Conditional Gas Heat EUI (kBtu/Sq.Ft)	Total Gas EUI (kBtu/Sq.Ft)[a]
Assembly	6.91	10.9%	32.9	40.4
Education	8.08	12.8%	42.3	48.7
Food Sales	0.79	1.2%	28.5	49.9
Food Serv.	1.17	1.9%	44.7	156.6
Hospital	1.62	2.6%	33.9	116.5
Lodging	3.48	5.5%	40.2	73.9
Lrg. Office	6.96	11.0%	13.2	33.0
Sml. Office	5.28	8.4%	46.0	33.0
Retail/Serv	12.37	19.6%	38.7	47.5
Warehouse	9.26	14.6%	36.0	40.3
Misc. Bldgs	7.29	11.5%	42.2	NA
All Buildings	63.21	100.0%	36.4	50.5

(a) Published figures from EIA (1992).

(a) Converted to kBtu from thousand ft^3.

the building types are not exactly comparable throughout,[a] the values clearly indicate that the dramatic differences in intensities in the EIA report reflect more the differences in non-heating consumption as opposed to heating. This is particular true for the food service and hospital building types.

(a) Hospitals in the EIA aggregation are actually part of a somewhat larger health care classification that include out-patient facilities. Thus, the value shown in the last column is for health care. In this study out-patient facilities are included with offices. For offices, we show the average EIA value for all offices, not distinguishing by large and small. Finally, there is no single published value corresponding to the miscellaneous building category.

8.0 EXTENSIONS OF THE CURRENT ANALYSIS

This final chapter explores a number of extensions and refinements to the work described in this report. This work falls under two general areas. The first is to further develop the SAE procedures to improve the accuracy of the EUI estimates, especially for NHVAC and non-heating end uses. The second is to undertake additional modifications of the input assumptions in FEDS to develop an improved linkage between the model outputs and the billing data from the CBECS. Beyond the goal of contributing to improved EUI estimates, this second activity would yield other substantial benefits to energy modeling and planning activities within DOE.

8.1 IMPROVEMENT OF SAE PROCEDURES

The work undertaken during this study represents one of the most ambitious attempts to utilize an building engineering model, along with monthly billing data, as a means of estimating end use consumption for a national sample of commercial buildings. The billing decomposition procedure provides a good method of separating HVAC consumption from non-HVAC usage. The SAE models developed in this study help explain about twice the cross-sectional variance of annual EUIs as compared to results from the engineering model alone. The regression fits of the model are sufficiently accurate to be used by EIA to estimate consumption in buildings where no billing data can be obtained.

Nevertheless, the study still leaves a number of unresolved issues. Many of these were not anticipated at the outset of the project; others we felt we could address with more rigorous data screening. In some cases, attempts were made to develop more satisfactory solutions, but the work could not be completed due to schedule and budget considerations.

Some of the issues can be addressed with more recent versions of FEDS that became available after the estimates in this study were required. Others may involve a more stringent data validation approach by EIA to ensure that seasonal patterns of energy consumption are consistent with the reported end uses.

8.1.1 More Detailed SAE Models for Electricity

Perhaps the area with the highest priority for additional analysis concerns more detailed SAE models for electricity. Such models would be used to refine the individual end-use estimates within the broad HVAC and non-HVAC control estimates.

On the HVAC side, additional work may be beneficial to refine the estimates of electric space heating. As discussed in chapter 5, separate adjustments were made to the FEDS electric heating in two building types. The monthly intensity plots in Appendix D suggest that the heating estimates are reasonable on a building type basis. Nevertheless, a more rigorous SAE procedure would likely improve the heating estimates for subsets within building types.

The FEDS model made some changes in the way it treats ventilation demand in the core zones of buildings. Some additional simulations would also be helpful for buildings that are likely to use constant (as opposed to cycling) ventilation control. This work may allow us to construct an SAE model that can employ the billing data to provide separate adjustment coefficients for ventilation and cooling.

Of higher priority is additional analysis directed to the non-HVAC end uses, particularly electric water heating. The current estimates reflect an asymmetry of approaches applied to electric versus natural gas water heating. The gas water heating EUI estimates have a more direct linkage to the CBECS data than do the electricity estimates.

Some regression work was undertaken to estimate separate adjustment coefficients for non-HVAC end uses, but the results were unsatisfactory. The adjustment coefficients for lighting were significantly less than one, and the coefficients for hot water and miscellaneous equipment were often much greater than one. Some preliminary effort to account for an errors-in-variables problem (see section 4.3) was undertaken (using an instrumental variables approach), but insufficient time was available to thoroughly test this procedure.

Any future efforts to provide a better empirical framework for the NHVAC end-use estimates will also benefit from recent improvements in the FEDS domestic hot water model. These improvements, in part, changed the basis on which total water heating demands are calculated for some building types.

8.1.2 Non-Heating EUIs for Natural Gas

Additional study is warranted to refine the estimates for the non-heating EUIs for natural gas. The bill decomposition procedure used in this effort provides a reasonable basis for separating heating consumption from these other uses, but the procedure to split the non-heating uses can be further improved.

One area that can contribute to more accurate EUIs is to develop a means of rationalizing the monthly patterns of gas consumption with the reported end uses. As discussed in chapter 6, the 1989 CBECS contains a considerable number of buildings that report no heating use of gas, but whose gas bills display a seasonal pattern that strongly suggests that gas is used for heating. On the other hand, there are also a large number of buildings that report only heating consumption, but show consumption throughout the summer.

Two other end uses appear to manifest a similar problem. As mentioned in chapter 6, only about a dozen buildings (out of more than 100) which reported gas use for cooling showed any significant increase in summer gas consumption. The data concerning cogeneration also seems to be inconsistent with respect to actual consumption. For many buildings it appears that a positive response to the cogeneration question from the CBECS indicates the presence of a backup system or a system that is used only occasionally.

These problems can best be addressed by EIA as part of its data consistency checking procedures. It will probably involve additional follow-up questions to survey respondents to rationalize the observed billing consumption patterns.

From the statistical modeling aspect, additional observations would be helpful. As we discussed in chapter 6, we believe the heterogeneity of building activities makes the assumption of additivity of end-use consumption (a key element of the conditional demand estimation approach) tenuous. This

places a premium on observations for which a single end use is present. The reliability of these estimates could be enhanced with pooling the results of the 1989 with those from the 1986 and 1992 surveys.

8.1.3 Improved Treatment of High Intensity Cases

An unresolved problem in analyzing the CBECS is how to treat high intensity cases. As in previous surveys, the 1989 CBECS contains a number of buildings that displays total EUIs that are 20, to as many as 50, times the mean intensity within a single building type.

A requirement of this study and many other analyses of the CBECS requires calibration with the published fuel consumption total. Since these buildings are used in the calculation of total consumption and building average intensities, they cannot be simply omitted from the entire analysis.

In this study, an allocation of end uses was made for these cases, but as discussed in section 5.3, they were omitted from the SAE regression models. The criteria for what represents a high intensity case was based upon a judgmentally determined multiple of the FEDS model output.[a]

Unfortunately, in allocating fuel usage by end use, we are still hampered by lack of any empirical basis for the causes for the extremely high intensities. In the present study, we assumed that any consumption over the FEDS-defined limit fell into the miscellaneous equipment category.

Future work should be devoted in exploring available audit data sets and perhaps in reinterviewing CBECS sample buildings to attempt to generalize some basic reasons for this phenomenon.

From an energy policy perspective, it is important to know whether a majority of these cases stem from, say, a poorly controlled HVAC system or are due to energy-intensive equipment not normally found in a typical building.

(a) For the cross-section time series SAE work, we developed a two-stage estimation procedure that used a purely statistical basis for identifying high intensity outliers. Observations with errors whose studentized t-values were greater than three were omitted from a second stage regression.

Clearly, more information about these buildings could prove highly useful in deciding whether to target the population of such buildings for cost-effective conservation improvements.

8.2 IMPROVE THE ACCURACY OF THE FEDS ENGINEERING MODEL

A second set of activities relates to modifying the input assumptions in the FEDS model to better represent the consumption behavior of the buildings in the CBECS. In essence, this activity would reduce the importance of the SAE procedures as used in this study. A building simulation model that was calibrated to the CBECS would be a powerful tool to examine market potentials in the commercial sector for new building-related technologies.

Even using the monthly bill decomposition study used in this study, the current approach still relies heavily upon a SAE methodology. Predicted energy consumption for end uses or combinations of end uses are used as independent variables a regression model to explain total consumption. The coefficient on each end use provides a measure of how much the predicted estimate should be adjusted to best fit the observed total consumption data.

One alternative approach varies strategic parameters within the building simulation model to best fit the observed total energy consumption *for each building* in the sample. This approach is called the building-specific engineering calibration. This requires modifying the building simulation code so that it can be embedded within an optimization framework suitable for data fitting. The end-use interactions within the building simulation models will lead to specifications requiring nonlinear optimization methods.

The calibrated engineering model approach has the advantage that it can address envelope-HVAC interactions in a more consistent manner. For example, adjusting the thermal conductivity of the shell (UA) as part of the calibration procedure will affect both heating and cooling loads. This feature is lost in the SAE models, where the estimated coefficients on the predicted heating and cooling consumption incorporate a variety of errors, including envelope characteristics, system type, and plant efficiency. The current

study, in fact, leaves a nagging question in this regard. The SAE procedure reduced the FEDS-generated estimates of cooling consumption while increasing the loads for miscellaneous uses.

In addition to improving the technical foundation for EUI estimates, the results of such work would lay the groundwork for a powerful analytical tool to examine conservation potential in the commercial sector. For example, more efficient lighting technologies could be examined across the entire commercial building population as represented by the CBECS. The tool could be used to develop more accurate estimates of aggregate heating and cooling loads that will cover the full range of building types within the commercial sector. The latter application would rectify some the existing problems in using only office and retail prototypes to represent the commercial building stock. This tool could also employ the range of retrofit options that have already been incorporated as part of the overall FEDS model.[a]

Although a building-specific calibration procedure has strong appeal from a building modeling perspective, the current study also indicates the potential for additional calibration work that could be applied on a cross-section basis. Time and resource constraints in the current study limited the number of modifications that could be made to FEDS model. Future work would extend the engineering simulation work to yield FEDS results that better correlate with the billing data on a cross-section basis. In essence, this work would build upon the present approach without going to a building-specific optimization framework.

Several areas appear promising for this type of analysis. One would involve more experimentation with various ventilation strategies that may better represent the stock of a particular building type (ventilation is a characteristic for which little CBECS-specific information exists). A second

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(a) This study made use only of the loads calculation routines of the overall FEDS models. Another set of routines is used to search for optimal (in a life-cycle cost context) combinations of retrofit options for any given set of characteristics defining a single building.

area would attempt to improve the influence of building schedule on energy consumption; the SAE results suggested a strong role for weekly operating hours in the regression analysis.

The goal of this effort would be to calibrate the engineering model in a way such that any after-the-fact statistical adjustment will not significantly improve the model's explained variance of the cross-sectional energy intensities. After this objective has been reasonably met, we will have more confidence that we have a good engineering-based foundation for the observed energy consumption.

From that point, we can use the model as we would any set of prototypical buildings to perform "before" and "after" simulations with various engineering parameters. Thus, as mentioned above as an example, we might investigate market potential of improved lighting technologies across the entire sample of commercial buildings. As compared to most studies using prototypical buildings, the FEDS simulations with these buildings would start from a baseline that matches historical electricity and gas consumption levels on a national basis by building type.

9.0 REFERENCES

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APPENDIX A

IMPUTATION OF FEDS INPUT PARAMETERS FROM CBECS SURVEY DATA

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IMPUTATION OF FEDS INPUT PARAMETERS FROM CBECS SURVEY DATA

The FEDS Level 1 building model was intended to minimize the input required from a user. Therefore, most of the building characteristics are inferred or calculated based on the nominal set of characteristics provided by user input. A major task in the development of the CBECS end use estimation system will be the incorporation of the data available from the CBECS survey into the existing FEDS building defaults module.

Sources for the inferences about the building characteristics are:

- Results of regressions on NBECS[a] data
- Delphi committee decisions
- ELCAP[b] commercial and residential studies
- A priori knowledge (ASHRAE[c], NOAA[d], DOE2[e] defaults, etc...)

A major source of building characteristics for typical applications of FEDS come from a series of regressions made on data from the NBECS data base. The methodology used to develop these results is described in Appendix B. For this study, however, most of these characteristics for each sample building are taken directly from the 1989 CBECS. However, in a few instances where the 1989 survey dropped questions that were asked in 1986, the regression-based inferences are still used.

A second source used was the decisions of a group of experienced building engineers, dubbed the "Delphi" committee (after the pagan Greek oracle). Load shape and installed capacity data from the ELCAP commercial and residential monitoring studies provided information for lighting and equipment characteristics. Finally, much of the weather and building thermal

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[a] Nonresidential Building Energy Consumption Survey. Data from 1986 was used.

[b] End Use Load and Consumer Assessment Project (now known as REMP--Regional End Use Monitoring Program), a large, ongoing, monitoring project funded by BPA.

[c] American Society of Heating, Refrigeration and Air conditioning Engineers

[d] National Oceanic and Atmospheric Administration

[e] DOE2 is a detailed hourly building energy simulation program with in depth HVAC system modeling capabilities.

characteristics is based upon "a priori" knowledge, i.e., industry handbooks (ASHRAE Fundamentals), and other sources (DOE2 defaults, etc.).

Default characteristics are derived for the following areas:

- Building Geometry
- Building Envelope Thermal Characteristics
- Weather Variables
- ASHRAE Solar and Thermal Storage Factors
- Energy Using Equipment Descriptions
- HVAC Operational Characteristics

A.1 BUILDING GEOMETRY

Assumptions relating to building geometry are:

- shape
- aspect ratio
- orientation
- ceiling height
- floor to floor height
- number of stories
- window-to-wall ratio
- HVAC zoning strategy

The building shape is assumed to be a rectangular cube, oriented on a north-south pointing axis. The aspect ratio is defined as the ratio of the length of the north-south facing walls to the length of the east-west facing walls. If it is greater than one, then the long side of the rectangle will be facing north-south. Otherwise, the long side will face east-west. This aspect ratio is used to obtain differences in building envelope areas and surface to volume ratios for different HVAC zones. However, in order to avoid biasing the solar gains calculation, the envelope areas are normalized to average areas for all the exterior zones before this calculation is made.

The 1989 CBECS did not obtain information about the percent of window area, so the window to wall ratio is calculated from the 1986 NBECS regression results. The exception to this is for buildings with the "Window or vision glass" wall construction type. In order accurately reflect the effect of solar gains for buildings with this wall construction type, the window to wall ratio is calculated based on the floor-to-floor height ($height_{floor-floor}$) and floor-to-ceiling height ($height_{floor-ceil}$) assumptions for the building type, and the number of stories (floor) for the building (which is provided from the 1989 CBECS). For these buildings, the total wall area (tot.wall) is:

$$tot.wall = nfloor \times height_{floor\text{-}floor} \times perim \quad (1)$$

where perim, the building perimeter, need not be defined for this derivation.

For each story, the portion of the wall that will not be covering occupied space (and therefore will not be contributing to the solar gains) will be the space between the ceilings and the floor for the next story (i.e., the plenum).[a] The area of this portion of the wall can be calculated as follows:

$$net.wall = nfloor \times (height_{floor\text{-}floor} - height_{floor\text{-}ceil}) \times perim \quad (2)$$

The ratio of the window to the gross wall area is the ratio of the net wall area (net.wall) to the total wall area (tot.wall) subtracted from one. Substituting equations 1 and 2, and simplifying (the perimeter and the number of floor variables both cancel), the window to wall ratio for buildings with the vision glass construction type can be calculated as follows:

$$wndw.wall = 1 - \frac{(height_{floor\text{-}floor} - height_{floor\text{-}ceil})}{height_{floor\text{-}floor}} \quad (3)$$

The default floor-to-floor and floor-to-ceiling heights, as well as the default aspect ratios, were determined for each building type by the Delphi committee. Table A.1 summarizes these assumptions

[a]It is reasonable to assume that the portion of the wall covering the plenum will be made of either opaque glass or concrete panels.

TABLE A.1. Building Geometry Defaults

Building Type	Aspect Ratio	Ceiling Height	Floor-Floor Height
Assembly	1.5:1	12 ft	14 ft
Education	3:1	12 ft	14 ft
Food Sales	1.5:1	20 ft	21 ft
Food Service	2:1	12 ft	16 ft
Health Care	2:1	9 ft	13 ft
Lodging	4:1	8 ft	9 ft
Mercantile/Service	2:1	12 ft	14 ft
Office	1.5:1	10 ft	14 ft
Public Order/Safety	1.5:1	10 ft	14 ft
Warehouse	2:1	20 ft	20 ft
Other Non-Residential	3:1	18 ft	18 ft

Building geometry variables, including wall, window, roof and floor areas, can be calculated using these assumptions.

A.2 BUILDING ENVELOPE THERMAL CHARACTERISTICS

Thermal characteristics are determined for wall, window and roof envelope components. For FEDS Level 1, doors and floors are ignored. CBECS survey information about the construction materials and the presence or absence of insulation is used as the starting points for assumptions about the thermal characteristics of walls and floors. Window characteristics are determined from the CBECS data for the presence or absence of multiple panes, shading, and tinted or reflective films. The following sections describe the development of U-values and thermal mass levels for each type of component from these starting points (see the Ambient Condition Variables section for significance of mass levels).

NOTE: All R-values in this section are in units of (hr-ft^2-°F)/BTU. U-values are the inverse, BTU/(hr-ft^2-°F). Fiberglass insulation is a common insulation type used in walls and ceilings. It has insulation value of 3.2 hr-ft^2-°F/Btu/inch. This is the FEDS Level 1 default thermal resistance value per inch of insulation thickness.[a]

[a]Source: Means Building Construction Cost Data 1991, 49th Annual Edition, Kingston, MA, 1990.

A.2.1 Building Envelope Thermal Characteristics--Walls

For FEDS Level 1, the 1986 NBECS results gave five potential wall construction types:

- Wood siding over wood frame
- Masonry facade over wood frame
- Masonry facade over masonry frame
- Masonry facade over steel frame (i.e., curtain walls)
- Pre-fabricated metal panels

The 1989 CBECS survey provides the following wall construction types:

- Window or vision glass
- Decorative or construction glass
- Concrete panels
- Brick, stone, stucco or other masonry
- Wood, plastic, or metal siding, shingles or shakes
- Pre-engineered metal or light-weight metal panels

The following steps map the 1989 CBECS wall construction types to the FEDS Level 1 (1986 NBECS) wall construction types:

1. Window or vision glass, decorative or construction glass and concrete panels are all mapped to the masonry facade over steel frame (curtain wall construction). The effect of the transparent glass wall construction on solar gains is captured by the window to wall ratio calculation described in the building geometry section above.

2. For buildings with brick, stone, stucco or other masonry construction types, the 1986 NBECS regression results are used to determine whether it is more likely that the wall is masonry facade over wood frame or masonry facade over masonry frame.

3. Wood, plastic or metal siding, shingles or shakes are mapped to the wood siding over wood frame type.

4. Pre-engineered metal or light-weight metal panels are mapped to the pre-fabricated metal panel type.

Example constructions were developed from engineering judgement and examples and values obtained from Chapter 23 in the 1985 ASHRAE Fundamentals Handbook (ASHRAE 1985). Assumptions about the level of insulation are based on the age category of the building for definition of age categories), if the CBECS data indicates the presence of insulation. Otherwise, an air space was assumed where appropriate. The detailed assumptions for each construction type follows.

Vintage:	Year Built
ancient	< 1946
old	1946-1960
middle age	1961-1973
youthful	1974-1979
infant	1980-1984 and beyond]

Wood Siding Over Wood Frame

The basic constituents of this construction type were derived from example 1 on page 23.10 in 1985 Fundamentals:

Construction material	Between Framing R-values	At Framing R-values
exterior air film	0.17	0.17
lapped siding	0.81	0.81
sheathing	see Table A.2	see Table A.2
insulation or air space	see Table A.3	----
2 x 4 wood stud	----	4.38
gypsum wall board	0.45	0.45
interior air film	0.68	0.68

The R-values for the sheathing and the insulation (if present) were assumed to be dependent upon the age of the building. The sheathing and insulation values were assumed to be:

TABLE A.2. Sheathing Values for Wood Siding over Wood Frame

Year Built:	<1974	>= 1974
Material:	0.5" plywood	0.5" poly bead board + 0.5" plywood
R-value:	0.62	2.62

TABLE A.3. Insulation Values for Wood Siding over Wood Frame

Year Built:	<1974	1974-1979	1980-1984
R-value:	7.0	11.0	19.0

If no insulation was present, the R-value of the air space was assumed to be 2.0.

The total R-values for the wall, between the framing (R_b) and at the framing (R_f) can be expressed as:

$$R_b = 0.17 + 0.81 + R_{sheath} + R_{insul} + 0.45 + 0.68 \quad (4)$$

and

$$R_f = 0.17 + 0.81 + R_{sheath} + 4.38 + 0.45 + 0.68 \quad (5)$$

Fifteen percent framing was assumed. The overall U-value of the wall can then calculated:

$$U\text{-}value_{wall} = 0.85 \times \frac{1}{R_b} + 0.15 \times \frac{1}{R_f} \quad (6)$$

Masonry Facade Over Wood Frame

The basic constituents of this construction type were assumed to be:

Construction material	Between Framing R-values	At Framing R-values
exterior air film	0.17	0.17
4" face brick	0.44	0.44
sheathing	see Table A.2	see Table A.2
insulation or air space	see Table A.3	----
2 x 4 wood stud	----	4.38
gypsum wall board	0.45	0.45
interior air film	0.68	0.68

The R-values for the sheathing and the insulation (if present) were assumed to be dependent upon the age of the building. The sheathing and insulation values were assumptions were the same as those for the wood siding over wood frame wall type.

The total R-values for the wall, between the framing (R_b) and at the framing (R_f) can be expressed as:

$$R_b = 0.17 + 0.44 + R_{sheath} + R_{insul} + 0.45 + 0.68 \quad (7)$$

and

$$R_f = 0.17 + 0.44 + R_{sheath} + 4.38 + 0.45 + 0.68 \quad (8)$$

Fifteen percent framing was again assumed. The overall U-value of the wall can then calculated as in equation 6.

Masonry Facade Over Masonry Frame

The basic constituents of this construction type were assumed to be as follows:

Construction material	Between Furring R-values	At Furring R-values
exterior air film	0.17	0.17
4" face brick	0.44	0.44
insulation or air space	see below	see below
8" concrete block	1.72	1.72
0.75" air space	1.01	----
0.75" wood furring	----	0.94
gypsum wall board	0.45	0.45
interior air film	0.68	0.68

The R-value for the insulation was assumed to be 5.32. If no insulation was present, the R-value of the air space was assumed to be 1.10.

The total R-values for the wall, between the furring (R_b) and at the furring (R_f) can be expressed as:

$$R_b = 0.17 + 0.44 + R_{insul} + 1.72 + 1.01 + 0.45 + 0.68 \quad (9)$$

and

$$R_f = 0.17 + 0.44 + R_{insul} + 1.72 + 0.92 + 0.45 + 0.68 \quad (10)$$

Fifteen percent furring was assumed. The overall U-value of the wall can then calculated as in equation 6.

Masonry Facade Over Steel Frame

This wall was assumed to be of the "curtain" wall type. The steel framing was ignored in U-value calculations. The constituent materials were assumed to be:

Construction material	R-values
exterior air film	0.17
2" light weight concrete panel	1.70
insulation or air space	see Table A.3
gypsum wall board	0.45
interior air film	0.68

The R-value for the insulation (if present) was assumed to be dependent upon the age of the building, as in Table A.3. If no insulation was present, the R-value of the air space was assumed to be 2.0.

The overall u-value for this wall type can be calculated:

$$U\text{-}value_{wall} = \frac{1}{0.17 + 1.70 + R_{insul} + 0.45 + 0.68} \tag{11}$$

Prefabricated Metal Panels

R-values for this type were based upon information in Table 5.C on page 23.16 in 1985 Fundamentals. The overall R-value and U-value is given, dependant on the construction year of the building:

Year Built:	<1974	1974-1979	1980-1984
R-value:	5.93	6.63	8.79
U-value:	0.17	0.15	0.11

For uninsulated walls, the thermal resistance of the metal walls was assumed to be approximately zero. The R-value, then, was based upon a 1.5 inch air space enclosed by galvanized steel with a bright emissivity (see Table 2B, page 23.5 in 1985 Fundamentals) and horizontal heat flow. That value was interpolated from table 2A (p. 23.5, 1985 Fundamentals) to be 2.8. Including the resistance of the indoor and outdoor air films, the total R-value was assumed to be 3.65, giving a U-value of 0.27.

Thermal Mass Levels For Walls

Mass levels were assigned based on the constructions assumed above. Descriptions of the different levels can be found in table 30, page 26.35 in the 1989 ASHRAE Fundamentals (ASHRAE 1989). The mass levels are given for insulated and uninsulated conditions for each wall type.

Construction Type	Mass Level Uninsulated	Insulated
Wood siding over wood frame	G	F
Masonry facade over wood frame	E	D
Masonry facade over masonry frame	C	B
Masonry facade over steel frame	G	G
Pre-fabricated metal panels	F	E

For walls, A is the most "massive" (i.e., has the highest thermal storage capacity) and G the least.

A.2.2 Building Envelope Thermal Characteristics--Roofs

Three FEDS Level 1 roof construction types were developed from the 1986 NBECS results:

- Built up roofing
- Metal Roof (pre-fabricated metal panels)
- Shingles

The roof construction types in the 1989 CBECS surveys were:

- Wood shingles, shakes or other wooden materials
- Slate or tile shingles
- Asphalt, fiberglass or other shingles
- Built-up
- Metal surfacing
- Plastic, rubber or synthetic sheeting
- Concrete

These construction types can be mapped to the FEDS construction types as follows:

1. Wood shingles, shakes or other wooden materials, slate or tile shingles, and asphalt, fiberglass or other shingles can be mapped to the FEDS shingles type.

2. Built-up, plastic, rubber or synthetic sheeting, or concrete types can be mapped to FEDS built up roofing. A concrete type will be defaulted to the concrete roof deck assumptions.

3. Metal surfacing will be mapped to the FEDS metal roof type.

For built-up roofing, it is necessary to assume a deck material. That assumption was based primarily upon the wall type; for 1989 CBECS concrete roof types, the deck type will be assumed to be concrete.

TABLE A.4. Built-up Roof Deck Materials

Wall Construction Type	Roof Deck Material
Wood siding over wood frame	Wood
Masonry facade over wood frame	Wood
Masonry facade over masonry frame	Concrete
Masonry facade over steel frame	Metal
Pre-fabricated metal panels	Metal

Example constructions were developed from prototypical constructions found in Tables 4H-4J & 4L on pages 23.23-23.26 in the 1981 ASHRAE Fundamentals (ASHRAE 1981). The assumptions are described below:

Built-up Roofing, Wood Deck

The basic constituents of this type were taken from table 4I, page 23.24 in 1981 Fundamentals (ASHRAE 1981).

Construction material	Between Joists R-values	At Joists R-values
exterior air film	0.17	0.17
built up roof	0.33	0.33
rigid deck insulation	4.00	4.00
plywood deck, 5/8"	0.78	0.78
insulation or air space	see below	----
2" x 8" ceiling joists	----	9.06
ceiling	1.70	1.70
interior air film	0.61	0.61

If insulated, the insulation R-value was assumed to be 20.05. If uninsulated, the R-value of the air space was assumed to be 0.93. The total R-values for the roof, between the joists (R_b) and at the joists (R_j) is:

$$R_b = 0.17 + 0.33 + 4.00 + 0.78 + R_{insul} + 1.70 + 0.61 \quad (12)$$

and

$$R_j = 0.17 + 0.33 + 4.00 + 0.78 + 9.06 + 1.70 + 0.61 = 16.65 \quad (13)$$

Assuming 10% framing, the overall U-value for this roof type is:

$$U\text{-}value_{roof} = 0.9 \times \frac{1}{R_b} + 0.1 \times \frac{1}{R_j} \tag{14}$$

Built-up Roofing, Concrete Deck

The R-values for this construction type were taken directly from table 4H, page 23.23, in 1981 Fundamentals. The values were:

	R-value	U-value
Uninsulated:	4.73	0.21
Insulated:	8.90	0.11

Built-up Roofing, Metal Deck

The constituents for this roof type were taken from table 4J, page 23.24 in the 1981 Fundamentals. The thermal resistance of the metal deck and the metal joists is assumed to be approximately zero; only the value between the joists is considered.

Construction material	Between Joists R-values
exterior air film	0.17
built up roof	0.33
rigid deck insulation	4.00
metal deck	~0.00
insulation or air space	see below
ceiling	1.70
interior air film	0.61

If insulated, the insulation R-value was assumed to be 20.05. If uninsulated, the R-value of the air space was assumed to be 0.93. The overall U-value for this roof type is:

$$U\text{-}value_{roof} = \frac{1}{0.17 + 0.33 + 4.00 + R_{insul} + 1.70 + 0.61} \tag{15}$$

Pre-fabricated Metal Roof

R-values were obtained from table 4L, page 23.26, 1981 Fundamentals. Values were assumed to be dependent upon age.

Year Built:	<1974	1974-1979	1980-1984
R-value:	5.00	7.15	8.69
U-value:	0.20	0.14	0.12

As with the pre-fabricated metal walls, the uninsulated R-value was taken to be 2.8, giving a total R-value (with air films) of 3.65 and a U-value of 0.27.

Shingle Roofs

This roof type was prototyped as a pitched wood deck roof. The assumption was made that the area over the ceiling was an unconditioned, ventilated attic. If insulation was not present, then the R-value between the rafters was considered to be based on the construction of the roof above the attic. This reflects the assumption that the temperature in the attic is very close to the interior temperature:

Uninsulated Shingle Roofs

Construction material	Between Rafters R-values	At Rafters R-values
exterior air film	0.17	0.17
asphalt shingle roofing	0.44	0.44
felt building membrane	0.06	0.06
plywood sheathing, 5/8"	0.77	0.77
air space	2.17	----
2" x 4" ceiling rafters	----	4.35
wall board, foil backed	0.45	0.45
interior air film	0.62	0.62

Assuming 10% framing, the overall U-value for uninsulated shingle roofs is:

$$U\text{-}value_{roof} = 0.9 \times \frac{1}{3.47} + 0.1 \times \frac{1}{6.86} = 0.27 \qquad \textbf{(16)}$$

When insulation is present, it is assumed it is laid on the ceiling, and the R-value for the roof then becomes the R-value for the ceiling and insulation:

Insulated Shingle Roofs

Construction material	R-values
interior air film	0.62
insulation	see table A.3
wall board, foil backed	0.45
interior air film	0.62

The R-value for the insulation is assumed to be age-dependant:

TABLE A.5. Insulation Values for Shingle Roofs

Year Built:	<1974	1974-1979	1980-1984
R-value:	11.0	19.0	30.0

For insulated shingle roofs, the overall U-value can be calculated as:

$$U\text{-}value_{roof} = \frac{1}{0.62 + R_{insul} + 0.45 + 0.62} \tag{17}$$

Thermal Mass Levels for Roofs

Thermal mass level assignments for the roofs were based on the contents of table 29, page 26.34, in the **1989** ASHRAE Fundamentals.

The mass characteristics of roofs are dependant, in part, on the presence or absence of suspended ceilings. The assumption was made that all buildings built after 1974 had suspended ceilings, and that those built before then did not. For built-up roofs, the mass was also dependant upon the deck material. For built-up roofs:

Deck Material	<1974	1974-1979	1980-1984
Wood	2	7	10
Concrete	4	10	12
Metal	1	2	7

For pre-fabricated metal panel roofs, the mass level was assumed to be 1, regardless of age. For shingle roofs, the mass level was assumed to be 2 unless the roof was insulated and the building was built after 1974 (i.e., a suspended ceiling was assumed to be present). In that case, the level was assumed to be 7.

A.2.3. Building Envelope Thermal Characteristics--Windows

For windows, the 1989 CBECS survey provides information regarding whether or not multiple panes were present, whether or not exterior shading was present, and whether or not tinting or reflective film was on the windows. These three pieces of information, along with the wall construction type, were used as the basis of the assumptions about the window thermal characteristics.

The characteristics of interest included not only the U-value and the thermal mass level, but also the shading coefficient (SC, see load calculation section). The assumptions are presented in the following tables, along with the sources from chapter 27 in the 1989 ASHRAE Fundamentals used.

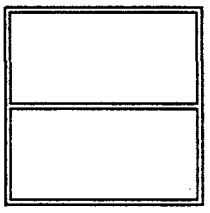
TABLE A.6. Window U-values, based on Table 13, pg. 27.16

Wall Construction Type	Window Frame Type	Window Frame Configuration[a]	U-Values for # panes Single	U-Values for # panes >Single
Wood siding over wood frame	Wood	R	0.90	0.54
Masonry over wood frame	Wood	R	0.90	0.54
Masonry over masonry frame	Metal	C	1.23	0.78
Masonry over steel frame	Metal	C	1.23	0.78
Pre-fabricated metal panels	Metal	C	1.23	0.78

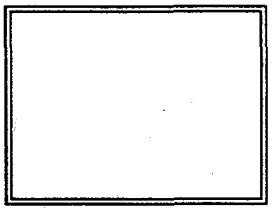
TABLE A.7 Window Thermal Mass Levels, based on Wall Construction Type

Wall Construction Type	Assumed Flooring	Mass Level, if no shading present
Wood siding over wood frame	Wood	Light
Masonry facade over wood frame	Wood	Light
Masonry facade over masonry frame	Concrete Slab	Heavy
Masonry facade over steel frame	Suspended Concrete	Medium
Pre-fabricated metal panels	Wood	Light

(a) R denotes residential type window frame:



C denotes commercial type window frame:



Shading Coefficients were based on the number of panes, and the presence or absence of exterior shading and tinted or reflective film:

Multiple Panes?	Shading?	Tinted or Reflective Film?	SC	1989 ASHRAE Fundamentals Table No.	Page No.
No	Yes	Yes	0.42	25	27.30
No	Yes	No	0.75	25	27.30
No	No	Yes	0.50	25	27.30
No	No	No	0.94	20	27.26
Yes	Yes	Yes	0.34	26	27.31
Yes	Yes	No	0.62	26	27.31
Yes	No	Yes	0.40	26	27.31
Yes	No	No	0.81	20	27.26

A.3 WEATHER VARIABLES

FEDS uses the following kind of weather data:

- Monthly average profiles of outdoor dry bulb temperature, clearness factors, and humidity ratio for modeling monthly heating and cooling load profiles.
- Profiles for the peak heating and cooling days in each month to calculate peak heating and cooling profiles for the month.
- Profiles of the minimum (for heating) and maximum (for cooling) temperature for each hour, for use in the estimation of heating and cooling equipment capacity.
- The 65°F degree base heating and cooling degree days for determining the NBECS climate zone for each weather station. For the 1989 CBECS, the climate zone for each building is supplied by the survey data.

All of this data is derived from 8760 hourly weather files, of the type used in DOE2 and BLAST simulations. Calculation of the average profiles is straightforward. The value in question (temperature, clearness or humidity) is summed for each hour throughout a month. Then each hourly sum is divided by the number of days in the month to obtain the average profile:

$$v_h = \frac{1}{N_d} \times \sum_{d=1}^{N_d} v_{d_h} \qquad (18)$$

where h is any single hour
d is a day in any month
N_d is the number of days in the month
v is the value in question.

The peak heating and cooling profiles for each month are defined as the profiles for the days with the largest number of heating degree hours and cooling degree hours, respectively. Heating degree hours are:

$$HDH_{T_{base},d} = \sum_{h=1}^{24} (T_{base} - T_h); \quad T_h \leq T_{base} \qquad (19)$$
$$= 0; \quad T_h > T_{base}$$

and cooling degree hours:

$$CDH_{T_{base},d} = \sum_{h=1}^{24} (T_h - T_{base}); \quad T_h \geq T_{base} \qquad (20)$$
$$= 0; \quad T_h < T_{base}$$

For FEDS, T_{base} is 65°F.

The heating and cooling degree days are calculated using the heating and cooling degree hours as defined above:

$$HDD_{T_{base}} = \frac{1}{24} \times \sum_{m=1}^{12} \sum_{d=1}^{N_{d,m}} HDH_{T_{base},d} \qquad (21)$$

where $N_{d,m}$ is the number of days in month m. Cooling degree days are calculated in the same way.

Worst case design conditions are estimated by finding, for each month, the minimum and maximum temperature for each hour. These monthly worse case profiles are then compared, and the minimum and maximum profiles for the year are selected for the design conditions.

A.4 SELECTION OF APPROPRIATE ASHRAE SOLAR AND THERMAL STORAGE FACTORS

In addition to the weather data, the 8760 weather files also contain the latitude and longitude of the weather station. The latitude is of importance in the selection of the appropriate solar heat gain factors and latitude-month correction factors for the cooling load temperature differences used in the heating and cooling load calculations (see section C.4 for description of calculation process).

The FEDS load calculation method is based upon the CLTD/CLF load estimation method described in pages 26.33-26.48 in the 1989 ASHRAE Fundamentals. Cooling load temperature differences (CLTD) and cooling load factors (CLF) are obtained from look up tables, based upon appropriate selection criteria. The following sections describe those criteria and their implementation.

CLTD for Walls, Roofs and Windows

Wall CLTD's are selected according the mass level of the wall. Section A.2.1 above describes the assignment of mass levels according to wall type and insulation. Wall CLTD's are selected for each orientation (north, south, east and west). Selection of roof CLTD's is first dependent upon whether or not a suspended ceiling is present. There are 13 roof mass levels for each ceiling condition. Section A.2.2 describes the assignment of roof mass levels. One set of CLTD's are given for windows. Wall CLTD's are in table 31, page 26.36; roof CLTD's are in table 29, page 26.34; and, window CLTD's are in table 33, page 26.38; all in 1989 Fundamentals.

Latitude and Month (LM) Correction factors for Wall and Roof CLTD CLTD profiles were calculated for the solar radiation conditions found at 40°N latitude on July 21. The latitude and month correction factors modify the CLTD profiles to reflect the difference in solar conditions at different latitudes and during different months. The latitude-month correction factors, organized by orientation, are contained in table 32, page 26.37 in 1989 Fundamentals.

SHGF and CLF for Windows

Solar heat gain factors for windows are available for 20°N, 24°N, 28°N, 32°N, 36°N, 40°N, 44°N, and 48°N latitudes. For latitudes between these values, the SHGF should be interpolated. At each latitude, the SHGF are given by orientation and month. Window cooling load factors (CLF) are given by orientation for each of three room mass levels. Those levels are described in section A.2.3. The SHGF are contained in table 34, pages 26.39-26.40; CLF for unshaded windows are in table 36, page 26.41; CLF for shaded windows are in table 39, page 26.43; all in 1989 Fundamentals.

CLF for Lighting, Equipment and Occupant Internal Gain

The cooling load factors for these internal gains account for the reduction of heat that the HVAC system sees in any hour by the amount of heat stored in the room mass. The CLF profiles are dependent on the hours of operation of the building. Profiles are available for 8, 10, 12, 14 and 16 hours of operation. CLF profiles for hours of operation between these levels can be obtained from interpolation. For the profiles, hour 1 applies to the first hour of operation, not the first hour in the day (i.e., 1 am). The CLF profiles for a building then have to be shifted in order to be aligned with the hours of operation. Lighting CLF profiles are in tables 43-47, page 26.45-26.46 in 1989 Fundamentals. Equipment CLF profiles are in table 49, page 26.47; occupant CLF profiles are in table 40, page 26.44.

For lighting CLF, additional selections must be made for the appropriate "a" coefficient and "b" classification factors. The a coefficient reflects the effect of lighting fixture type and ventilation systems and rates on the thermal storage of heat from lighting. The b classification reflects the effect of room mass (floor weight in particular) and ventilation rates on the thermal storage. The Delphi committee assigned these factors by building type:

Building Type	"a" coefficient	"b" classification
Assembly	0.55	B
Education	0.55	C
Food Sales	0.55	C
Food Service	0.55	C
Health Care	0.55	C
Lodging	0.55	C
Mercantile/Service	0.55	C
Office	0.55	C
Public Order/Safety	0.55	C
Warehouse	0.45	D
Other Non-Residential	0.45	D

A.5 EQUIPMENT DEFAULTS

This section first lays out the defaults for heating and cooling equipment. The second part of the section discusses the approach for miscellaneous equipment.

A.5.1 HEATING AND COOLING EQUIPMENT DEFAULTS

Heating and Cooling Equipment Types

The CBECS survey provides information about the primary generator ("plant") for heating and cooling, as well as the primary heating and cooling fuels. The FEDS Level 1 heating equipment types are listed below:

TABLE A.8. FEDS Heating Equipment Types

Baseboard

Forced air

Air source heat pump

Water source heat pump (not selected as default)

Radiator

Fan Coil

Conventional Boiler

Conventional Furnace

High Efficiency Boiler (not selected as default)

High Efficiency Furnace (not selected as default)

No heating equipment

1. CBECS buildings with district hot water or steam as the primary heating fuels are given baseboard equipment types.[a]

2. A CBECS heat pump heating equipment type is assumed to be an air source heat pump.

3. CBECS packaged unit heating equipment is modeled as a conventional furnace.

4. CBECS space heaters and heating panels are mapped to the baseboard equipment type.

5. Coal as the primary heating fuel is assumed to always be a conventional boiler.

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[a] The district heating equipment was modeled as baseboard so that the appropriate conversion efficiency (i.e., 1) would be used in the calculation of the consumption. The version of FEDS used for CBECS does not incorporate detailed systems modelling; therefore, we did not use the CBECS information regarding distribution equipment (e.g., fan coil units, radiators, air handlers). However, we did use the CBECS data about the primary generators (e.g., boilers, furnaces, etc.).

Yes, we used the CBECS data for percent floor space lit by different types of lighting equipment.

6. For CBECS buildings less than 15% heated, the no heating equipment type is assigned.

The FEDS cooling equipment choices are:

TABLE A.9. FEDS Cooling Equipment Types

Evaporative cooler
Packaged unit
Air source heat pump
Water source heat pump (not selected as default)
Conventional Chiller
Absorption chiller
Chilled Water Coil
No cooling equipment

Mapping is as follows:

1. CBECS Evaporative cooler cooling type gets evaporative cooler equipment type.

2. CBECS packaged unit and window/wall air conditioners are assigned to packaged unit equipment types.

3. Chilled water cooling (district) are assigned to chilled water coil.

4. Electric heat pump cooling type is air source heat pump equipment type.

5. Single building electric chiller cooling type is assign conventional chiller equipment type.

6. Steam, hot water, gas and other heat source absorption chiller cooling types are assigned absorption chiller equipment type.

7. A CBECS building that is less than 15% cooled is assigned the no cooling equipment type.

Calculation of Equipment Age

For FEDS, the estimation of the nominal efficiency of furnaces, boilers, conventional chillers, heat pumps and packaged units uses an assumed age of the equipment. The CBECS survey supplies the vintage of central chillers and central packaged units. If that information is missing, as well as for heating equipment, where the vintage is not supplied, the age of the cooling equipment is inferred as follows:

1. A maximum life (max.life) for the equipment is first assumed. For furnaces and conventional chillers:

$$\max.life = 20\ years \tag{22}$$

for heat pumps and packaged units:

$$\max.life = 12\ years \tag{23}$$

for boilers:

$$\max.life = 40\ years \tag{24}$$

2. The age of the building (age_{bldg}) is checked. If age_{bldg} is less than max.life, then the equipment age is:

$$equip.age = age_{bldg} \tag{25}$$

If age_{bldg} is greater than or equal to max.life, then:

$$equip.age = \frac{\max.life}{2} \tag{26}$$

Heating Equipment Nominal Efficiency

After the equipment age has been estimated, the efficiencies estimate can be made. For gas and other fuel furnaces, the equation is

$$\eta = 0.550671 + 0.069970 \times \ln(20 - equip.age) \tag{27}$$

for oil furnaces:

$$\eta = 0.570671 + 0.069970 \times \ln(20 - equip.age) \tag{28}$$

For boilers, the efficiency is estimated as a bi-linear function of both equipment age (in years) and equipment capacity (in watts). For gas and other fuel boilers, the equation is:

$$\eta = 0.870886 - (3.69596\times10^{-3} \times equip.age) - (6.2348\times10^{-9} \times cap_{eq}) \quad (29)$$

for coal boilers:

$$\eta = 0.880886 - (3.69596\times10^{-3} \times equip.age) - (6.2348\times10^{-9} \times cap_{eq}) \quad (30)$$

and for oil boilers:

$$\eta = 0.890886 - (3.69596\times10^{-3} \times equip.age) - (6.2348\times10^{-9} \times cap_{eq}) \quad (31)$$

For the baseboard equipment type, the efficiency is assumed to by 0.98. For air source heat pumps, the **heating efficiency** (actually a COP) is 2.6 if the building was built before 1980 and 3.0 if the building was built in 1980 or later.

Cooling Equipment Nominal COP

Conventional chiller, air source heat pumps, and packaged unit COP estimations are functions of equipment age. For a piece of equipment, functions are applicable over ranges of equipment capacity. To wit:

For conventional chillers, less than 75 tons or 2.6378 x 10^5 watts capacity (FEDS assumes this to be a reciprocating chiller), the COP is:

$$COP = 1.960181 \times \exp(0.018748 \times (20 - equip.age)) \quad (32)$$

For capacity from 75 to 200 tons or 2.6378 x 10^5 W to 7.065 x 10^5 W capacity (again assumed to be a reciprocating chiller), the COP is:

$$COP = 2.205933 \times \exp(0.024885 \times (20 - equip.age)) \quad (33)$$

For capacity from 200 tons to 500 tons or 7.065 x 10^5 W to 1.758 x 10^6 W capacity (assumed in FEDS to be a centrifugal chiller), the COP is:

$$COP = 3.725112 + 0.118557 \times (20 - equip.age) \quad (34)$$

For capacity greater than 500 tons or 1.758 x 10^6 W capacity and less than or equal to 1200 tons or 4.219 x 10^6 W capacity (assumed to be centrifugal chiller), the COP is:

$$COP = 2.980651 \times (20 - equip.age)^{0.179470} \quad (35)$$

For an air source heat pump, the cooling COP is:

$$COP = 1.583302 \times (20 - equip.age)^{0.140525} \quad (36)$$

For packaged units (window) with less than 1.5 tons or 5.274×10^3 W capacity, the COP is:

$$COP = 2.4325 - 0.0325 \times equip.age \quad (37)$$

For packaged units with greater than or equal to 1.5 tons or 5.274×10^3 W capacity and less than 20 ton or 7.034×10^4 W capacity, the COP is:

$$COP = 2.172449 + 0.013995 \times (20 - equip.age) \quad (38)$$

For packaged units with a capacity greater than or equal to 20 ton, the COP is:

$$COP = 2.321385 + 0.01521 \times (20 - equip.age) \quad (39)$$

Absorption chiller COP is assumed to be 0.975; for evaporative coolers, the COP is assumed to be 10.

A.5.2 MISCELLANEOUS EQUIPMENT CONSUMPTION DEFAULTS

Most of the information for equipment defaults was obtained from the REMP data for commercial buildings. For non-residential buildings, the REMP data was used to obtained an average installed capacity (in watts per square foot) for each building type. Utilization factors, average values for occupied and unoccupied hours, are based on the average profiles for the REMP building types. Surrogate building types were used for FEDS non-residential building types not found in the REMP study. The surrogates were:

FEDS Type	REMP Surrogate
Assembly	School
Public Order	Office
Other	Warehouse

Additionally, for the Health Care type, a 24-hour always on profile was assumed for all equipment (the FEDS prototype for health care is a hospital).

Miscellaneous equipment information was broken into three subcategories, food preparation, refrigeration, and other equipment. This breakdown will allow future FEDS releases to treat the food preparation and refrigeration end uses separately for, say, food sales and food service building types.

Tables A.10 and A.11 below contain the average watts/sq. ft. and the utilization factors for non-residential building types.[a]

TABLE A.10. Average Installed Capacity by Building Type (W/ft^2)

	Food Prep	Refr	Other
Assembly	0.0043	0.0567	0.0236
Education	0.0043	0.0567	0.0236
Food Sales	0.4606	5.4390	0.3694
Food Service	0.6880	0.6589	0.6522
Health Care	0.6880	0.6589	2.0000
Lodging	0.0738	0.1064	0.0152
Merc. Service	0.0143	0.0409	0.0646
Office	0.0090	0.1338	0.1334
Public Order	0.0090	0.1338	0.1334
Warehouse	0.0048	0.0194	0.0373
Other	0.0038	0.0516	0.0722

(a) Food preparation and refrigeration values for hospitals were not available from REMP. These values were assigned the values for Food Service (see Section A.9).

TABLE A.11. Misc. Equipment Utilization Factors (dimensionless)

	Food Prep		Other		Refrigeration	
Building types	Unoccupied	occupied	unoccupied	occupied	unoccupied	occupied
assembly	0.0904	2.0750	0.2599	1.7403	0.8487	1.1081
school	0.0904	2.0750	0.2599	1.7403	0.8487	1.1081
food sales	0.6658	1.2829	0.8033	1.0984	0.9524	1.0477
Food service	0.3354	1.3987	0.6925	1.2603	0.8620	1.0985
health	0.0000	0.0000	1.0000	1.0000	0.0000	0.0000
lodging	0.3354	1.3987	0.3618	0.6048	0.8620	1.0985
merc. service	0.2236	1.6568	0.6066	1.3932	0.9204	1.0673
office	0.6278	1.3723	0.6897	1.2625	0.9447	1.0655
public order	0.6278	1.3723	0.6897	1.2625	0.9447	1.0655
warehouse	0.4057	1.8322	0.7721	1.3189	0.9451	1.0768
other	0.4057	1.8322	0.7618	1.2016	0.9451	1.0768

Default Fraction Heat-to-Space for Internal Gains

Engineering assumptions were made regarding the fraction of lighting and miscellaneous equipment consumption that was heat rejected to the conditioned space (as opposed to outside). It was also assumed that all heat associated with outside air and occupancy was seen in the conditioned space. Table A.12 contains the fraction heat to space by building type.

TABLE A.12 Fraction Heat-to-Space by Internal Gain Type (dimensionless)

	Lights	Equipment	Occupant	Outside Air
Assembly	1.0	1.0	1.0	1.0
Education	1.0	1.0	1.0	1.0
Food Sales	1.0	0.32	1.0	1.0
Food Service	1.0	0.58	1.0	1.0
Health Care	1.0	1.0	1.0	1.0
Lodging	1.0	1.0	1.0	1.0
Merc. Service	1.0	1.0	1.0	1.0
Office	0.8	1.0	1.0	1.0
Public Order	0.8	1.0	1.0	1.0
Warehouse	1.0	1.0	1.0	1.0
Other	1.0	1.0	1.0	1.0
Single fam, detached	1.0	1.0	1.0	1.0
Single fam, attached	1.0	1.0	1.0	1.0
multi, 2-4 units	1.0	1.0	1.0	1.0
multi, >= 5 units	1.0	1.0	1.0	1.0
mobile home	1.0	1.0	1.0	1.0

A.6 HVAC OPERATIONAL CHARACTERISTICS

Assumptions regarding thermostat settings, night set-back warmup periods, peak heating and cooling day types, occupant sensible and latent heat gains, and the heat capacity of the building furnishings must be made in order to calculate the consumption due to heating and cooling. These assumptions were based on engineering judgements, and are documented below.

Occupancy Heat Gains

The assumed occupancy heat gains are based on presumed activity levels within a building type. These values come from table 3, page 26.7 in the 1989 Fundamentals.

Table A.13 Occupant Sensible and Latent Heat Gains (W/person)

	Heat Gains	
Building Type	Sensible	Latent
Assembly	60	40
Education	75	75
Food Sales	90	95
Food Service	75	95
Health Care	75	75
Lodging	75	75
Mercantile Service	90	95
Office	75	75
Public Order	75	75
Warehouse	100	205
Other Non-Residential	100	205

Peak Day Types

Heating and cooling peak day type selections were based upon building type. The peak heating day type was chosen to be the day type for which internal gains were assumed to be lowest; the reverse assumption was made for cooling peak day type. The peak day types are:

TABLE A.14. Heating and Cooling Peak Day Types

Building Type	Heating	Cooling
Assembly	weekday	Sunday
Education	Sunday	weekday
Food Sales	weekday	Saturday
Food Service	Saturday	weekday
Health Care	Sunday	weekday
Lodging	Saturday	weekday
Mercantile Service	weekday	Saturday
Office	Sunday	weekday
Public Order	Sunday	weekday
Warehouse	Sunday	weekday
Other Non-Residential	Sunday	weekday

Thermostat Settings

Assumptions about thermostat settings were based upon engineering judgements. The thermostat set points are in the table below. It is assumed that the cooling in the warehouse and other non-residential building types is unitary, hence the higher thermostat setting.

TABLE A.15. Thermostat Settings (°F)

Building Type	Heating	Cooling
Assembly	70	74
Education	70	74
Food Sales	70	74
Food Service	70	74
Health Care	74	76
Lodging	70	74
Mercantile Service	70	74
Office	70	74
Public Order	70	74
Warehouse	55	85
Other Non-Residential	60	80
All Residential	70	74

The CBECS survey indicates whether or not there is an off-hours reduction in cooling or heating, as well as whether or not there is an EMCS system controlling the heating and cooling system. For buildings with either of these features, a night set-back (or, for cooling, set-up) of 10 °F is assumed. A default night setback/setup warmup period of one hour was also assumed.

Thermal Capacitance

The thermal capacity of the building furnishings is based on building type. The values are:

TABLE A.16. Thermal Capacity for Building Furnishings (C_m) (W-h/°F/ft^2 floor area)

Building Type	Heating
Assembly	0.5860
Education	0.7325
Food Sales	1.7580
Food Service	0.8790
Health Care	1.1720
Lodging	0.9376
Mercantile Service	1.4650
Office	1.1720
Public Order	1.1720
Warehouse	1.7580
Other Non-Residential	0.5860

For all building types, the thermal capacity of the air and the "quick" mass (C_a) is 0.293 W-h/°F/ft^2 floor area. The assumed air film resistance for the furnishings (h_m) is 0.4395 W/°F/ft^2 floor area.

Outdoor Air Ventilation and Infiltration

Outdoor air ventilation rates are based on the Universal Building Code ventilation requirements. It was assumed that there was no mechanical ventilation for warehouses, other non-residential, and all residential. For all other commercial building types except lodging, the outdoor air ventilation rate was assumed to be 5 ft^3 per minute per building occupant. For lodging, the ventilation rate was based on air changes per hour (ACH). The code requires 2 ACH, 20% of which should be outside air. The volume of the building can then be used to calculate the required ventilation rate:

$$V_{lodging} = 0.2 \times \left(\frac{volume \times \frac{2 \text{ air changes}}{\text{hour}}}{60 \frac{\text{min}}{\text{hour}}} \right) \qquad (40)$$

The infiltration rate is dependant upon whether or not there are multiple panes in the windows in the building, and upon the occupancy status. If there are not multiple panes in the building, then the unoccupied

infiltration rate is 0.2 ACH. If multiple panes are present, then the unoccupied infiltration rate is 0.14 ACH. For either case, the occupied infiltration rate is assumed to be half of the unoccupied rate.

Building Humidity Ratio

It is assumed that the relative humidity (R.H.) of the building is 50%. This value, combined with the thermostat setpoint for cooling, and the assumed atmospheric pressure of 14.696 psia, was used to calculate the humidity ratio. For thermostat settings of 74°F, the ratio is 0.0089 lb water/lb dry air. For the 76°F setting (health care building type), the ratio is 0.0096 lb water/lb dry air.

A.7 LIGHTING DEFAULTS

FEDS models eight types of lighting technologies:

- Incandescent (conventional)
- Incandescent (high efficiency)
- Fluorescent (conventional)
- Fluorescent (high efficiency)
- Mercury vapor
- Metal Halide
- High pressure sodium
- Low pressure sodium

FEDS uses default values for lighting fixture capacity in watts per fixture, based on the lighting technology type; the fixture density (fixtures per square foot of floor area), based on lighting technology type and building type; and, lighting utilization factors, the fraction of the installed lighting capacity that is on during occupied and unoccupied periods, based on the building type. For the end-use estimation study, the CBECS data for the percentage of how space lit by different types of light equipment was used.

Lighting Capacity

Lighting capacities were developed from manufacturer's information. The values are given by technology type:

Table A.17: Lighting Capacities (W/fixture)

Lighting Technology	Watts
Conventional Incandescent	75
High Efficiency Incandescent	500
Conventional Fluorescent	196
High Efficiency Fluorescent	119
Mercury Vapor	210
Metal Halide	95
High Pressure Sodium	188
Low Pressure Sodium	135

Lighting Density

Lighting densities were developed from ELCAP connected load survey information.

A.18: Lighting Densities
(fixtures/ft^2)

Lighting Technology	Assembly	Education	Food Sales
Conventional Incandescent	2.62E-02	5.01E-02	5.83E-02
High Efficiency Incandescent	2.82E-03	5.39E-03	6.27E-03
Conventional Fluorescent	3.81E-03	7.29E-03	8.47E-03
High Efficiency Fluorescent	4.07E-03	7.78E-03	9.05E-03
Mercury Vapor	3.90E-03	7.45E-03	8.66E-03
Metal Halide	7.41E-03	1.42E-02	1.65E-02
High Pressure Sodium	2.06E-03	3.93E-03	4.57E-03
Low Pressure Sodium	2.19E-03	4.19E-03	4.88E-03

Lighting Technology	Food Service	Health Care	Lodging
Conventional Incandescent	4.86E-02	5.61E-02	3.39E-02
High Efficiency Incandescent	5.23E-03	6.04E-03	3.65E-03
Conventional Fluorescent	7.06E-03	8.16E-03	4.93E-03
High Efficiency Fluorescent	7.54E-03	8.71E-03	5.27E-03
Mercury Vapor	7.22E-03	8.34E-03	5.05E-03
Metal Halide	1.37E-02	1.59E-02	9.59E-03
High Pressure Sodium	3.81E-03	4.40E-03	2.66E-03
Low Pressure Sodium	4.07E-03	4.70E-03	2.84E-03

Lighting Technology	Mercantile & Service	Office	Public Order & Safety
Conventional Incandescent	4.66E-02	6.83E-02	5.12E-02
High Efficiency Incandescent	5.02E-03	7.35E-03	5.51E-03
Conventional Fluorescent	6.78E-03	9.93E-03	7.45E-03
High Efficiency Fluorescent	7.24E-03	1.06E-02	7.95E-03
Mercury Vapor	6.93E-03	1.02E-02	7.62E-03
Metal Halide	1.32E-02	1.93E-02	1.45E-02
High Pressure Sodium	3.66E-03	5.36E-03	4.02E-03
Low Pressure Sodium	3.90E-03	5.72E-03	4.29E-03

Lighting Technology	Warehouse & Storage	Other
Conventional Incandescent	2.59E-02	4.52E-02
High Efficiency Incandescent	2.79E-03	4.87E-03
Conventional Fluorescent	3.77E-03	6.58E-03
High Efficiency Fluorescent	4.03E-03	7.02E-03
Mercury Vapor	3.86E-03	6.73E-03
Metal Halide	7.33E-03	1.28E-02
High Pressure Sodium	2.04E-03	3.55E-03
Low Pressure Sodium	2.17E-03	3.79E-03

Lighting Technology	All Residential
Conventional Incandescent	1.66E-02
High Efficiency Incandescent	1.79E-03
Conventional Fluorescent	2.41E-03
High Efficiency Fluorescent	2.58E-03
Mercury Vapor	2.47E-03
Metal Halide	4.69E-03
High Pressure Sodium	1.30E-03
Low Pressure Sodium	1.39E-03

Lighting Utilization Factors

Lighting utilization factors were derived from ELCAP hourly energy data. The values in the table below are the fraction of the installed capacity that is on during occupied and unoccupied time periods, by building type.

A.19: Utilization Factors
(fractional)

Building Type	Occupied	Unoccupied
Assembly	0.57	0.08
Education	0.57	0.08
Food Sales	0.65	0.36
Food Service	0.56	0.13
Health Care	0.80	0.20
Lodging	0.32	0.16
Mercantile & Service	0.80	0.15
Office	0.63	0.17
Public Order/Safety	0.80	0.20
Warehouse & Storage	0.60	0.10
Other	0.60	0.10
All Residential	0.22	0.06

Seasonal Occupancy

In a seasonally occupied building, FEDS assumes that during the unoccupied months, the utilization factors for all lighting types for both the occupied and unoccupied periods, are zero.

A.8 SERVICE HOT WATER DEFAULTS

The defaults required for modeling hot water consumption are:

- System type (central or distributed)
- Number and volume of storage tanks (N_{tank}, V_{tank})
- Dimensions of storage tank(s) (D_{tank}, H_{tank})
- Thickness and conductivity of tank insulation ($th.ins_{tank}$, $k.ins_{tank}$)
- Daily hot water use (in gallons) (shw.use)
- Ground water temperature (°F, T.ground)

- Presence or absence of a recirculation system
- Service hot water generator conversion efficiency
- Default piping loss for buildings without recirculation systems (pipe.loss, in W/°F)
- Required output capacity for service hot water generators (cap.shw, in watts)

The following information is required to generate these defaults:

- Building type
- Building location (climate zone)
- Total floor area (floor.area)
- Number of occupants (N_{occ})
- Year building was constructed
- Predominant (by floor area served) service hot water fuel source

Assumptions:

- Specific heat of water is 8.33 Btu/gal (c_p)

The steps are:

1. Determine service hot water system type.
This is based on fuel type and building type. For health care (prototype is hospital) and lodging building types, the system is always central. For single family residential types (attached, detached and mobile), the system is always distributed. For all other building types, table A.20 gives the mapping of fuel types to system types:

Table A.20: Service Hot Water System/Fuel Type Map

Fuel Type	System Type
Electric Resistance	Distributed
Electric Heat Pump	Distributed
Steam	Central
Hot Water	Central
Oil	Central
Natural Gas	Distributed
Coal	Central
Other (LPG assumed)	Distributed

A. Calculate occupancy unit (occ.unit), by building type.
For lodging,

$$occ.unit = \frac{N_{occ}}{2} \tag{41}$$

For multi-family (2-4 units and 5 or more units),

$$occ.unit = \frac{N_{occ}}{3} \tag{42}$$

For 2-4 units, occ.unit should be >=2 and <=4. For five or more units, occ.unit should be >=5 units.

For restaurants,

$$occ.unit = \frac{floor.area}{\frac{42ft^2}{seat}} \tag{43}$$

For all other non-residential building types:

$$occ.unit = N_{occ} \tag{44}$$

For application to the CBECS end use estimation, N_{occ} is the number of employees during the main shift.

B. Calculate the occupancy distribution (occ.dist).
This is the total floor area divided by the occupancy units:

$$occ.dist = \frac{floor.area}{occ.unit} \tag{45}$$

C. Select the default recovery capacity (cap.rec), based on building type.

Table A.21: Service Hot Water Recovery Capacity (gal/hr/occ.unit)[a]

Building Type	Recovery Capacity
Assembly	0.003151*occ.dist
Education	0.50
Food Sales	0.003834*occ.dist
Food Service	0.90
Health Care	2.40
Lodging	2.10
Mercantile/Service	0.003989*occ.dist
Office	0.003151*occ.dist
Public Order	0.003151*occ.dist
Warehouse/Storage	0.001141*occ.dist
Other Non-Residential	0.001141*occ.dist
Multi-family (2-4 units)	3.40
Multi-family (>= 5 units)	3.40

D1. Select or calculate the required useable storage capacity ($cap.stor_{occ}$), based on building type.

[a]Recovery capacities for selected building types obtained from REMP data.

Table A.22: Service Hot Water Storage Capacity
(gal/occ.unit)

Building Type	Storage Capacity	Source[a]
Assembly	see Office equations	fig. 12
Education	1.00	fig. 16, cap.rec=0.50
Food Sales	see Office equations	fig. 12
Food Service	2.50	fig. 13, curve A
Health Care	5.00	fig. 11, cap.rec=2.40
Lodging	4.00	fig. 9, cap.rec=2.10
Mercantile/Service	for **0.1** < cap.rec < **0.35**: -1.14301*ln(2.427538*cap.rec); cap.rec **< 0.1**: use 1.75; **>0.35: use 0.1**	fig.12
Office		
Public Order		
Warehouse/Storage		
Other Non-Residential		
Multi-family (2-4 units)	6.00	fig. 10, cap.rec=3.40,
Multi-family (> 5 units)	6.00	20 or fewer units curve

E. Calculate the overall required storage capacity for building (cap.stor). This is the useable storage capacity per occ.unit, multiplied by the occ.unit and divided by the estimated ratio of usable volume to total volume for a water heater storage tank (0.70):

$$cap.stor = \frac{cap.stor_{occ} \times occ.unit}{0.70} \tag{46}$$

F. Calculate number and dimensions of storage tanks, based on system type.

i. Central Systems:
For a central system, $N_{tank} = 1$. The volume, in cubic inches, required is calculated:

$$V_{tank} = 231 \frac{in^3}{gal} \times cap.stor\ (gal) \tag{47}$$

[a]All storage capacity values and equations were derived from figures 9-16, pages 54.8-54.9 in ASHRAE 1987 HVAC Systems and Applications Handbook. Single number values are the storage capacities for the mid-range (mid-way between the minimum and the maximum values) of the available recovery capacities on a figure. The equations are estimates of the equations for the curves in the figures.

To obtain tank dimensions, a ratio of tank height to diameter (a) must be assumed. For the electric fuel type, a is assumed to be 2.5. For all other fuel types, a is assumed to be 2.7. The diameter of the tank can then be calculated:

$$D_{tank} = \sqrt[3]{\frac{4 \times V_{tank}}{\pi \times a}} \tag{48}$$

The height is then:

$$H_{tank} = a \times D_{tank} \tag{49}$$

ii. Distributed systems:

Current assumption is that for commercial buildings, tanks are 80 gallons.

$$N_{tank,i} = \frac{cap.stor}{V_{tank,i}} \tag{50}$$

Each $N_{tank,i}$ should then be truncated to a whole number. The number of tanks should be selected by finding the minimum of this function:

$$[V_{tank,i} \times (N_{tank,i} + 1)] - cap.stor \tag{51}$$

G. Select insulation thickness and thermal conductivity, based on building construction year and fuel type. This is only for distributed systems. Central system tanks are assumed to be uninsulated.

Table A.23: Insulation Thickness and Conductivity, Commercial Water Heaters[a]

Electric Fuel Type

Construction Year	Insulation Thickness (in.)	Insulation Conductivity (Btu*in/hr/ft^2/°F)
Before 1975	1.00	0.353
1975-1985	2.00	0.273
1985-present	2.00	0.165

Gas Fuel Type and Other

Construction Year	Insulation Thickness (in.)	Insulation Conductivity (Btu*in/hr/ft^2/°F)
Before 1975	0.50	0.353
1975-1985	1.00	0.273
1985-present	2.00	0.256

H. Calculate average daily use (shw.use), by building type.

Table A.24: Service Hot Water Average Daily Use ($shw.use_{oc\ c}$) (gal/occ.unit)[b]

Building Type	Daily Use	Building Type
Assembly	1.0	Office
Education	1.8	Jr. & Sr. High School
Food Sales	1.0	Office
Food Service	2.4	Type A (full service)
Health Care	18.4	Nursing Homes
Lodging	13.1	Men's Dormitories
Mercantile/Service	1.0	Office
Office	1.0	Office
Public Order	1.0	Office
Warehouse/Storage	1.0	Office
Other Non-Residential	1.0	Office
Multi-family (2-4 units)	42.0	< 20 units
Multi-family (>= 5 units)	42.0	< 20 units

The average daily use for the building is then:

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[a]Note: Thermal conductivities from 1982 ADL report on "Consumer Product Efficiency Standards."

[b]Values from Table 1, page 54.4 in ASHRAE 1987 HVAC Systems and Applications Handbook (ASHRAE 1987b). Building Type column indicates building type from Table 1.

$$shw.use = shw.use_{occ} \times occ.unit \quad (52)$$

FOR ALL BUILDING TYPES:
1. Set ground water temperatures by facility climate zone[a]:

Climate Zone	Ground Water Temperatures (°F)
Zone 1 (< 2,000 CDD and > 7,000 HDD)	48°F
Zone 2 (< 2,000 CDD and 5,000 to 7,000 HDD)	54°F
Zone 3 (< 2,000 CDD and 4,000 to 5,499 HDD)	58°F
Zone 4 (< 2,000 CDD and < 4,000 HDD)	63°F
Zone 5 (> 2,000 CDD and < 4,000 HDD)	70°F

2. Supply temperature is 140 °F.

3. Recirculation flag is yes for lodging and health care building types; no for all other types.

4. Set conversion efficiencies. Efficiencies are defaults based on system type, fuel type, building category (residential or commercial) and age:

A. For distributed systems:

Residential, gas:

Age	Efficiency
pre-1975	0.70
1975-1990	0.75
1990-present	0.77

Commercial, gas:

Age	Efficiency
pre-1975	0.70
1975-1990	0.75
1990-present	0.76

Any building, electric: Efficiency = 0.98

B. For central systems:

Calculation of Remaining Life
For FEDS, the estimation of the nominal efficiency of furnaces, boilers, conventional chillers, heat pumps and packaged units uses an assumed remaining

---

[a]These temperatures represent eyeball averages that were developed by overlaying USGS ground water temperature on the Climate zone map from NBECS.

life of the equipment. The remaining life of the equipment is inferred as follows:

i. A maximum life (max.life) for the equipment is first assumed. For furnaces, conventional chillers, heat pumps, and packaged units:

$$\text{max.}life = 20\ years \tag{53}$$

for boilers:

$$\text{max.}life = 40\ years \tag{54}$$

ii. The age of the building (age_{bldg}) is checked. If age_{bldg} is less than max.life, then the remaining life is:

$$rem.life = \text{max.}life - age_{bldg} \tag{55}$$

If age_{bldg} is greater than or equal to max.life, then:

$$rem.life = \frac{\text{max.}life}{2} \tag{56}$$

iii. For shw boilers, the efficiency is estimated as a bi-linear function of both remaining life (in years) and equipment capacity (in watts). For gas boilers, the equation is:

$$\eta = 0.723048 - (3.69596\times10^{-3} \times rem.life) + (6.6916\times10^{-9} \times cap_{eq}) \tag{57}$$

and for oil boilers:

$$\eta = 0.743048 - (3.69596\times10^{-3} \times rem.life) + (6.6916\times10^{-9} \times cap_{eq}) \tag{58}$$

5. Set the default (uninsulated) piping loss to 0.205 W/°F for all building types without re-circulation systems (i.e., every type BUT lodging and health care).

Calculate required service hot water generator output capacity (shw.cap).

Output capacity is function of the specific heat of water (c_p), recovery capacity (cap.rec), ground temperature (T.ground), supply temperature (T.supply), occupancy unit (occ.unit) and number of tanks (N_{tank}).

$$shw.cap = \left(\frac{cap.rec \times occ.unit \times c_p \times (T.supply - T.ground)}{N_{tank}}\right) \times 0.293\frac{W\text{-}hr}{Btu} \quad (59)$$

For single family residences, use a recovery capacity of 3.40 gal/hr/occupancy unit; calculate the occupancy unit as in equation 2 above.

A.9 CHANGES MADE TO FEDS DEFAULTS AFTER PRELIMINARY DATA ANALYSIS

Primarily based upon the monthly billing decomposition analysis, a number of changes to the FEDS default values were made to produce a "second-round" set of engineering end-use consumption estimates. The major changes involved ventilation, refrigeration, and lighting. Changes made to FEDS default assumptions for the final SAE analysis with the CBECS were as follows:

1. Hospitals/health care: Change the misc. equipment defaults by setting refrigeration and food prep w/sf and utilization factors to the same values as Food Service; set the health care misc. equipment to 0.125 W/sf, occupied utilization of 0.9, unoccupied of 0.3.

2. Lodging: Use the FEDS lighting utilization factors, instead of the factors supplied by CBECS.

3. Warehouse and Other: set the ventilation mode to DEMAND (from OFF) for these building types.

4. Reduce the Office refrigeration W/sf by 20%.

5. Hospital: change ventilation mode to ON (on all the time).

6. Office: for large offices (floor area >= 50000 sqft), change ventilation mode to ONDEMAND (on all the time during occupied hours, in demand mode during unoccupied hours).

In addition to the changes made directly within the FEDS code, several adjustments were made to the end-use estimates in the adjustment program software prior to the regression analysis. These changes were:

1. FEDS-generated electricity consumption for all end uses in education building were reduced by the following amounts over the summer months: June (-20%), July (-25%), August (-20%), and September (-5%).

2. The FEDS refrigeration consumption in grocery (food sales) stores was reduced by 55%.

3. In lodging, lighting and miscellaneous equipment use from FEDS were reduced by 50%.

A. 10 REFERENCES--APPENDIX A

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APPENDIX B

INFERENTIAL METHOD BASED ON 1986 NBECS

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An important data source used to infer basic building characteristics for FEDS Level-1 is the 1986 Nonresidential Building Energy Consumption Survey (NBECS), conducted by the DOE's Energy Information Administration (EIA). As the third comprehensive national sample of commercial buildings conducted by EIA, the 1986 NBECS included over 6,000 buildings (EIA 1988). The survey collected a variety of information on general construction materials (e.g., type of wall or roof construction), HVAC and lighting equipment, window characteristics, and basic conservation features.

In the end-use estimation work in this study, the 1986 NBECS was used only to infer characteristics that were dropped in the 1989 CBECS. The main characteristic that the inferential method was applied for was the percentage of exterior wall surface covered by glass.

B.1 BASIC ASSUMPTIONS AND APPROACH

The basic assumption behind the inferential method is that for a specific building type, buildings with a common vintage and size, and built in the same climate region, often display similar characteristics. Given these classifying categories of age, size, and climate region, the most probable characteristics in the NBECS buildings are mapped to the buildings being analyzed by the FEDS level-1 building model.

One approach to using the NBECS is to assign the characteristic in question from the appropriate vintage-size-climate region cell in the NBECS to the FEDS buildings.[a] Unfortunately, at the building type level, the sample size in NBECS are generally not large enough to provide robust results. As an example, consider the fraction of Retail/Service buildings using tinted or reflective glass. The raw survey results indicate that 48% of these buildings, in the size range of 25,000 to 50,000 ft^2, that were built before 1946 have tinted or reflective glass. This percentage was based on two observations using the NBECS sample weights. For the subsequent vintage (1946 to 1960), the survey indicates less than 11% of the same type and size of buildings used tinted or reflective glass. This percentage is based on five observations. Because of the small sample sizes, implausible discontinuities such as this are pervasive at the building type level.

To overcome this problem, some structure was imposed on the various effects attributable to each of these variables. An additive effects model was used, estimated by a statistical regression of the building characteristics on categories of vintage, size, climate region, and building type. The linear model underlying this regression assumes that the effects of age, size,

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[a] This project used the public use file from the 1986 CBECS as provided by EIA. The total sample size was 6,222 observations.

and climate zone are first approximations, independent of each other. This formulation also implies that marginal contributions of a given variable (e.g., moving from buildings built between 1946 and 1960 to buildings built between 1961 and 1973, as in the case above) are also independent of the other categorical variables. Thus, the change in the fraction of buildings using tinted glass between adjacent vintages is assumed to be similar across climate zones, building types, and building sizes.

Table B.1 shows the variables used in each of the building characteristics regressions. Compact (dummy) variable names are shown in parentheses to motivate the discussion.

TABLE B.1. Categories for Explanatory Variables in Commercial Buildings Characteristics Regressions

Size (ft^2)	
less than 5,000	(D-Size1)
5,000 to 10,000	(D-Size2)
10,000 to 25,000	(D-Size3)
25,000 to 50,000	(D-Size4)
50,000 to 100,000	(D-Size5)
over 100,000	(D-Size6)

Climate zone		
HDD	CDD	
> 7,000	< 2,000	(D-Clim1)
5,500 to 7,000	< 2,000	(D-Clim2)
4,000 to 5,500	< 2,000	(D-Clim3)
2,000 to 4,000	< 2,000	(D-Clim4)
2,000 to 4,000	> 2,000	(D-Clim5)

Vintage (Year Constructed)	
before 1946	(D-Vint1)
between 1946 and 1960	(D-Vint2)
between 1961 and 1973	(D-Vint3)
between 1974 and 1979	(D-Vint4)
between 1980 and 1986	(D-Vint5)

Building Type	
Office	(D-Type1)
Retail/Service	(D-Type2)
Assembly	(D-Type3)
Food Sales	(D-Type4)
Public Order	(D-Type5)
Warehouse	(D-Type6)
Education	(D-Type7)
Food Service	(D-Type8)
Hospital	(D-Type9)
Lodging	(D-Type10)
Other	(D-Type11)
Vacant	(D-Type12)

All of the variables in Table B.1 are qualitative or dummy variables, which take on only the values of zero or one. Thus, for warehouses with over 100,000 ft^2, in climate zone 4, built in 1977, the following variables would be set to 1.0:

D-Type6 = 1.0
D-Size6 = 1.0
D-Clim4 = 1.0
D-Vint4 = 1.0

All other variable are set to zero.

As discussed above, the value of specific building characteristic X (e.g., fraction of the wall area that is glass) was assumed to follow an additive (linear) form:

$$\begin{aligned} X = a &+ b2 * D\text{-}Size2 + \ldots + b6 * D\text{-}Size6 + \\ &c2 * D\text{-}Vint2 + \ldots + c5 * D\text{-}Vint5 + \\ &d2 * D\text{-}Clim2 + \ldots + d5 * D\text{-}Clim5 + \\ &e2 * D\text{-}Type2 + \ldots + e12 * D\text{-}Type12 + \\ &(D\text{-}Size6 * D\text{-}Type) + v \end{aligned} \tag{B.1}$$

where X = value of building characteristic (or fraction of buildings with specific characteristic)

D-Sizei, D-Vinti, D-Climi, and D-Typei = size, vintage, climate region, and building type dummy variables

v = random disturbance term

Because the model was estimated with a constant term (a), the first dummy variable in each set must be dropped from the equation to avoid a linear dependence (see any introductory econometrics text, e.g., Johnston [1972]). One interaction variable was added to the regression to better capture the special features of very large office buildings. This variable was assigned the value of 1.0 for offices greater than 100,000 ft^2. The final model contained 26 variables, not including the constant term.

All but a few of the building characteristics which need to be adapted from the NBECS were qualitative variables. At the individual observation level, a building either had the characteristic in question (e.g., tinted glass) or it did not. For these variables, the metric of interest is the probability that the building with a certain age-size-climate zone configuration contained the characteristic. To infer these probabilities, the predicted fraction of buildings within given subsets or cells of the sample was used. The cells were defined along the same categories as shown in Table B.1. The product of vintage (5), size (6), climate zone (5), and

building type (12) results in a potential 1,800 cells or observations. For each cell, the fraction, (using the sample weights provided with the NBECS) of buildings containing the characteristic was calculated. In practice, however, many of the cells contain no observations. The actual number of observations used in the regressions was a little over 1,200.[a]

As mentioned above, the small number of observations in the individual cell suggests that the variance of the estimated characteristics levels may be relatively high. Because the number of observations differs by cell, the standard of assumption of constant variances for the individual cell-based observations, implicit in the standard least squares regression procedure, does not hold. To account for this, we assume that the variance of the each observation [v in (1) above] is proportional to the number of observations. This results in a weighted least squares estimation in which each observation is multiplied by $1/\sqrt{n}$.

B.2 ILLUSTRATIVE RESULTS

Table B.2 provides an illustration of the estimation results; in this case for the fraction of buildings with tinted or reflective glass. Across the 1,231 cells with observations, the percentage of total variance explained by the model is 45% (RSQ = 0.4468). With the exception of a few of the building-type dummy variables, all of the variables are statistically significant at the 95% level. The coefficients show an expected pattern. The first five coefficients show that increasingly larger buildings, new buildings, and buildings in the warmest climate zones are more likely to employ tinted or reflective glass.

Office buildings are incorporated as part of the constant term. Thus, the coefficients on the building-type dummy variables indicate differences from the average office building. The fact that all of these coefficients are negative reveals that other building types are less likely to use tinted or reflective glass than office buildings. Tinted glass is especially prevalent in large office buildings, as shown by the positive coefficient on "D-Large Office."

Using the regression results within the FEDS Level-1 software is straight forward. For example, consider buildings in the following category: retail/service, 10 to 25,000 ft^2, built between 1974 and 1979, and located in climate zone 2. The fraction of such buildings with tinted or reflective glass is estimated to be

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[a] An alternative approach to the existence of a qualitative dependent variables is to use a qualitative choice model, normally a logit specification. This type of procedure would have entailed considerably more effort and cost and would probably not have changed the overall results from the FEDS screening energy analysis.

$$F = 0.07 - 0.16 + 0.13 + 0.19 + 0.09$$
$$(Bldg\ Type)\quad (Size)\quad (Vintage)\quad (Climate\ Zone)$$

$$F = 0.32$$

The FEDS Level-1 software interprets this result as a probability. In most cases, a probability of less than 0.5 results in the assumption that the characteristic in question is not present. An equation-generated probability of greater than 0.5 results in using that particular characteristic for building energy simulation. For continuous variables, such of the fraction as wall area that is glass, the equation-generated result is used directly in the building energy simulation.

TABLE B.2. Regression Results for Tinted or Reflective Glass (Fraction of Buildings)

$R^2 = 0.4468$

	Coef.	T-stat.
Constant	0.07	5.14
D-Size (5-10K)	0.07	7.72
D-Size (10-25K)	0.13	14.06
D-Size (25-50K)	0.18	17.22
D-Size (50-100K)	0.24	20.79
D-Size (> 100K)	0.34	30.10
D-Large Office	0.05	2.88
D-Vint (1946-1960)	0.07	7.20
D-Vint (1961-1973)	0.14	16.74
D-Vint (1974-1979)	0.19	18.70
D-Vint (1980-1986)	0.26	27.28
D-Clim (Zone 2)	0.09	8.28
D-Clim (Zone 3)	0.05	4.39
D-Clim (Zone 4)	0.17	15.11
D-Clim (Zone 5)	0.19	16.24
Retail/Service	-0.16	-15.31
Assembly	-0.10	-8.41

Food Sales	-0.08	-3.46
Public Order/Safety	-0.16	-5.71
Warehouse	-0.30	-26.78
Education	-0.25	-20.46
Food Service	-0.03	-1.87
Hospital	-0.00	-0.05
Lodging	-0.17	-10.80
Other	-0.21	-11.06
Vacant	-0.21	-13.44

Note: the base building is an Office, < 5,000 ft^2, built before 1946, in Climate Zone 1

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APPENDIX C

DESCRIPTION OF LOAD CALCULATION AND CONSUMPTION METHODS

APPENDIX C

DESCRIPTION OF LOAD CALCULATION AND CONSUMPTION METHODS

This appendix describes the methods used to calculate loads and energy consumption in FEDS. Before turning to the equations used in FEDS we define some key terms used throughout this appendix.

C.1 KEY TERMS

The terms profile, loads, consumption, and capacity are key terms that need to be clearly defined.

Profile

Throughout this document, the term profile is used as shorthand to describe a vector of 24 values, indexed by hour of the day. In order to estimate peak energy consumption, and accommodate time of day energy pricing, FEDS energy calculations are done using profiles. For example, consumption, load and occupancy profiles are calculated for the three day types: weekday, saturday, and sunday. Furthermore, consumption and load profiles are also calculated by month for each end use addressed by FEDS level 1. Consumption for a building can be described by a four dimensional array, indexed by:

- end use
- month
- day type
- hour of day

Loads vs. Consumption vs. Capacity

In this document, the term load will refer to the required energy output for an end use. Consumption will refer to the energy input required, after adjustments for efficiency, in order for the energy using equipment to meet the loads. Capacity refers to the amount of energy a piece of equipment would use if it were to run all the time. Capacity is an attribute of the piece of equipment; loads are attributes of the buildings; and, consumption is the energy that a piece of equipment uses to meet the loads generated within a building.

C.2 STEPS FOR CALCULATING CONSUMPTION

The fundamental steps to calculate building level consumption are:

I. Calculate lighting consumption for all day types and months
II. Normalize lighting to building square footage, for use in zone level calculations
III. Execute ZONE LEVEL calculations:
   A. Calculate glass UA, net UA and total zone UA values
   B. Use normalized lighting profile to calculate lighting profile for zone
   C. Determine required heating and cooling capacity for zone (based on peak days)
   D. Add this zone's heating and cooling capacities into building heating and cooling capacities
   E. FOR EACH MONTH:
      1. Calculate the solar gains
      2. FOR EACH DAY TYPE:
      a. Calculate equipment and service hot water consumption
      b. Calculate the internal gains (both to air and to building mass) from lights, equipment, and people.
      c. Calculate outdoor air ventilation volume.
      d. Calculate heating and cooling loads
      e. Calculate ventilation consumption
      f. Add this zone's end use consumptions for this month and day type into building end use consumptions for this month and day type

IV. RETURN TO THE BUILDING LEVEL, AFTER COMPLETION OF ZONE LEVEL CALCULATIONS: Calculate heating and cooling equipment efficiencies, which are based in part on the estimated capacities (see III.D)

C.3 BUILDING LEVEL CALCULATIONS

Lighting Consumption Calculations

NOTE: ALL CALCULATIONS ARE FOR HOURLY VALUES.

I. For each lighting type, τ:

A. Estimate the installed capacity, in watts/sq. ft.

$$light.cap_{\tau} = N_{\tau,b} \times f_{\tau} \times cap_{\tau} \quad (watts\ per\ ft^2) \tag{1}$$

where $light.cap_{\tau}$ = installed lighting capacity for lighting type τ

$N_{\tau,b}$ = lighting fixtures per square foot floor area for lighting type τ in building type b

f_{τ} = fraction of floor area served by lighting type τ in building type b

cap_{τ} = capacity per fixture of lighting type τ, in watts

B. Estimate the hourly lighting consumption profiles for each day type, based on the occupancy schedule and the utilization factors for occupied and unoccupied periods.

For each hour,

$$light.cons_{T,d} = light.cap_T \times light.util(occ.status_d) \quad (watts\ per\ ft^2) \quad (2)$$

where $light.cons_{T,d}$ = lighting consumption for lighting type τ, in the hour of day d

$light.cap_T$ = installed lighting capacity for lighting type τ

$light.util(occup.status_d)$ = lighting utilization factor for the occupancy status for the hour of day type d

II. The normalized lighting consumption profile for the building is simply the sum of the normalized consumption for each of the lighting types.

For each hour,

$$cons_{ilt,d} = \sum_{T=1}^{N_T} light.cons_{T,d} \quad (watts\ per\ ft^2) \quad (3)$$

Equipment Consumption Profiles

The miscellaneous equipment ('plug') end use can be broken down into three component end uses; food preparation, refrigeration, and other. Average daily consumption for these three components, $equip.cap_{foo}$, $equip.cap_{rfr}$, and $equip.cap_{oth}$ are selected by building type. These average consumptions are then multiplied by utilization factors for occupied and unoccupied periods (again selected by building type).

$$equip.cons_{T,d} = equip.cap_T \times equip.util(occ.status_d) \quad (watts\ per\ ft^2) \quad (4)$$

where $equip.cons_{T,d}$ = equipment consumption for equipment type τ, in the hour of day d

$equip.cap_T$ = installed capacity for equipment type τ (see Table A.10)

$equip.util_{\tau}(occup.status_d)$ = equipment utilization factor for equipment type τ, for the occupancy status for the hour of day type d (see Table A.11 for $occup.status_d$)

The normalized total equipment consumption profile for the building is simply the sum of the normalized consumption for each of the equipment types.

For each hour,

$$cons_{eqp,d} = \sum_{\tau=foo}^{oth} equip.cons_{\tau,d} \quad (watts\ per\ ft^2) \tag{5}$$

C.4 ZONE LEVEL CALCULATIONS

UA Calculations

The overall thermal conductivity of the building envelope (the exterior walls, roofs and windows in FEDS 1) is calculated for each zone. The conductivity of the walls and roof are calculated for each orientation contained in the zone. The window conductivity is summed across all orientations in the zone. The total UA for the zone, across all of the zone orientations, is also calculated. The overall thermal conductivity for a component (wall, roof or window) is calculated as follows:

$$UA_{comp,or} = U\text{-}value_{comp} \times Area_{comp,or} \tag{6}$$

For five-zone buildings, the perimeter zones will have contributions from all three components. For the core (interior) zone, the UA will be only for the roof.

The total zone conductive UA will be:

$$UA_{tot} = \sum_{comp=north}^{horiz} \sum_{comp=wall}^{roof} UA_{comp,or} \tag{7}$$

Lighting and Equipment Consumption Calculations

The lighting and equipment profiles for a zone are calculated by multiplying the normalized profile for the building by the zonal floor area. For lights:

$$cons_{ilt,z,d} = cons_{ilt,d} \times floor.area_z \quad (watts) \quad (8)$$

For equipment:

$$cons_{eqp,z,d} = cons_{eqp,d} \times floor.area_z \quad (watts) \quad (9)$$

How FEDS Uses the ASHRAE ASEAM (CLTD/CLF) Load Calculation Methodology

The CLTD/CLF method is based upon the use of cooling load temperature differences (CLTD) and cooling load factors (CLF) generated using transfer function methodology for a given thermal mass level, indoor and outdoor temperatures, and solar characteristics (latitude and time of year). The resulting CLTD and CLF profiles are then adjusted for differences in mass levels and ambient conditions and then used to estimate building HVAC load.

The CLTD profiles account for the storage of some of the solar energy incident upon the building envelope within the building envelope. This stored energy transfers into the building after the sun has set.

When addressing internal gains, the ASEAM method assumes constant loads that are completely ON during occupied periods, and completely OFF during unoccupied periods. A CLF profile accounts for the thermal storage in the mass of the furnishings of some of the constant load during the occupied period, to be released to the air during the unoccupied period.

The REMP information used by FEDS indicates that unoccupied loads are greater than zero (not completely OFF). This unoccupied load can be characterized as a constant base load, for which the CLF is 1. The difference between the occupied load and the unoccupied load is then the transient load which is effected by the CLF profiles. See Fig. load1 for an illustration:

Solar Gain Calculations

Solar gains are calculated for exterior walls, roofs, and long and short wave radiation through windows. The estimate for solar gains for the walls, roofs and long wave radiation starts with the cooling load temperature difference (CLTD) profiles selected for the component (wall, roof or window in FEDS-1) mass levels (for details on mass levels and selection of CLTD, cooling load factors--CLF's, and solar heat gain factors--SHGF--see section A.4, Default Value Generation). Cooling load temperature differences are specified by component, and are further specified by orientation for exterior wall components.

The methodology for using CLTD's (see chapter 26, ASHRAE Fundamentals, for description of CLTD/CLF methodology) require that the CLTD's be adjusted for latitude and month, mean indoor temperature different from 78 °F and mean outdoor temperature different from 85 °F:

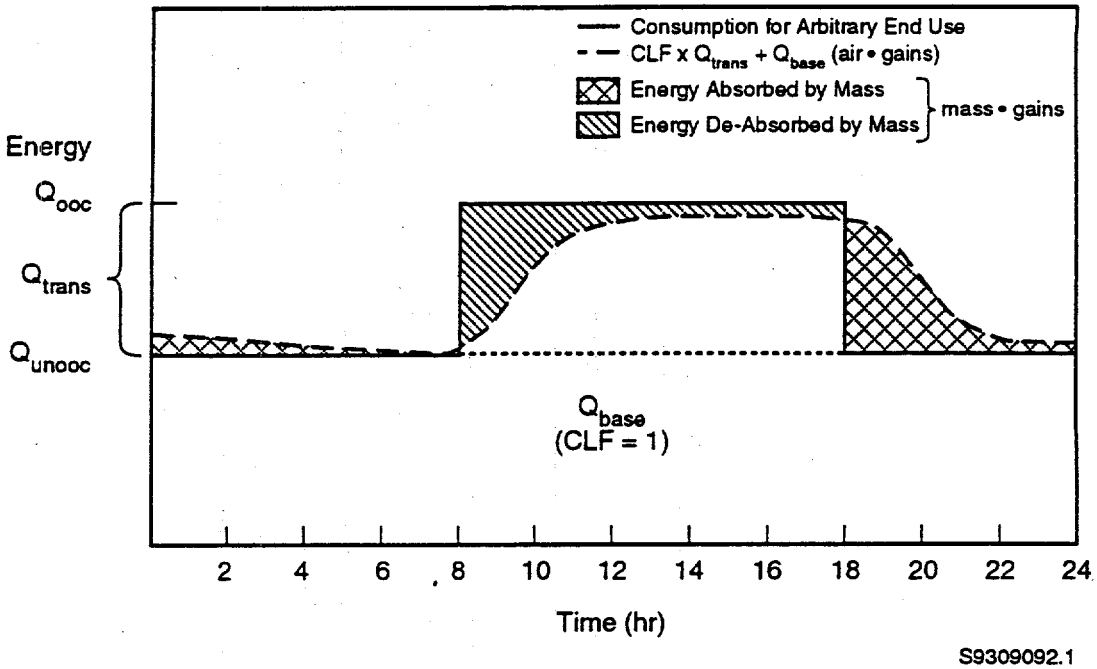

FIGURE C.1. Interaction of Consumption and Mass Storage as Estimated by Cooling Load Factors (CLF)

$$CLTD_{corr,comp,or} = (CLTD_{comp,or} + LM_{l,m,or}) \times K + (78 - T_{int}) + (T_{out} - 85) \quad (10)$$

The CLTD model then will estimate both the heat gain in a space due to insolation and the gain due to straight conductance through the components. Both of these are gains directly to the air.

$$UA_{comp,or} \times CLTD_{corr,comp,or} = UA_{comp,or} \times (T_{out} - T_{int}) + air.gains_{sol,comp,or} \quad (11)$$

Substituting in equation (10) for $CLTD_{corr,comp,or}$, and rearranging:

$$air.gains_{sol,comp,or} + UA_{comp,or} \times (T_{out} - T_{int}) = UA_{comp,or} \times ((CLTD_{comp,or} + LM_{l,m,or}) \times K + (T_{out} - T_{int}) + (78 - 85)) \quad (12)$$

Which reduces to a solution for $q_{sol,comp,or}$:

$$air.gains_{sol,comp,or} = UA_{comp,or} \times ((CLTD_{comp,or} + LM_{1,m,or}) \times K - 7) \quad (13)$$

During the hours the sun is up (daylight hours), the short wave radiation through the windows ends up in two places, in the air, and absorbed by the furnishings in the room. After the sun has set, the energy absorbed by the furnishings will be released back into the air. These quantities are calculated using solar heat gain factors (SHGF--specified by orientation, month and latitude) and cooling load factor profiles for windows (CLF_g--specified by orientation and mass of furnishings). During daylight hours, the CLF profiles adjust the total amount of heat gain in a space by the amount that is stored in room furnishings. After daylight hours, the CLF profile indicates the rate at which heat is transferred from the room furnishings to the air. A shading coefficient (SC) is applied to adjust the gains for the presence of tinted or reflective coatings.

The portion of the solar gain due to short wave radiation that goes to the air in the zone is calculated by equation 14. This holds true for any hour in the day:

$$air.gains_{sol,g,or} = Area_{g,or} \times SC \times SHGF_{m,or} \times CLF_g \quad (14)$$

The total solar gains to the air in the zone is then:

$$air.gains_{sol} = \sum_{or=north}^{horiz} (air.gains_{sol,g,or} + \sum_{comp=wall}^{roof} air.gains_{sol,comp,or}) \quad (15)$$

During daylight hours, the portion that is absorbed by the furnishings is:

$$mass.gains_{sol,g,or} = Area_{g,or} \times SC \times SHGF_{m,or} \times (1 - CLF_{g,or}) \quad (16)$$

During non-daylight hours, the portion that is de-absorbed by the furnishings is:

$$mass.gains_{sol,g,or} = Area_{g,or} \times SC \times SHGF_{m,or} \times (-CLF_{g,or}) \quad (17)$$

The solar mass gains can then be summed across orientations to obtain $mass.gains_{sol}$.

Internal Gains Calculations

In addition to the solar gains, the HVAC systems see the heat generated by lighting, equipment and people present in the zone. Waste heat can end up in one of three places:

- Some of the heat is rejected outside of the conditioned space (e.g., central refrigeration compressors in a grocery store).

The heat that is rejected in the conditioned space becomes part of the internal gains seen by the HVAC systems. Of that heat:

- Some of this heat is immediately seen by the HVAC system; in other words, the heat goes directly to the air.

- Some of the heat is absorbed by the furnishings in the zone, raising the temperature of the furnishings.

This first kind of heat is accounted for by a heat-to-space factor (frac.hts), which will only be less than one when some of the lighting or equipment heat is rejected outside of the conditioned space. Both kinds of internal gains are estimated using the cooling load factor (CLF) method (see chapter 26, ASHRAE Fundamentals). CLF profiles for lighting, equipment and people are selected according to the procedures described in section A.4.

To calculate lighting gains, the base and transient components of the lighting consumption are first calculated. The base component is:

$$cons.base_{ilt,z,d} = cons_{ilt,z,d}(occ.status = unoccupied) \quad (18)$$

The transient component of the consumption is:

$$cons.trans_{ilt,z,d} = cons_{ilt,z,d}(occ.status = occupied) - cons.base_{ilt,z,d} \quad (19)$$

Then the lighting gains directly to the air are calculated as follows:

$$air.gains_{ilt} = frac.hts_{ilt} \times (cons.base_{ilt} + cons.trans_{ilt} \times CLF_{ilt}) \quad (20)$$

For occupied hours, the gains absorbed by the mass are:

$$mass.gains_{ilt} = frac.hts_{ilt} \times cons.trans_{ilt} \times (1 - CLF_{ilt}) \quad (21)$$

During unoccupied hours, the gains de-absorbed by the mass are:

$$mass.gains_{ilt} = frac.hts_{ilt} \times cons.trans_{ilt} \times (-CLF_{ilt}) \quad (22)$$

Internal Gains Due to Occupancy

The equipment gains are calculated in exactly the same manner, substituting equipment consumption for lighting consumption.

For the occupants gains, a profile of the number of occupants in a zone is first calculated from the occupancy density profile and the zone floor area:

$$N_{occ,z} = occ.dens \times floor.area_z \quad (23)$$

The base and transient number of occupants is then calculated. The base number is:

$$base.N_{occ} = N_{occ}(occ.status = unoccupied) \quad (24)$$

And the transient number is:

$$trans.N_{occ} = N_{occ}(occ.status = occupied) - base.N_{occ} \quad (25)$$

To obtain the air gains, the base and transient numbers of occupants is then multiplied by the occupant sensible heat gain factor. The heat gain due to the transient occupancy is also adjusted by the CLF_{occ}:

$$air.gains_{occ} = HG_{sens} \times (base.N_{occ} + (trans.N_{occ} \times CLF_{occ})) \quad (26)$$

During occupied hours, gains for the occupants absorbed by the mass are:

$$mass.gains_{occ} = trans.N_{occ} \times (1 - CLF_{occ}) \tag{27}$$

During unoccupied hours, gains for the occupants de-absorbed by the mass are:

$$mass.gains_{occ} = trans.N_{occ} \times (-CLF_{occ}) \tag{28}$$

C.5 GAINS DUE TO VENTILATION

Calculation of Total Outdoor Air Volume

The volumetric flow rate of outdoor air is a function of intentional ventilation and unintended, but expected, infiltration through openings in the building envelope (e.g., cracks around doors and window frames). The fraction of ventilation air that is outdoor air is established by building codes in units of ft^3 per minute. The infiltration is estimated as air changes per hour (ACH). Both quantities are functions of the occupancy status (occupied or unoccupied). The total outdoor air flow rate is calculated as follows:

$$\dot{V}_{OA} = vent_{OA}(occ.status_d) + \left(\frac{ACH(occ.status_d) \times volume_z}{60 \frac{minutes}{hour}}\right) \tag{29}$$

Calculation of Sensible Gains from Outdoor Air

The internal gains due to outdoor air are entirely air gains; that is, the heating or cooling system sees the total effect of the outdoor air immediately. Sensible heat gains are a function of the outdoor-indoor temperature difference and the heat capacity of the air (1.10 BTU/(hr-CFM-°F) or 0.3223 W/(CFM-°F)):

$$air.gains_{OA} = \dot{V}_{OA} \times 0.3223 \times (T_{out} - T_{int}) \tag{30}$$

Total Internal Gains

The total internal gains for air and mass can be calculated for each hour as follows:

$$air.gains_{tot} = air.gains_{sol} + air.gains_{ilt} + air.gains_{eqp} + air.gains_{occ} + air.gains_{OA} \quad (31)$$

and

$$mass.gains_{tot} = mass.gains_{sol} + mass.gains_{ilt} + mass.gains_{eqp} + mass.gains_{occ} \quad (32)$$

Latent Cooling Load Calculations

Latent cooling load (the energy required to condense water vapor from the air, or dehumidify it) is an additional gain to be considered when a system is in cooling mode. There are two sources of latent cooling load, the outdoor air and the latent load associated with the presence of people in a building.

For outdoor air, the latent heat gains are a function of the outdoor-indoor humidity ratio (lb water/lb dry air) and the heat of vaporization for water at standard temperature and pressure (4840 BTU/(hr-CFM) or 1418 W/CFM):

$$lat.gains_{OA} = \dot{V}_{OA} \times 1418 \times (hum_{out} - hum_{int}) \quad (33)$$

The latent heat gains due to building occupants are a function of the occupancy profile (N_{occ}, in equation (23)) and the occupant latent heat gain factor:

$$lat.gain_{occ} = N_{occ} \times HG_{lat} \quad (34)$$

The total latent cooling load is then:

$$lat.gain = lat.gain_{OA} + lat.gain_{occ} \quad (35)$$

Zone HVAC Load Calculations--ETP based methodology

The ETP-based calculation method provides a mechanism for accounting for the heat transfer circuit formed by the storage capacity of the room mass and

the air, the heat transfer resistance of the envelope and the film between the mass and the air, and the internal generation of heat within the zone.

The thermal interactions in the zone are modeled after an RC circuit, with thermal storage analogous to capacitance; thermal resistance (the reciprocal of the conductance) is analogous to electrical resistance; temperature to voltage; heat sources to current sources. The FEDS version of this model is shown in Figure C.2.

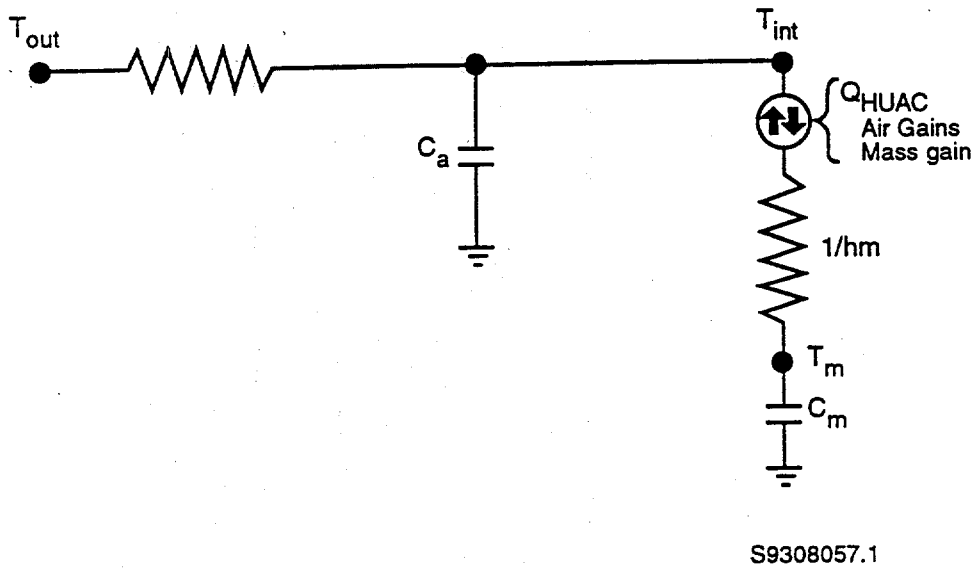

FIGURE C.2. Electrical Analog to ETP-based Calculation Method

Most of the terms in this figure have been defined above. C_a is a term combining the heat capacity of the air and the part of the mass in a room that stores and releases heat relatively quickly. For this analysis, C_a is estimated to be about 1 BTU/(°F-ft^2 floor area), or 0.293 W-hr/(°F-ft^2 floor area). Similarly, C_m is the estimated heat capacity of the "slower" mass in a room. The values for C_m vary according to building type (see section A.2.1 in Appendix A. h_m is the film conductance between the mass and the air in a zone. For this analysis, h_m is estimated to be about 1.5 Btu/(hr-°F-ft^2 floor area), or 0.4395 W/(°F-ft^2 floor area). T_m is the temperature of the mass. q_{hvac} is the energy added to (or, if cooling, removed from) the zone.

At the zonal level, C_a, C_m, and h_m must be multiplied by floor.area$_z$ for use in these calculations.

Using conservation of heat, the equations at T_{int} and T_m are as follows:

$$q_{hvac} + air.gains_{tot} = UA_{tot} \times (T_{out} - T_{int}) + h_m \times (T_{int} - T_m) + C_a \times \frac{dT_{int}}{dt} \tag{36}$$

and

$$h_m \times (T_{int} - T_m) + mass.gains_{tot} = C_m \times \frac{dT_m}{dt} \tag{37}$$

For the FEDS solution method, the terms for the first derivative with respect to time can be approximated by:

$$\frac{dT_{int}}{dt}\Big|_{t=t_0} \approx \frac{(T_{int}(t=t_0) - T_{int}(t=t_0-\Delta t)}{\Delta t} \tag{38}$$

and similarly for T_m. For brevity, let:

$$T_{int}(t=t_0) \equiv T_{int} \quad and \quad T_{int}(t=t_0-\Delta t) \equiv T_{int,last} \tag{39}$$

Again, similarly for T_m. Substituting these approximations in equation (36), solutions for both T_{int} and q_{hvac} can be obtained:

$$T_{int} = \frac{q_{hvac} + air.gains_{tot} + h_m \times T_{m,last} + UA_{tot} \times T_{out} + \frac{C_a \times T_{int,last}}{\Delta t}}{\frac{C_a}{\Delta t} + UA_{tot} + h_m} \tag{40}$$

and

$$q_{hvac} = T_{int} \times \left(\frac{C_a}{\Delta t} + UA_{tot} + h_m\right) - \frac{C_a \times T_{int,last}}{\Delta t} - UA_{tot} \times T_{out} - h_m \times T_{m,last} - air.gains_{tot} \tag{41}$$

Also, similar substitutions into equation (37) yields a solution for T_m:

$$T_m = \frac{\frac{C_m \times T_{m,last}}{\Delta t} + h_m \times T_{int} + mass.gains_{tot}}{\frac{C_m}{\Delta t} + h_m} \tag{42}$$

These three equations, (40), (41), and (42), serve as the core of the FEDS heating and cooling load calculation method. The solution of these differential equations is implicit. Initial conditions are estimated and then the solution is stepped through a finite number of 24 hour "days". The current assumption is that the method will be close enough to convergence after a few (at this point, three) days. The current value for Δt is 0.25 hour. The general solution steps are as follow:

1. At the beginning of each hour, calculate air.gains, mass.gains and lat.gains.

   for each increment of Δt:

2. Set $T_{int,last} = T_{int}$ obtained from previous Δt step. Same for $T_{m,last}$.

3. Solve for new T_{int}, with no heating or cooling energy ($q_{hvac} = 0$).

4. Check to see if the new T_{int} is within the deadband for the heating or cooling thermostat settings. If it is, set q_{hvac} for that time step to 0, and skip to step 6.

5. If T_{int} is outside of the thermostat deadbands, then set T_{int} to the appropriate (heating or cooling) thermostat setting, and solve for the value of q_{hvac} that would be required for T_{int} to be at the setting. If the mode is cooling, then add lat.gains to q_{hvac}, to obtain the total cooling load.

6. If q_{hvac} is less than or equal to the estimated heating or cooling capacity for the zone, then skip to step 8.

7. If q_{hvac} is greater than the estimated capacity, and the mode is heating, set q_{hvac} to the heating capacity and solve for T_{int} with this q_{hvac}. This is to be T_{int} in this case. If the mode is cooling, set q_{hvac} to the cooling capacity less the value of lat.gains, and then solve for T_{int}.

8. Solve for T_m. Cycle to next Δt period.

This generalized method is modified for two special cases. The first is when it is used to estimate the required heating and cooling capacity for a zone. In this case, step 7 is omitted. The maximum value in the resulting profile is used as the estimate for the capacity; the solution is run once for peak heating conditions and once for peak cooling conditions.

The second case can occur during either the calculation of loads or capacity. This is when the thermostat is set to different values during occupied and unoccupied periods (e.g., night setback during the heating season). During the transition period (as defined by the warm-up period default for the building), it is assumed that T_{int} increases (or decreases, for cooling) linearly from its value at the beginning of the transition to the occupied thermostat setting at the end of the transition period. In this way, T_{int} is known throughout the transition period, so q_{hvac} and T_m are the only quantities solved for during that time.

Calculation of Zonal Heating and Cooling Capacities

Heating and cooling capacities for a zone are calculated using the same methods as the heating and cooling load calculations. However, the extreme hot and cold temperature profiles are used to calculate the peaks; and rather than a profile, the quantity of interest is maximum consumption for an hour.

Calculation of Zone Ventilation Consumption

FEDS models five potential modes of ventilation operation:

- no mechanical ventilation
- demand ventilation (cycles on and off with heating and cooling)
- constant ventilation (on 24 hours)
- constant ventilation during occupied periods, demand ventilation during unoccupied
- constant ventilation during occupied periods, off during unoccupied

Ventilation (fan) power consumption is dependent upon the air coil supply temperatures, thermostat settings, the static pressure of the air handling system, and the efficiency of the fan motor. For demand modes, the heating and cooling loads are also required to estimate the power. For constant ventilation, the heating and cooling capacities are required.

For demand ventilation modes, the calculations are:

1. Determine the total ventilation rate required to deliver heating or cooling to the zone. This rate calculated dividing the heating or cooling load (whichever is on at that hour) by the difference of the supply temperature and the desired temperature (thermostat setting) multiplied by the heat capacity of the air (1.08 BTU/(hr-°F-cfm) or 0.31644 W/(°F-cfm)):

$$V_{tot} = \frac{q_{hvac}}{(Tsupply_{mode} - Tset_{mode}) \times 0.31644} \qquad (43)$$

2. The power is the ventilation rate multiplied by the static pressure and the energy required to push the cfm against the static pressure (0.117528 W/(in. water-cfm), and divided by the fan motor efficiency:

$$cons_{vnt} = \frac{V_{tot} \times P_{static} \times 0.117528}{\eta_{fan}} \tag{44}$$

For constant ventilation, the ventilation rate is calculated by substituting first the heating capacity and temperatures, and then the cooling capacity and temperatures for q_{hvac}, Tsupply, and Tset in equation (43). The maximum of the two values is then used in equation (44) to calculate the consumption.

C.6 SERVICE HOT WATER CONSUMPTION

This module calculates the service hot water consumption due to service hot water use. It then sums this consumption with the tank and pipe standby losses (see Section C.7) to produce a profile of total service hot water consumption.

Required input:

- Building average daily hot water use, gal/day (shw.use)
- Service hot water supply temperature (T.supply)
- Ground water temperature (T.ground)
- Water heater efficiency (η_{shw})
- Number of service hot water tanks in the building (N_{tank})
- Presence of absence of a recirculation system

Assumptions:

- Specific heat of water is 8.33 Btu/gal (c_p)

Output:

- A 24-hour profile of hot water consumption for a particular technology ($cons_{shw}$)

1. Convert average daily water use to hourly average required energy:

$$shw.use_{avg,h} = \frac{\text{shw.use}}{24\text{hrs}} \times c_p \times (T.supply - T.ground) \times 0.293 \frac{\text{W-hr}}{\text{Btu}} \tag{45}$$

2. Select load profile appropriate for building type ($prof_{shw}$)

TABLE C.1. Protypical SHW Consumption Profiles[1]

Hour	Retail	Grocery	Office	Restaur.	School	Warehouse	Other	Residential
1	0.087	0.359	0.054	0.190	0.029	0.030	0.017	0.250
2	0.027	0.041	0.000	0.072	0.012	0.044	0.036	0.080
3	0.007	0.001	0.084	0.033	0.019	0.052	0.029	0.020
4	0.000	0.000	0.181	0.013	0.031	0.110	0.017	0.000
5	0.019	0.083	0.005	0.000	0.000	0.052	0.012	0.020
6	0.019	0.216	0.062	0.041	0.012	0.162	0.692	0.350
7	0.084	0.458	0.350	0.283	0.092	0.493	5.023	1.200
8	0.162	0.523	0.657	0.479	0.437	1.230	2.236	1.970
9	0.365	0.724	1.456	1.334	1.503	2.175	1.249	1.960
10	0.980	1.029	1.470	1.712	2.014	1.910	1.544	1.870
11	1.696	1.347	1.503	1.966	3.089	1.737	1.706	1.700
12	1.966	1.511	2.443	2.026	2.811	1.737	2.018	1.450
13	2.293	1.384	2.265	2.005	3.386	2.703	2.051	1.220
14	2.298	1.457	2.556	2.006	2.780	2.118	2.090	1.040
15	2.075	1.480	1.950	1.763	1.668	1.951	1.078	0.870
16	2.172	1.275	1.850	1.458	1.595	2.035	1.575	0.820
17	2.207	1.184	2.289	1.192	1.758	2.702	1.577	0.920
18	2.376	1.211	1.437	1.101	1.691	1.806	0.586	1.170
19	1.894	1.250	1.225	1.275	0.595	0.654	0.239	1.430
20	1.422	1.350	1.222	2.055	0.252	0.127	0.093	1.460
21	0.944	1.529	0.479	1.196	0.087	0.039	0.064	1.350
22	0.515	1.791	0.169	0.840	0.064	0.091	0.053	1.240
23	0.245	2.231	0.149	0.636	0.057	0.000	0.017	0.990
24	0.145	1.569	0.141	0.325	0.017	0.042	0.000	0.600

Map protype profiles to FEDS building type:

FED Building Type	Profile Prototype
Assembly	School
Education	School
Food Sales	Grocery
Food Service	Restaur.
Health Care	Residential
Lodging	Residential
Mercantile/Service	Retail
Office	Office
Public Order	Office
Warehouse/Storage	Warehouse
Other Non-Residential	Warehouse
All Residential Types	Residential

[1]Derived from ELCAP data; normalized to mean consumption after subtraction of standby load.

3. For each hour, calculate consumption due to service hot water usage:

$$cons.use_{shw,h} = \frac{shw.use_{avg,h} \times prof_{shw,h}}{\eta_{shw}} \tag{46}$$

4. For each hour, add in consumption due to pipe and tank standby loss with use consumption to obtain total service hot water consumption.

For systems without a recirculation system:

$$cons_{shw,h} = cons.use_{shw,h} + N_{tank} \times (cons.standby_{tank} + cons.standby_{pipe}) \tag{47}$$

For systems with a recirculation system:

$$cons_{shw,h} = cons.use_{shw,h} + (N_{tank} \times cons.standby_{tank}) + cons.standby_{pipe} \tag{48}$$

C.7 SERVICE HOT WATER STANDBY LOSS CALCULATION MODULE

These calculations are to be done for each service hot water technology. Both building and technology specific input data is required. The output will be technology specific.

Required inputs:

- Number and volume of storage tanks (N_{tank}, V_{tank})
- Dimensions of storage tank(s) (D_{tank}, H_{tank})
- Thickness and conductivity of tank insulation ($th.ins_{tank}$, $k.ins_{tank}$)
- Service hot water supply temperature (T.supply)
- Building floor area (floor.area)
- Pipe insulation thickness and conductivity ($th.ins_{pipe}$, $k.ins_{pipe}$)
- Service hot water fuel type ($fuel_{shw}$)
- Water heater efficiency (η_{shw})
- Piping loss, in W/°F (pipe.loss)
- Presence of absence of recirculation system

Output:

- Consumption due to tank standby loss, in watts ($cons.standby_{tank}$)
- Consumption due to pipe standby loss, in watts ($cons.standby_{pipe}$)

Assumptions:

- 70 °F ambient air temperature (T.ambient)
- 0.5 h-ft^2-°F/Btu (1.71 ft^2-°F/W) surface film resistance for air (h_{film})
- 0.064 h-ft^2-°F/Btu (0.217 ft^2-°F/W) surface film resistance for water in pipe (assumes laminar flow; h_{water})
- distribution system uses 1-inch nominal diameter pipes (approx. 1.1 inch OD-OD_{pipe}; approx. 1.05 inch ID-ID_{pipe})
- For recirculation system, average water temperature is 5 °F lower than T.supply
- Right cylindrical storage tanks

<u>Calculate Standby Loss for Storage Tank (loss.tank)</u>

1. Calculate loss from sides of tank:

   a. Calculate area of tank sides

$$area.tank_{side} = \frac{\pi \times (D_{tank} + 2 \times th.ins_{tank}) \times H_{tank}}{144 \frac{inches^2}{feet^2}} \tag{49}$$

   b. Calculate effective U-value for the tank sides (modeled as heat loss from cylinder)

$$U.tank_{side} = \frac{1}{\left(\frac{\frac{D_{tank}}{2}}{k.ins_{tank}}\right) \times \ln\left(\frac{D_{tank}+2\times th.ins_{tank}}{D_{tank}}\right) + \left(\frac{D_{tank}}{D_{tank}+2\times th.ins_{tank}}\right) \times h_{film}} \tag{50}$$

   c. Now calculate loss

$$loss.tank_{side} = U.tank_{side} \times area.tank_{side} \times (T.supply - T.ambient) \times \left(0.293 \frac{W\text{-}hr}{Btu}\right) \tag{51}$$

2. Calculate standby loss for an end of a tank

   a. Calculate area of tank end

$$area.tank_{end} = \frac{\pi \times \frac{D^2_{tank}}{4}}{144 \frac{inch^2}{foot^2}} \tag{52}$$

b. Calculate U-value for the tank end

$$U.tank_{end} = \frac{1}{\frac{th.ins_{tank}}{k.ins_{tank}} + h_{film}} \tag{53}$$

If this is a re-calculation of the tank end U-value after a wrap retrofit, the retrofitted U-value should only apply to ONE end (the top) of the tank. The baseline value of $U.tank_{end}$ should be used for the bottom of the tank.

c. Calculate loss from one end of the tank

$$loss.tank_{end} = U.tank_{end} \times area.tank_{end} \times (T.supply - T.ambient) \times 0.293 \frac{Whr}{Btu} \tag{54}$$

3. For distributed gas heaters, set $loss.tank_{flue}$ to 112 W.

4. Calculate total tank standby loss. For all but distributed gas heaters:

$$loss.tank = loss.tank_{side} + loss.tank_{end} + loss.tank_{end} \tag{55}$$

For distributed gas heaters, loss in bottom end is included in flue loss (see step 3):

$$loss.tank = loss.tank_{side} + loss.tank_{end} + loss.tank_{flue} \tag{56}$$

5. Convert standby loss to water heater demand

$$cons.standby_{tank} = \frac{loss.tank}{\eta_{shw}} \tag{57}$$

Calculate standby loss from piping system (loss.pipe)

1. For systems without re-circulation, piping loss is:

$$loss.pipe = pipe.loss \times (T.supply - T.ambient) \tag{58}$$

2. For systems with re-circulation,

   a. Estimate length of pipe, in feet[2]

$$L_{pipe} = 4 \times \sqrt{floor.area} \tag{59}$$

   b. Calculate surface area of the pipe system

$$area.pipe = \pi \times D_{pipe} \times L_{pipe} \tag{60}$$

   c. Calculate effective U-value for the pipe (modeled as heat loss from cylinder)

$$U.pipe = \frac{1}{\left(\frac{\frac{ID_{pipe}}{2}}{h_{water}}\right) \times \ln\left(\frac{ID_{pipe} + 2 \times (OD_{pipe} - ID_{pipe})}{ID_{pipe}}\right) + \left(\frac{ID_{pipe}}{OD_{pipe}}\right) \times h_{film}} \tag{61}$$

[2]This calculation approximates the building as single story square, and assumes pipe runs along each edge of the square.

d. Calculate estimate of circulation temperature

$$T.circ = T.supply - 5°F \tag{62}$$

e. Calculate loss from pipe

$$loss.pipe = U.pipe \times area.pipe \times (T.circ - T.ambient) \times 0.293 \frac{\text{W-hr}}{\text{Btu}} \tag{63}$$

f. Convert loss to equivalent water heater consumption

$$cons.standby_{\text{pipe}} = \frac{loss.pipe}{\eta_{\text{shw}}} \tag{64}$$

APPENDIX D

SAE REGRESSION RESULTS AND PLOTS BY BUILDING TYPE

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SAE REGRESSION RESULTS AND PLOTS BY BUILDING TYPE

Appendix D presents tabular and graphical results of the monthly predicted EUIs and SAE regression models for each of the 11 building types in the study. For each building type, eight pages are shown, in the following order:

1) Monthly average EUIs

2) SAE regression results for electricity

3) SAE regression results for gas

Variation of mean annual intensities by categories of:

4) Vintage

5) Building size

6) EIA climate region

7) Weekly hours

8) Employment density

Using small office and retail buildings as examples, these figures were discussed in chapters 5 and 6. All building-level EUIs are gross, in the sense that they are computed as total building consumption divided by total square footage. All average EUIs by building type, both monthly and annual, are unweighted. The number of observations for each category in plots (4) through (8) are shown at the top of the figures.

The categories in the annual plots [(4)- (8)] are generally self-explanatory[a]. The EIA climate zones are defined in Appendix B. Climate zone indices run from cold (zone 1) to hot (zone 5).

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[a] In some of the plots for natural gas, the total intensities from FEDS are too large to fit on the plot, given the y-axis scale chosen by the plotting software (e.g., pp. D.21; D.30; D.31; and D.38). The total is, of course, the sum of the heat and non-heat intensity shown in the plots to the right of that for the total intensity.

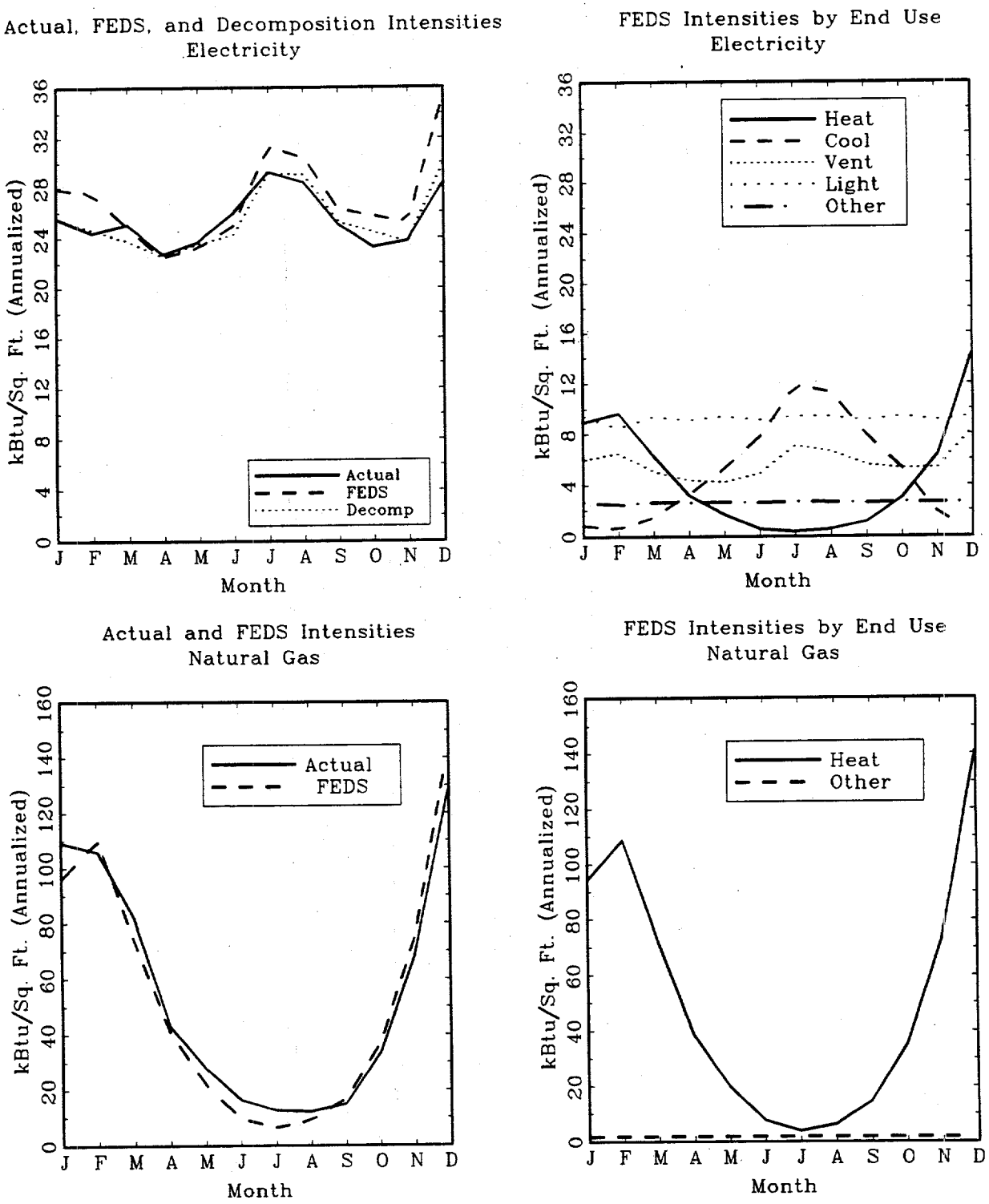

FIGURE D.1. Assembly: Monthly Average EUIs

HVAC

Valid cases:	445	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	245396.232	Degrees of freedom:	438
R-squared:	0.153	Rbar-squared:	0.141
Residual SS:	207869.198	Std error of est:	21.785
F(7,438):	11.296	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.537449	0.054897	9.790079	0.000	0.446383	0.453666
V1*HVf	-0.093350	0.123883	-0.753530	0.452	-0.038657	-0.008676
V2*HVf	0.246437	0.143486	1.717503	0.087	0.086946	0.148820
SQFT*HVf	0.000516	0.001260	0.409749	0.682	0.018371	-0.134992
CDD*HVf	0.000053	0.000053	1.001956	0.317	0.042068	0.101787
HRS*HVf	0.008953	0.001307	6.850915	0.000	0.286090	0.259447
EMP*HVf	0.050151	0.039182	1.279954	0.201	0.054055	0.140607

NHVAC

Valid cases:	445	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	396266.811	Degrees of freedom:	437
R-squared:	0.098	Rbar-squared:	0.083
Residual SS:	357520.622	Std error of est:	28.603
F(8,437):	5.920	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.252035	0.115636	10.827344	0.000	0.555421	0.515430
V1*NHVf	0.480836	0.209424	2.295991	0.022	0.105338	0.106262
V2*NHVf	1.158206	0.337769	3.428986	0.000	0.161954	0.055157
SQFT*NHVf	0.000127	0.000583	0.217747	0.828	0.009663	0.099949
CDD*NHVf	0.000026	0.000113	0.233829	0.815	0.009673	0.021428
HRS*NHVf	-0.002658	0.002033	-1.307720	0.192	-0.069703	0.269176
EMP*NHVf	0.055418	0.067219	0.824441	0.410	0.033685	0.061345
ElcMan	9.726374	14.437480	0.673689	0.501	0.027360	0.057892

FIGURE D.2. Assembly: SAE Regression Results for Electricity

Assembly	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	49.37	12.87	19.94	18.38	1.00	33.21	4.50

Assembly	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	4.85	261.73	1.11	2.47
Non-Baseload	1.00	7.86	74.25	.78	1.72

Valid cases:	294	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	1207004.965	Degrees of freedom:	287
R-squared:	0.259	Rbar-squared:	0.244
Residual SS:	894044.777	Std error of est:	55.813
F(7,287):	14.352	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	-0.132899	0.194571	-0.683037	0.495	-0.114436	0.636804
V1*SHf	0.109262	0.103735	1.053284	0.293	0.063510	0.486421
V2*SHf	0.690369	0.297532	2.320323	0.021	0.099812	0.200857
SQFT*SHf	0.000006	0.000004	1.627694	0.105	0.087513	0.391719
HDD*SHf	0.000075	0.000028	2.649703	0.009	0.423166	0.653559
HRS*SHf	0.000702	0.001560	0.450300	0.653	0.037031	0.609286
EMP*SHf	0.292491	0.055836	5.238443	0.000	0.318371	0.607703

FIGURE D.3. Assembly: SAE Regression Results for Natural Gas

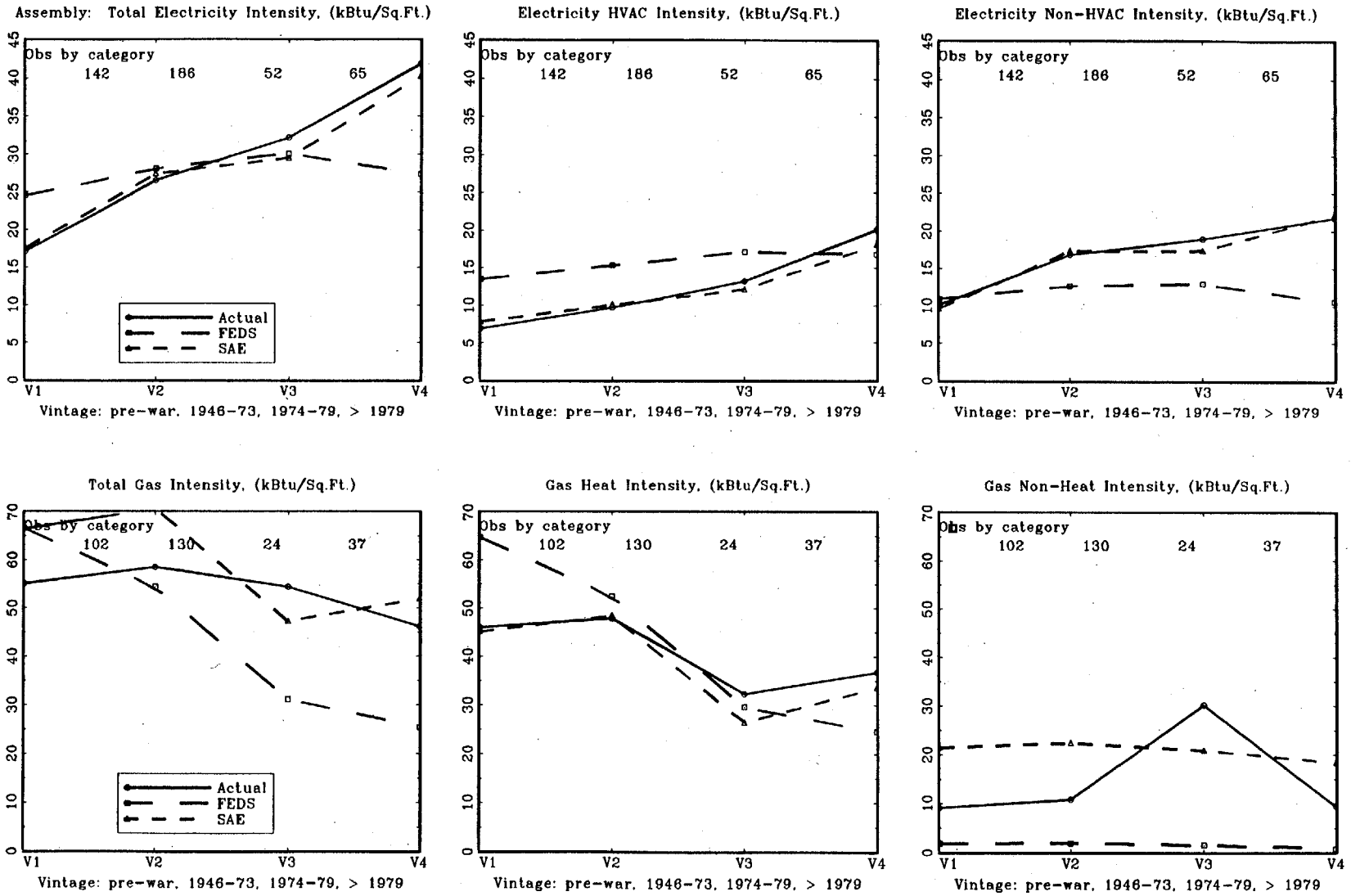

FIGURE D.4. Assembly: Actual, FEDS, and SAE Intensities By Vintage

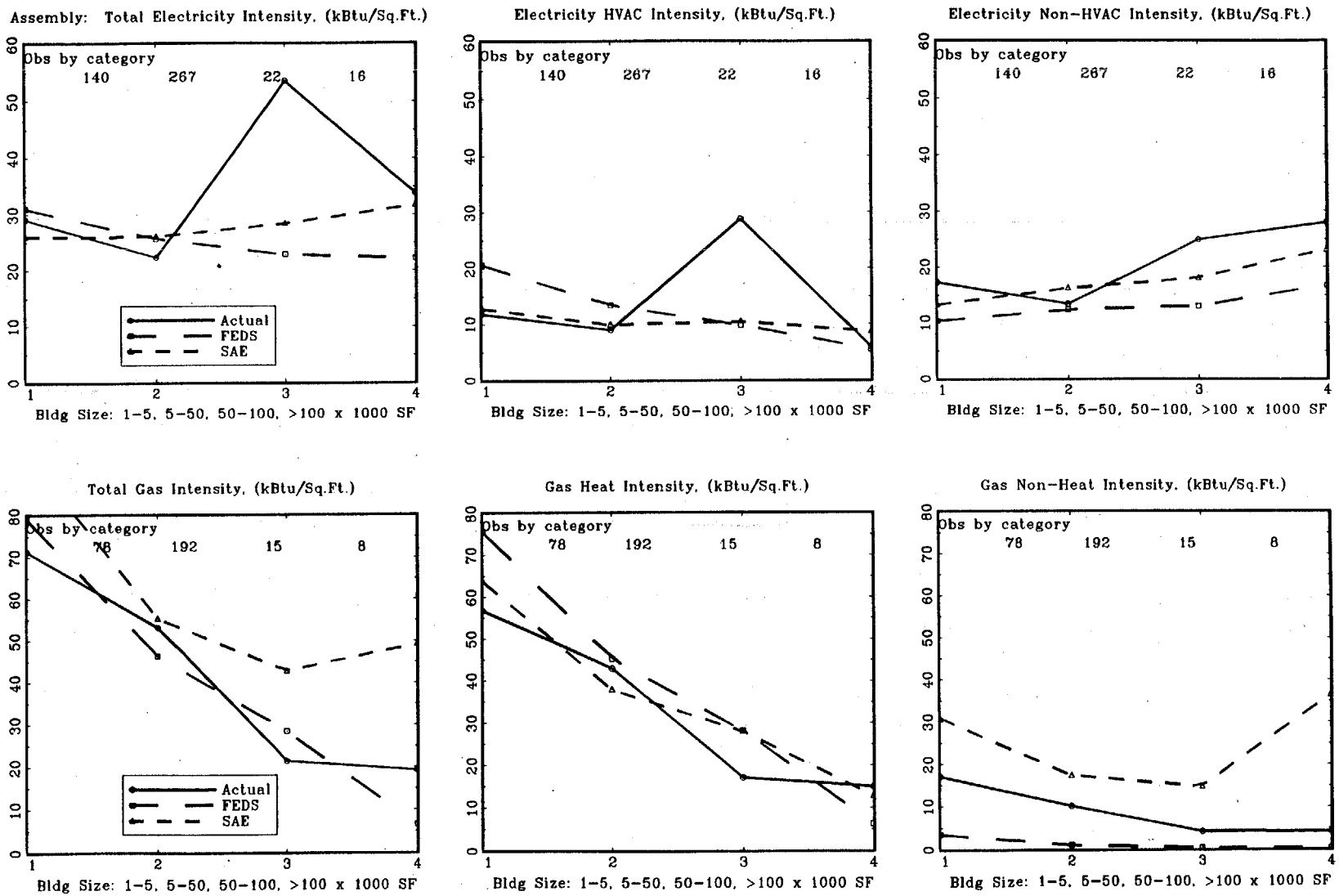

FIGURE D.5. Assembly: Actual, FEDS, and SAE Intensities By Building Size Category

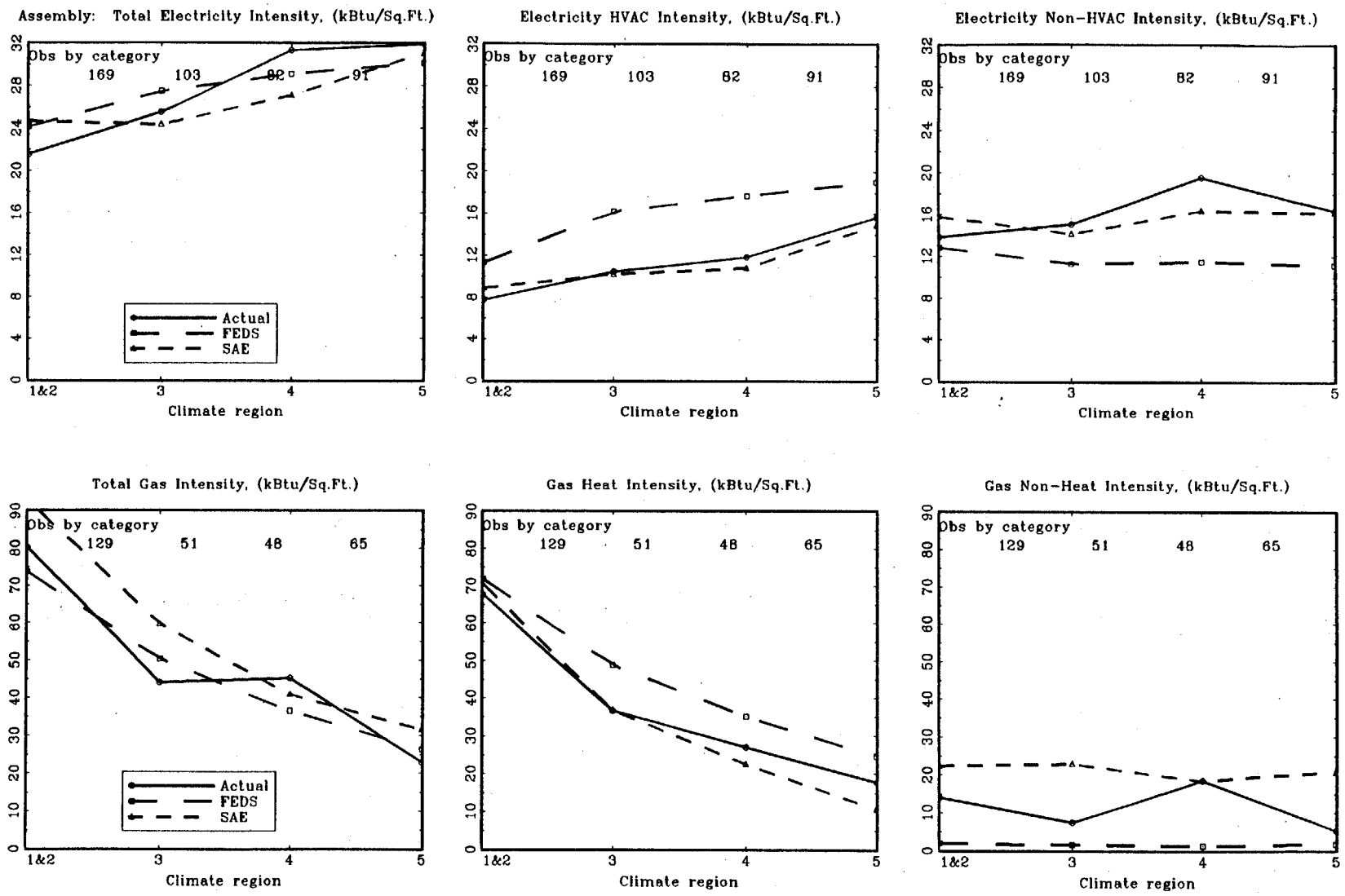

FIGURE D.6. Assembly: Actual, FEDS, and SAE Intensities By Climate Region

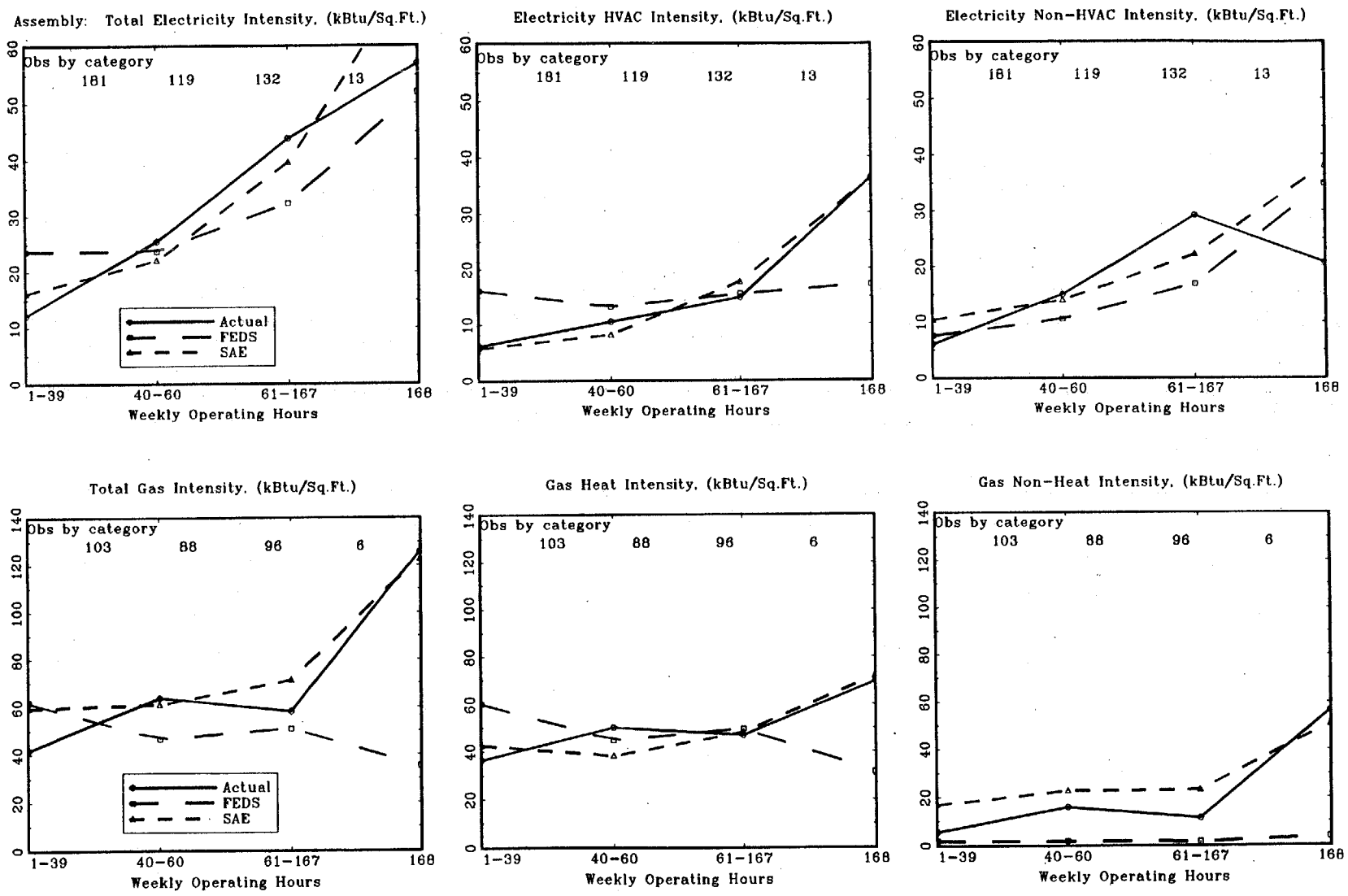

FIGURE D.7. Assembly: Actual, FEDS, and SAE Intensities By Weekly Hours Category

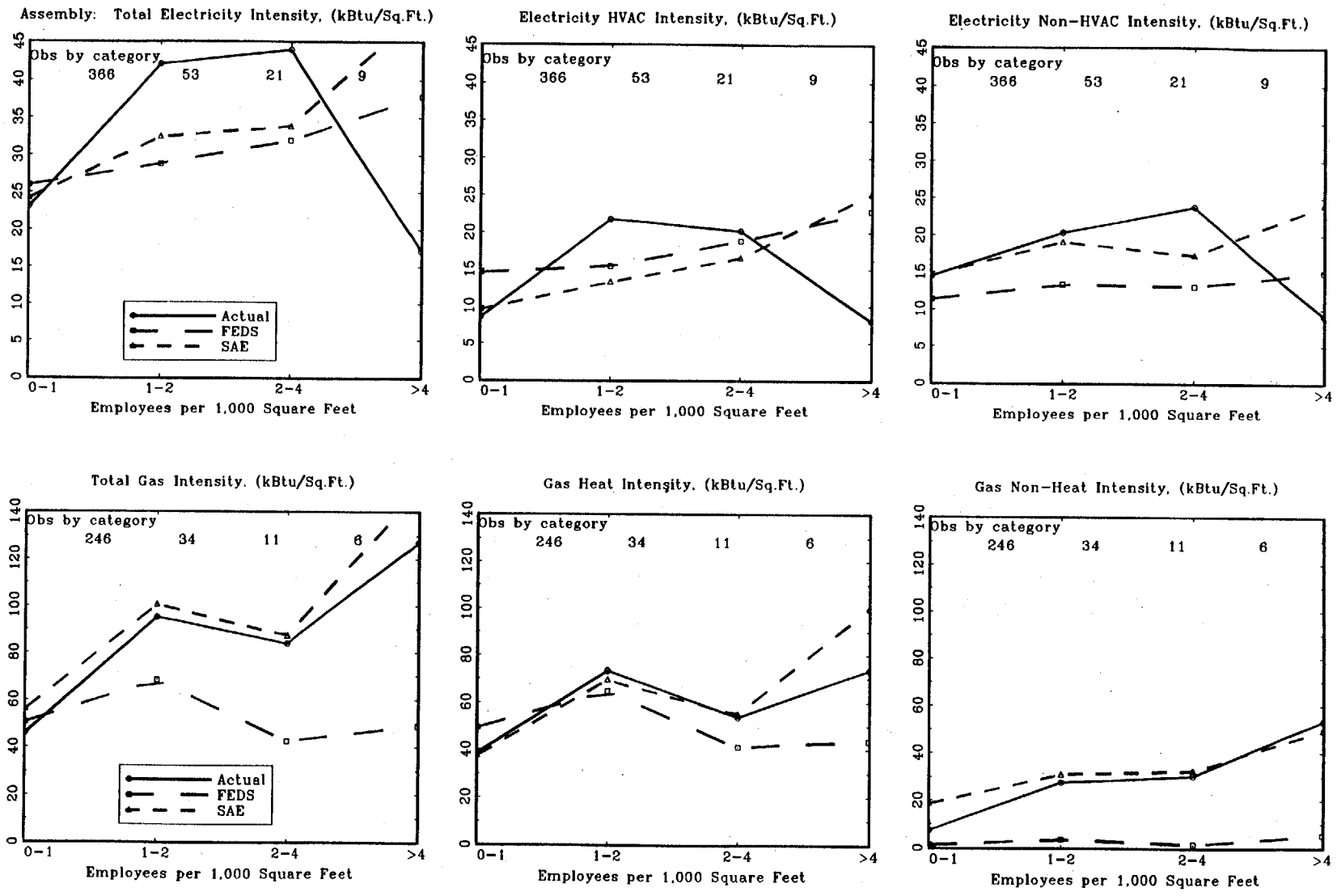

FIGURE D.8. Assembly: Actual, FEDS, and SAE Intensities By Employment Density Category

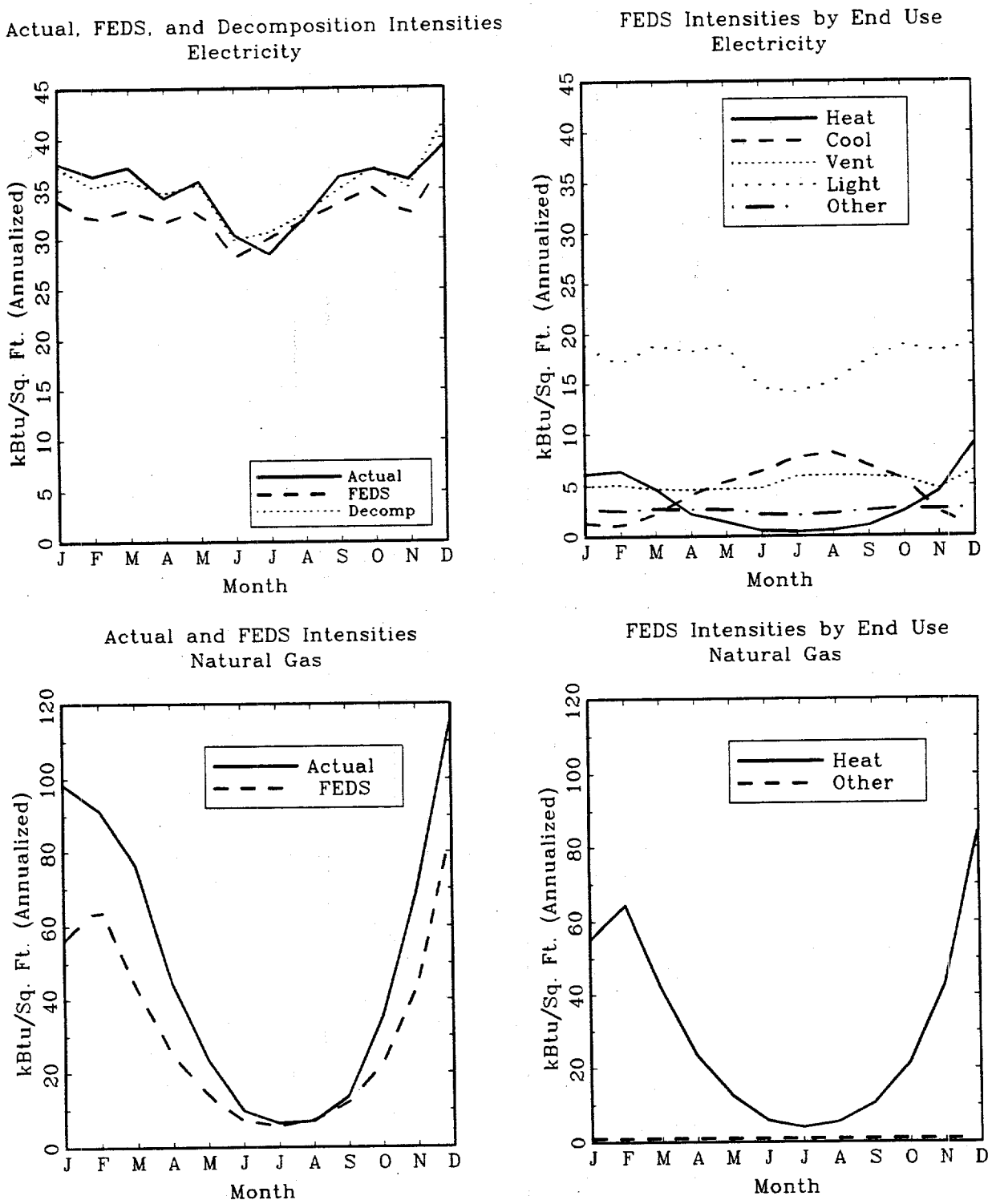

FIGURE D.9. Education: Monthly Average EUIs

HVAC

Valid cases:	314	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	137911.371	Degrees of freedom:	307
R-squared:	0.332	Rbar-squared:	0.319
Residual SS:	92138.759	Std error of est:	17.324
F(7,307):	21.787	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.660400	0.084407	7.823960	0.000	0.552040	0.624067
V1*HVf	0.486939	0.152139	3.200612	0.002	0.207943	0.010420
V2*HVf	0.238676	0.165695	1.440459	0.151	0.098934	0.149261
SQFT*HVf	0.001016	0.001025	0.991899	0.322	0.073932	-0.489675
CDD*HVf	0.000269	0.000056	4.810190	0.000	0.216295	0.262437
HRS*HVf	-0.004294	0.003345	-1.283947	0.200	-0.067319	-0.287403
EMP*HVf	0.093871	0.026207	3.581916	0.000	0.185524	0.411937

NHVAC

Valid cases:	314	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	449696.645	Degrees of freedom:	306
R-squared:	0.076	Rbar-squared:	0.055
Residual SS:	415458.541	Std error of est:	36.847
F(8,306):	3.152	Probability of F:	0.002

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.004766	0.106720	9.414962	0.000	0.485701	0.498705
V1*NHVf	0.591820	0.239221	2.473950	0.014	0.135135	0.115829
V2*NHVf	0.129065	0.360411	0.358106	0.721	0.020191	-0.009439
SQFT*NHVf	0.001506	0.000882	1.707991	0.089	0.088297	0.009788
CDD*NHVf	0.000202	0.000139	1.454515	0.147	0.068965	0.046415
HRS*NHVf	-0.004166	0.004092	-1.018062	0.309	-0.055021	0.190717
EMP*NHVf	0.489569	0.087355	5.604375	0.000	0.288591	0.302054
ElcMan	6.517711	13.182170	0.494434	0.621	0.023219	0.107695

FIGURE D.10. Education: SAE Regression Results for Electricity

Education	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	52.56	6.97	2.82	6.92	1.00	17.83	5.69

Education	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	3.38	26.22	3.34	.62
Non-Baseload	1.00	5.14	25.82	1.72	.32

Valid cases:	242	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	540900.948	Degrees of freedom:	235
R-squared:	0.227	Rbar-squared:	0.207
Residual SS:	418062.853	Std error of est:	42.178
F(7,235):	9.864	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.661144	0.320474	2.063016	0.040	0.488532	0.747773
V1*SHf	0.189208	0.126917	1.490799	0.137	0.110958	0.651882
V2*SHf	-0.269747	0.305856	-0.881941	0.379	-0.040737	0.076574
SQFT*SHf	0.000002	0.000001	1.992077	0.048	0.103641	0.466497
HDD*SHf	0.000052	0.000040	1.291898	0.198	0.231953	0.742639
HRS*SHf	-0.002319	0.003183	-0.728699	0.467	-0.101616	0.703719
EMP*SHf	-0.000571	0.037446	-0.015235	0.988	-0.000990	0.481287

FIGURE D.11. Education: SAE Regression Results for Natural Gas

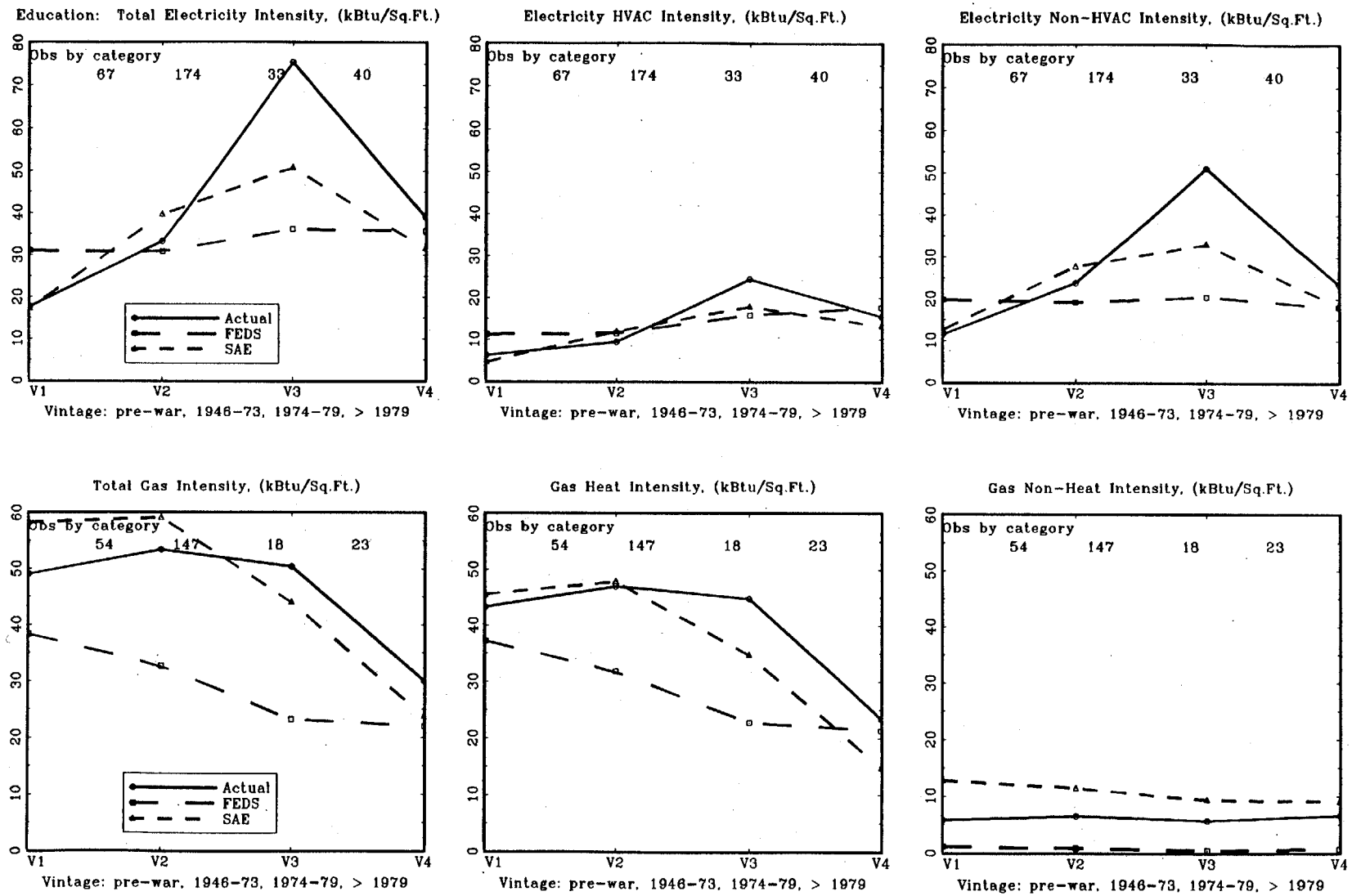

FIGURE D.12. Education: Actual, FEDS, and SAE Intensities By Vintage

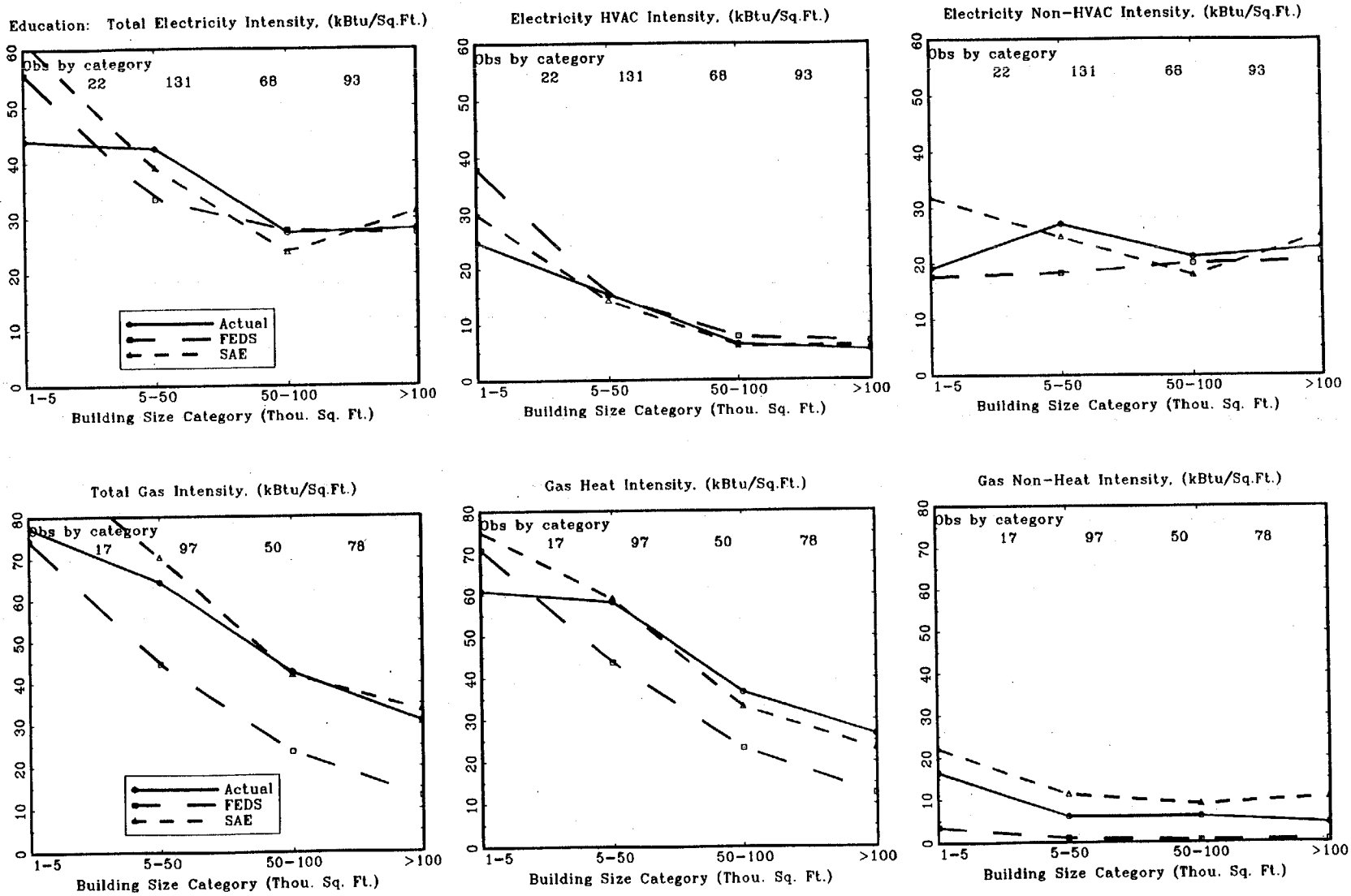

FIGURE D.13. Education: Actual, FEDS, and SAE Intensities By Building Size Category

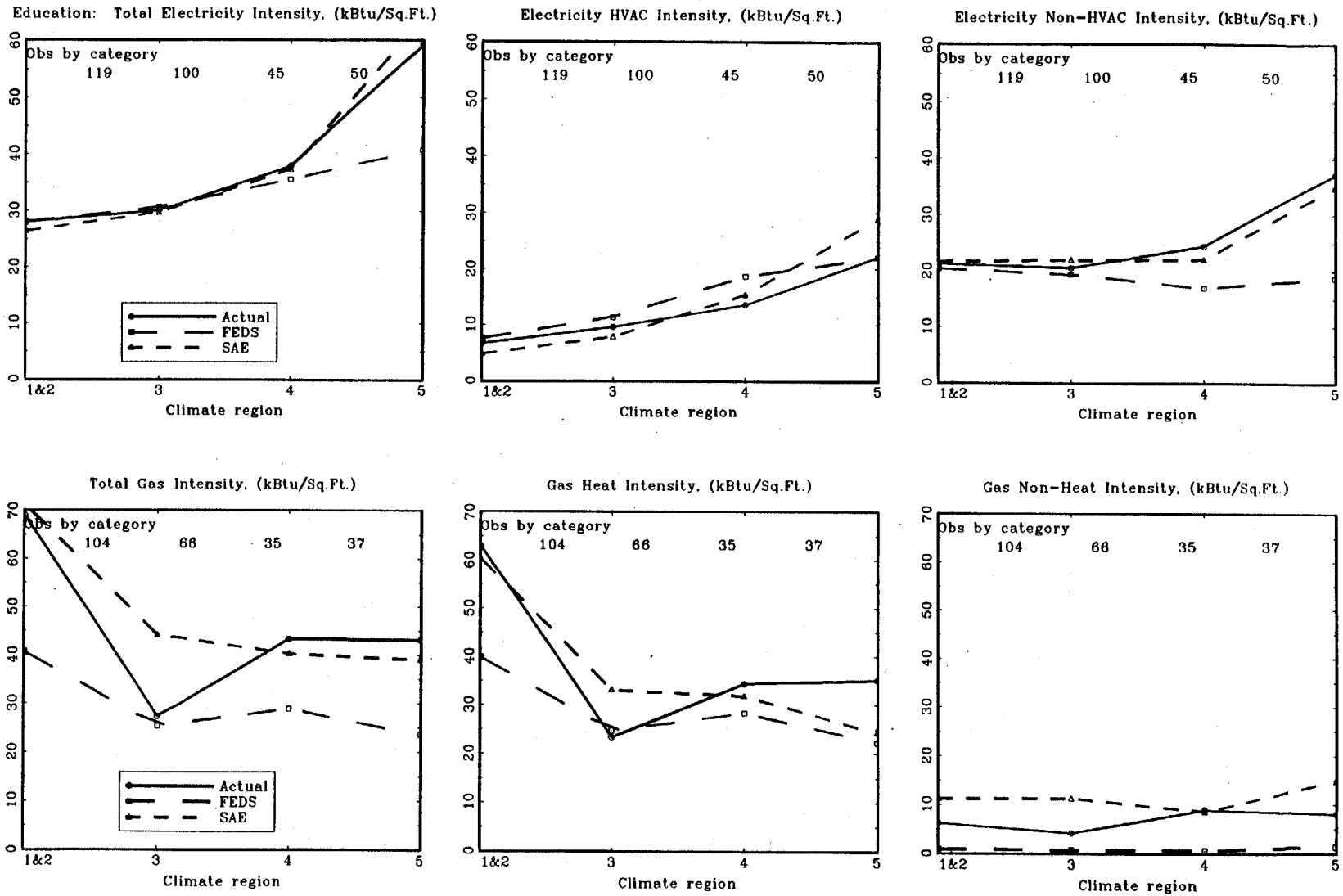

FIGURE D.14. Education: Actual, FEDS, and SAE Intensities By Climate Region

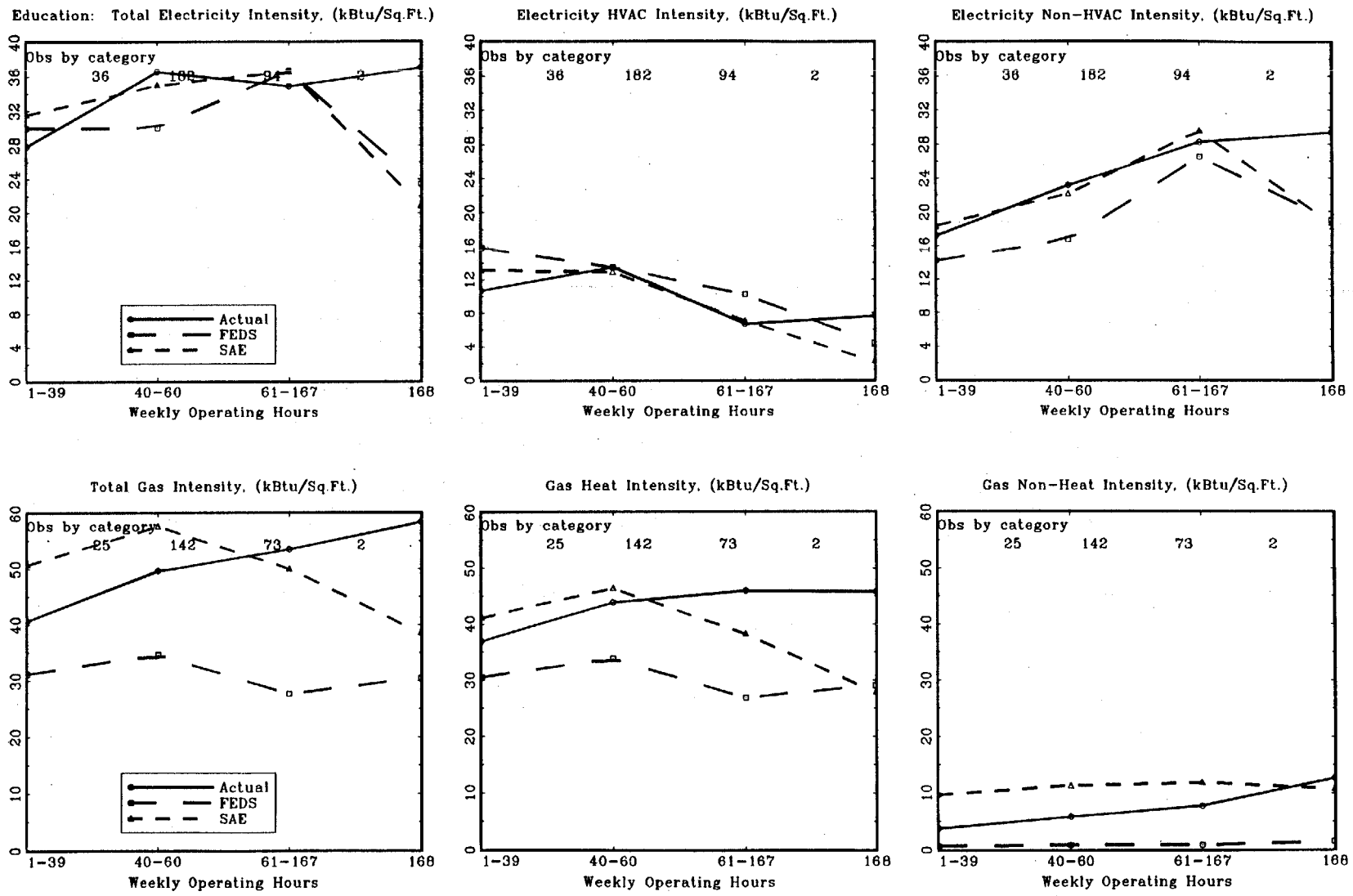

FIGURE D.15. Education: Actual, FEDS, and SAE Intensities By Weekly Hours Category

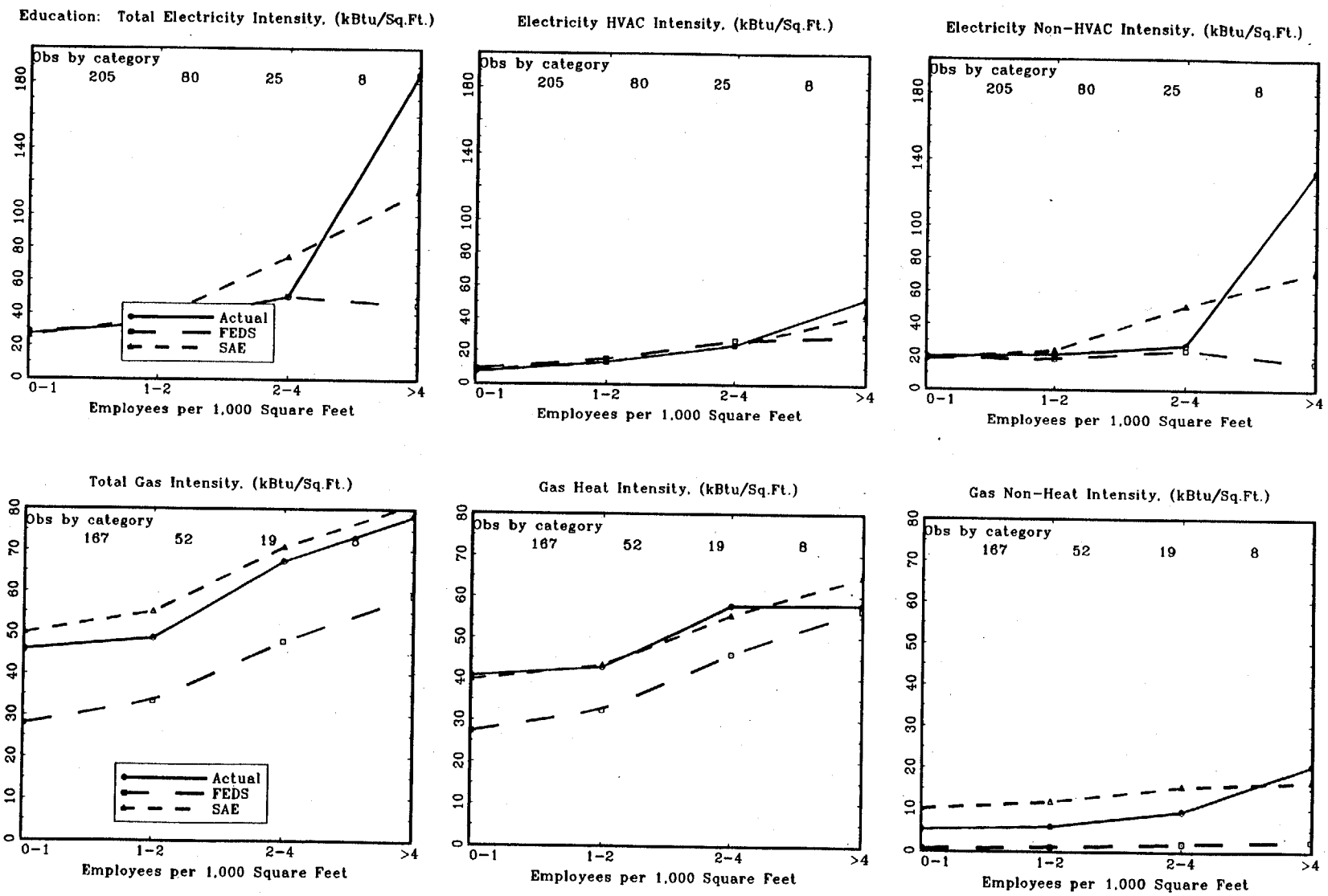

FIGURE D.16. Education: FEDS, and SAE Intensities By Employment Density Category

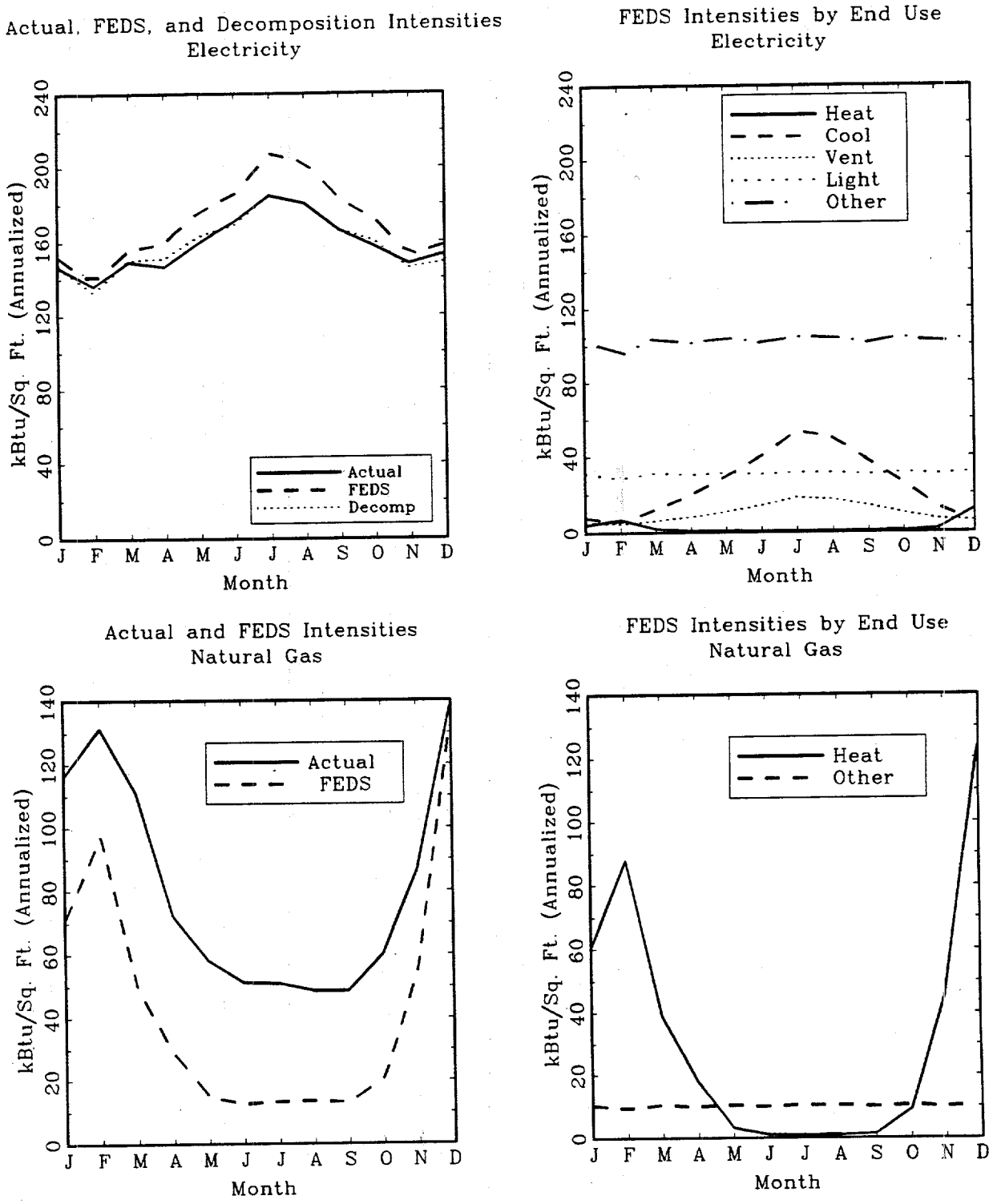

FIGURE D.17. Food Sales: Monthly Average EUIs

HVAC

Valid cases:	65	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	40883.619	Degrees of freedom:	58
R-squared:	0.569	Rbar-squared:	0.525
Residual SS:	17602.298	Std error of est:	17.421
F(7,58):	10.959	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.502271	0.062175	8.078406	0.000	0.616447	0.805159
V1*HVf	0.349073	0.128754	2.711173	0.009	0.214745	-0.067613
V2*HVf	0.291092	0.143840	2.023717	0.048	0.161733	0.165029
SQFT*HVf	-0.000542	0.003682	-0.147270	0.883	-0.010542	-0.339980
CDD*HVf	0.000166	0.000047	3.545720	0.000	0.276873	0.591209
HRS*HVf	0.001351	0.001747	0.773266	0.443	0.054168	0.080365
EMP*HVf	0.120311	0.034224	3.515419	0.000	0.238513	0.384250

NHVAC

Valid cases:	65	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	701219.853	Degrees of freedom:	57
R-squared:	0.287	Rbar-squared:	0.200
Residual SS:	499757.890	Std error of est:	93.636
F(8,57):	2.872	Probability of F:	0.009

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.019556	0.088969	11.459737	0.000	0.805778	0.805846
V1*NHVf	0.147631	0.213203	0.692444	0.491	0.058354	0.014029
V2*NHVf	0.193277	0.276958	0.697854	0.488	0.060613	0.053442
SQFT*NHVf	-0.004637	0.004574	-1.013884	0.315	-0.073564	-0.087607
CDD*NHVf	0.000091	0.000102	0.887595	0.378	0.069255	0.028938
HRS*NHVf	0.006407	0.002586	2.477037	0.016	0.182841	0.253404
EMP*NHVf	0.133036	0.053794	2.473061	0.016	0.177652	0.186251
ElcMan	-181.763853	107.962613	-1.683581	0.098	-0.132591	0.054244

FIGURE D.18. Food Sales: SAE Regression Results for Electricity

Grocery	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	44.61	8.64	111.02	89.03	1.00	1.00	3.00

Grocery	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	1.04	6.86	.53	4.21
Non-Baseload	1.00	5.14	25.82	.53	4.21

Valid cases:	36	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	55465.113	Degrees of freedom:	29
R-squared:	0.575	Rbar-squared:	0.487
Residual SS:	23562.660	Std error of est:	28.504
F(7,29):	5.609	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.405740	0.967309	0.419453	0.678	0.484187	0.837681
V1*SHf	-0.206975	0.174985	-1.182814	0.246	-0.152847	0.451923
V2*SHf	72.190429	85.761607	0.841757	0.407	0.076567	0.077589
SQFT*SHf	0.000037	0.000021	1.759692	0.089	0.269086	0.570819
HDD*SHf	-0.000139	0.000100	-1.394668	0.174	-1.177835	0.814170
HRS*SHf	0.011757	0.008152	1.442199	0.160	1.129578	0.845905
EMP*SHf	0.137012	0.129136	1.060987	0.297	0.352361	0.758996

FIGURE D.19. Food Sales: SAE Regression Results for Natural Gas

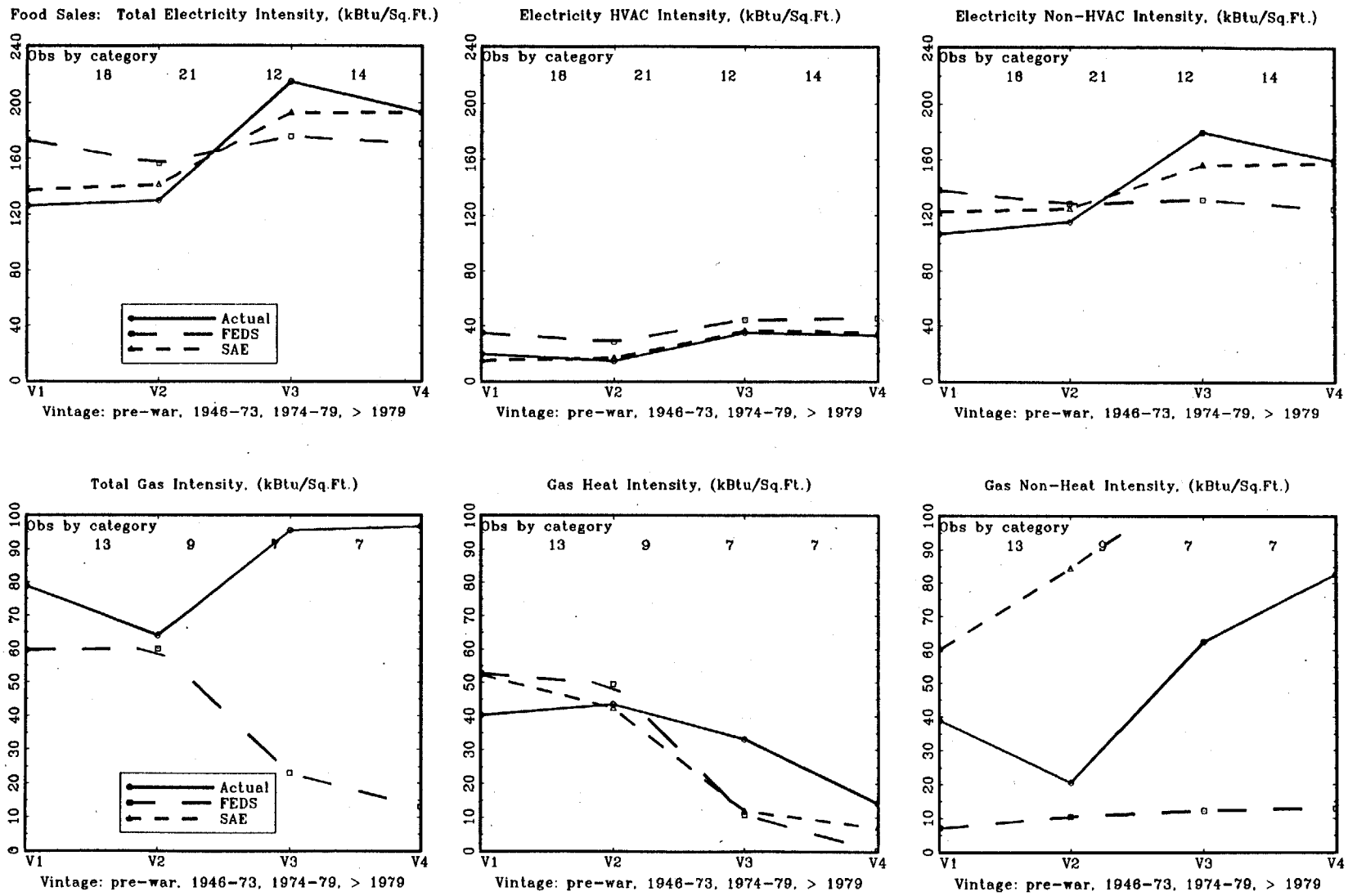

FIGURE D.20. Food Sales: Actual, FEDS, and SAE Intensities By Vintage

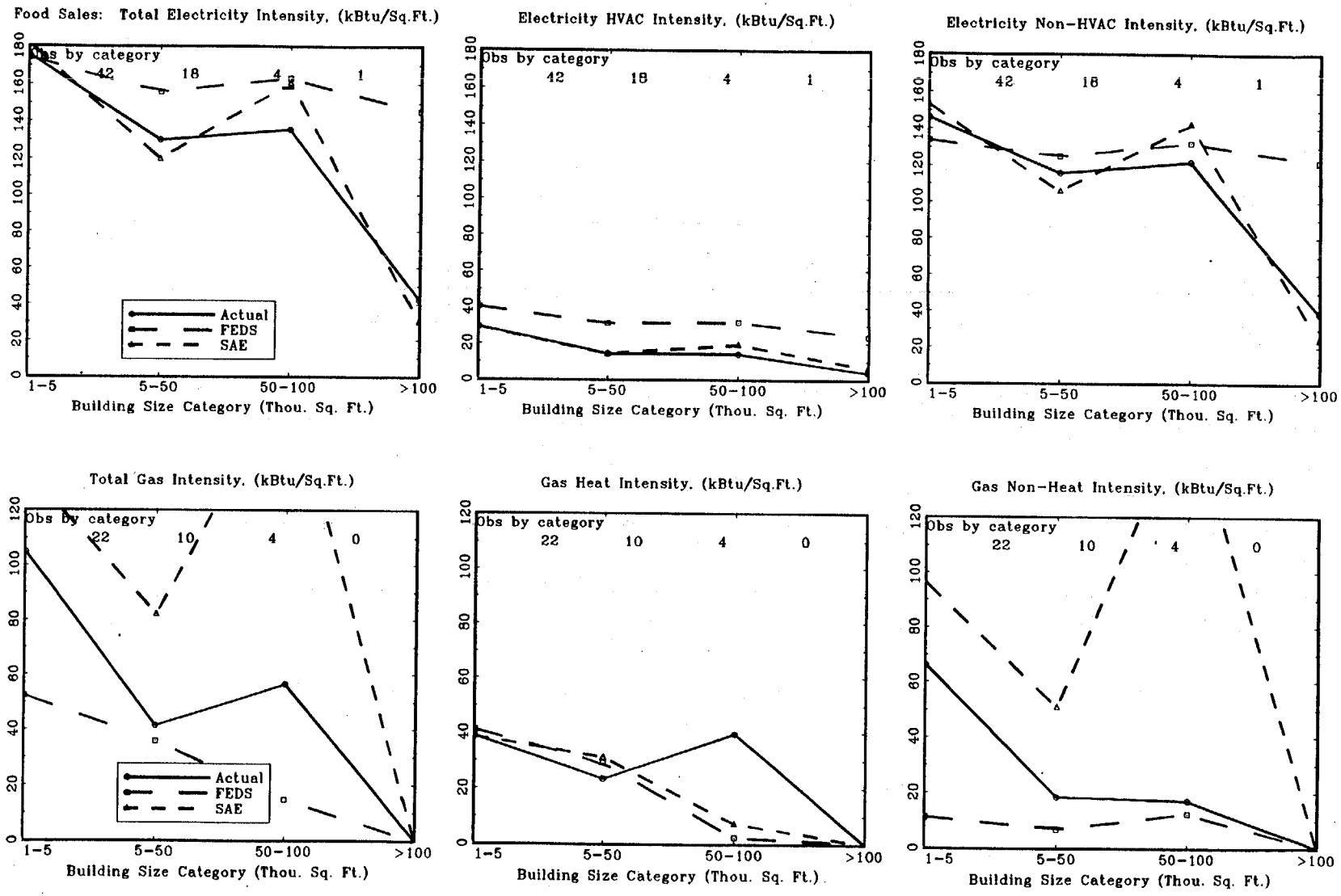

FIGURE D.21. Food Sales: Actual, FEDS, and SAE Intensities By Building Size Category

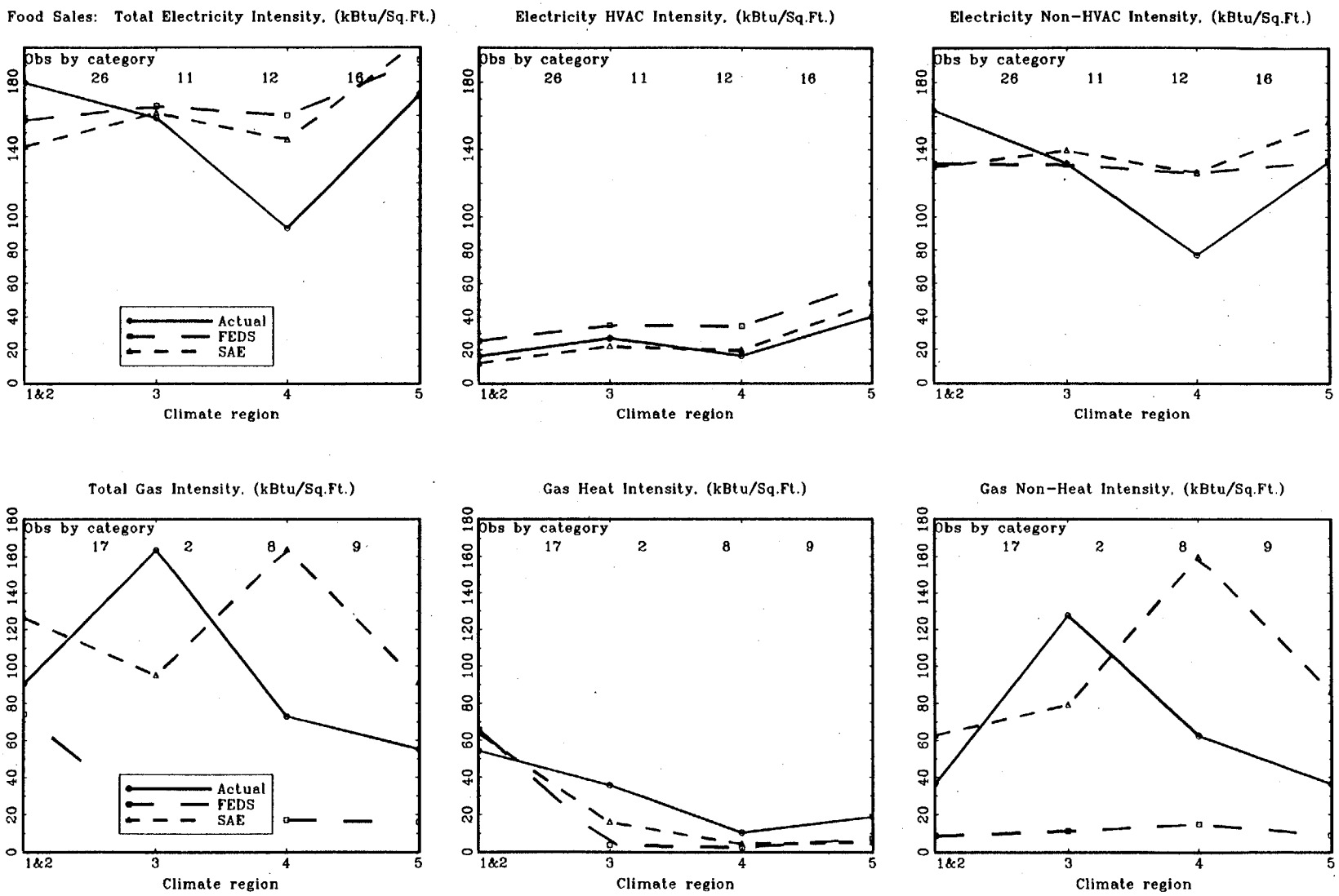

FIGURE D.22. Food Sales: Actual, FEDS, and SAE Intensities By Climate Region

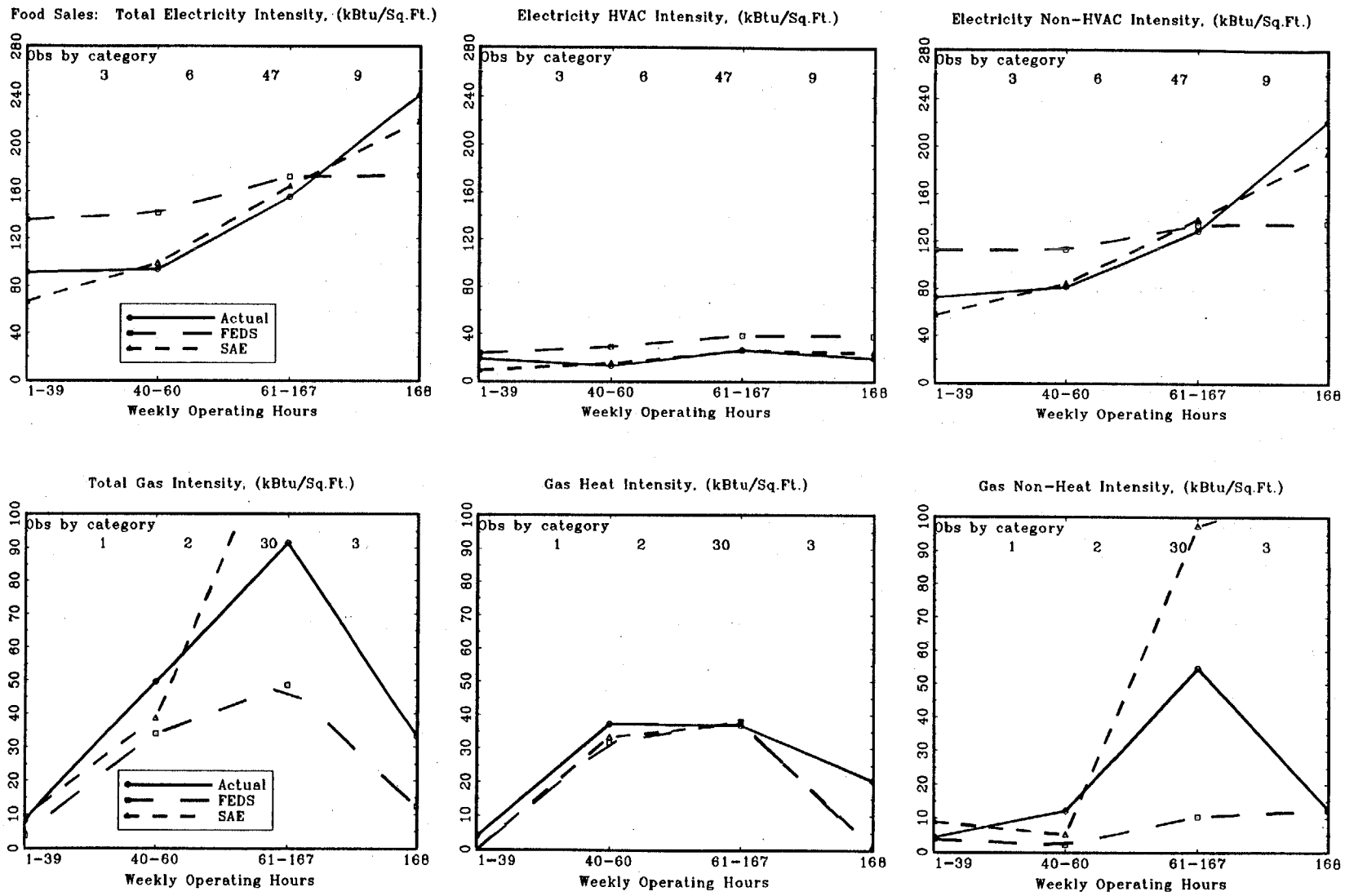

FIGURE D.23. Food Sales: Actual, FEDS, and SAE Intensities By Weekly Hours Category

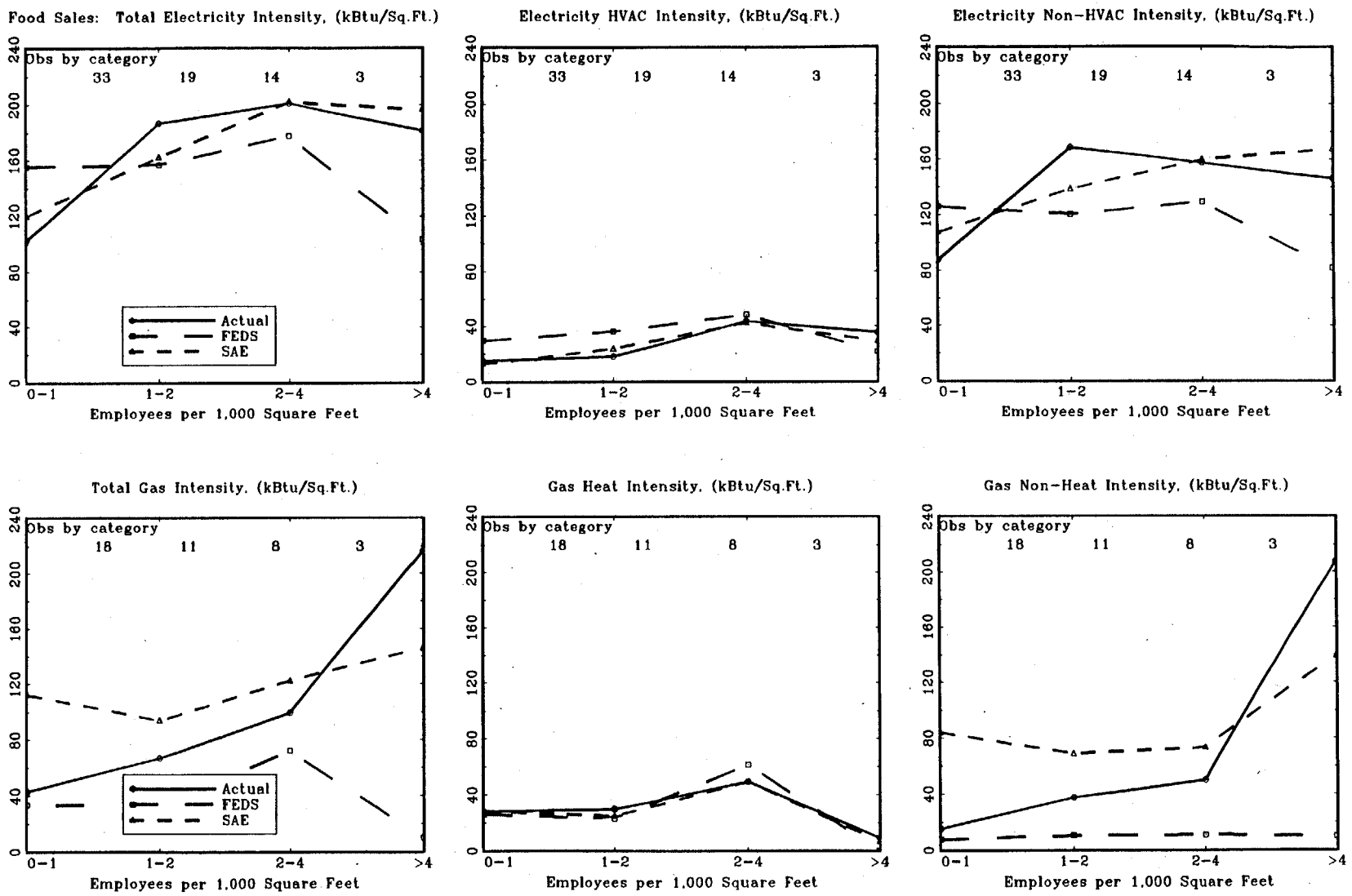

FIGURE D.24. Food Sales: Actual, FEDS, and SAE Intensities By Employment Density Category

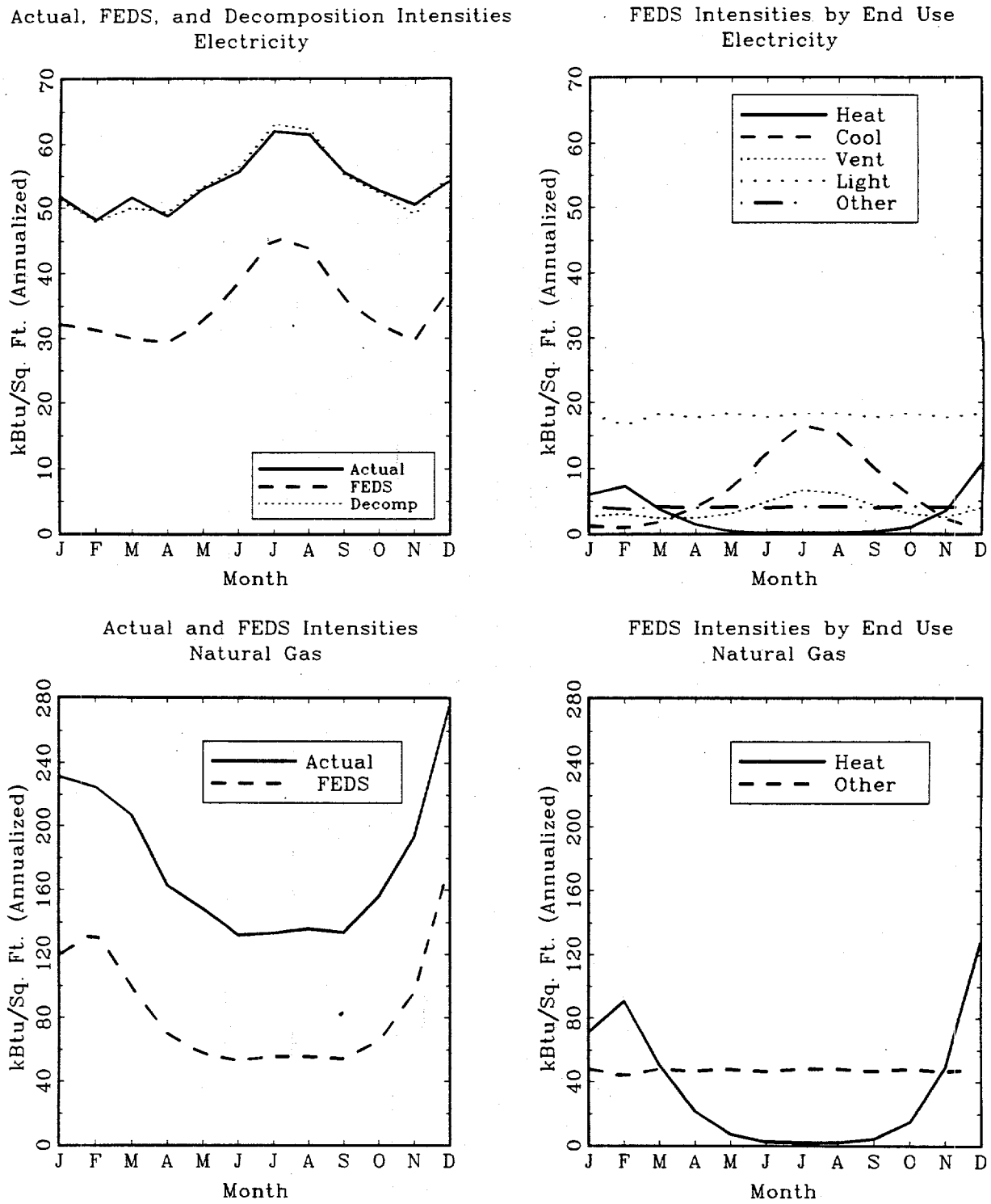

FIGURE D.25. Food Service: Monthly Average EUIs

HVAC

Valid cases:	132	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	466058.825	Degrees of freedom:	125
R-squared:	0.624	Rbar-squared:	0.606
Residual SS:	175433.652	Std error of est:	37.463
F(7,125):	29.582	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.920551	0.074751	12.314915	0.000	0.612133	0.713353
V1*HVf	0.035261	0.182631	0.193073	0.847	0.011521	0.013007
V2*HVf	0.656055	0.242056	2.710339	0.008	0.169720	0.273202
SQFT*HVf	-0.011953	0.008481	-1.409477	0.161	-0.066263	-0.305908
CDD*HVf	0.000035	0.000062	0.568011	0.571	0.031226	0.497892
HRS*HVf	0.004005	0.002228	1.797395	0.075	0.080233	0.160849
EMP*HVf	0.251049	0.032226	7.790243	0.000	0.393621	0.596629

NHVAC

Valid cases:	132	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	1423638.238	Degrees of freedom:	125
R-squared:	0.521	Rbar-squared:	0.498
Residual SS:	681863.451	Std error of est:	73.857
F(7,125):	19.426	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	0.931840	0.064665	14.410363	0.000	0.665961	0.717881
V1*NHVf	0.116792	0.158063	0.738893	0.461	0.041375	0.064278
V2*NHVf	0.231030	0.214058	1.079288	0.283	0.063768	0.144636
SQFT*NHVf	-0.011084	0.004645	-2.386187	0.019	-0.111915	-0.140825
CDD*NHVf	0.000097	0.000068	1.412522	0.160	0.067843	0.207758
HRS*NHVf	0.010840	0.002068	5.242356	0.000	0.245421	0.406773
EMP*NHVf	0.206138	0.032310	6.379932	0.000	0.326438	0.398742

FIGURE D.26. Food Service: SAE Regression Results for Electricity

Restaurant	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	79.52	262.82	128.84	160.85	1.00	1.00	30.72

Restaurant	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	4.54	7.35	.84	1.94
Non-Baseload	1.00	.36	2.32	.15	.34

Valid cases:	114	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	1291115.166	Degrees of freedom:	107
R-squared:	0.229	Rbar-squared:	0.186
Residual SS:	994942.616	Std error of est:	96.429
F(7,107):	4.550	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	-0.742891	0.988825	-0.751287	0.454	-0.389464	0.523676
V1*SHf	0.263516	0.288092	0.914697	0.362	0.102318	0.382342
V2*SHf	2.948715	0.850179	3.468347	0.000	0.305124	0.475479
SQFT*SHf	0.000061	0.000067	0.902275	0.369	0.097593	0.414449
HDD*SHf	0.000171	0.000126	1.357720	0.177	0.584694	0.529892
HRS*SHf	-0.002168	0.005605	-0.386712	0.700	-0.092561	0.506689
EMP*SHf	0.194906	0.089407	2.179982	0.031	0.287667	0.593353

FIGURE D.27. Food Service: SAE Regression Results for Natural Gas

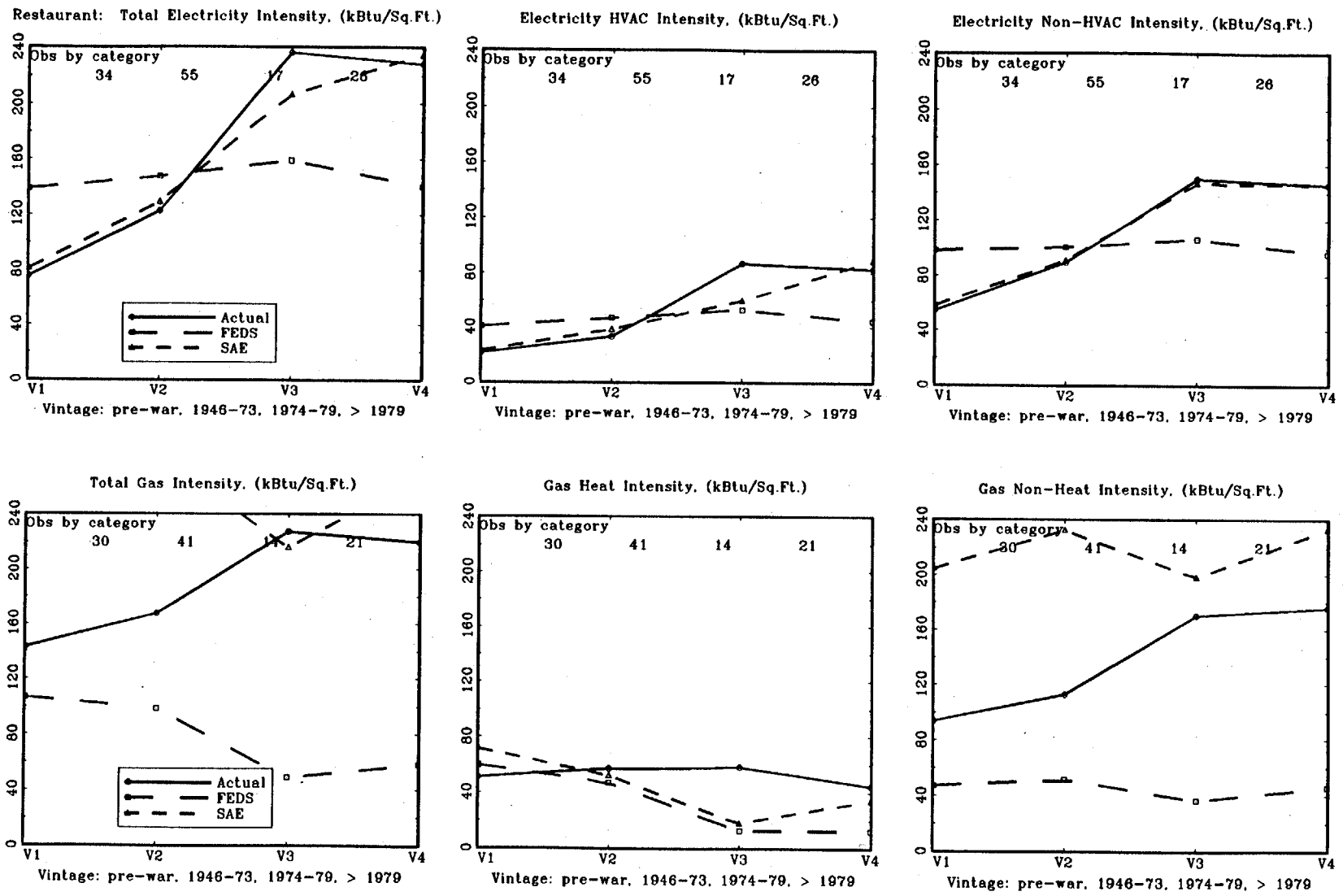

FIGURE D.28. Food Service: Actual, FEDS, and SAE Intensities By Vintage

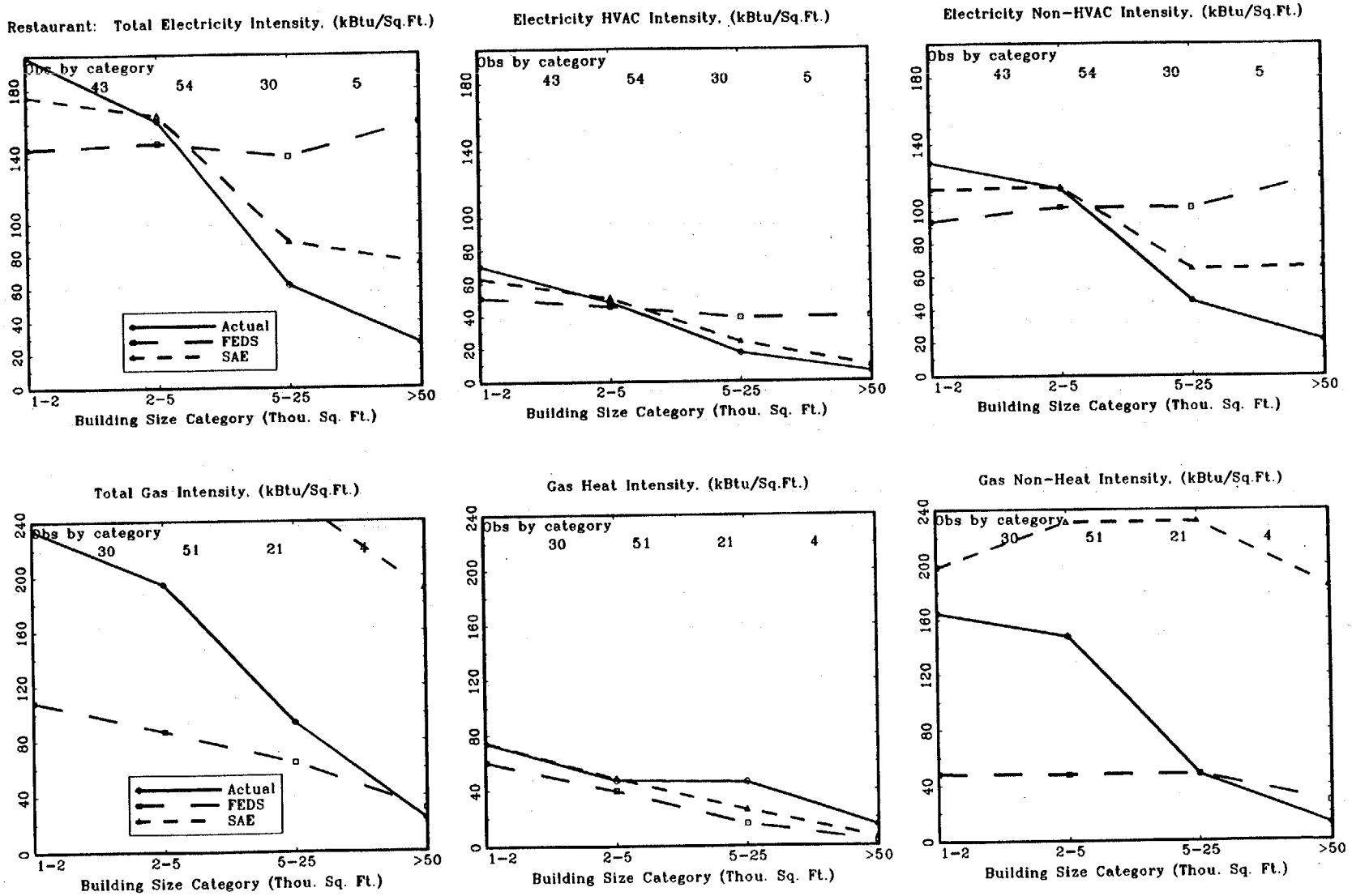

FIGURE D.29. Food Service: Actual, FEDS, and SAE Intensities By Building Size Category

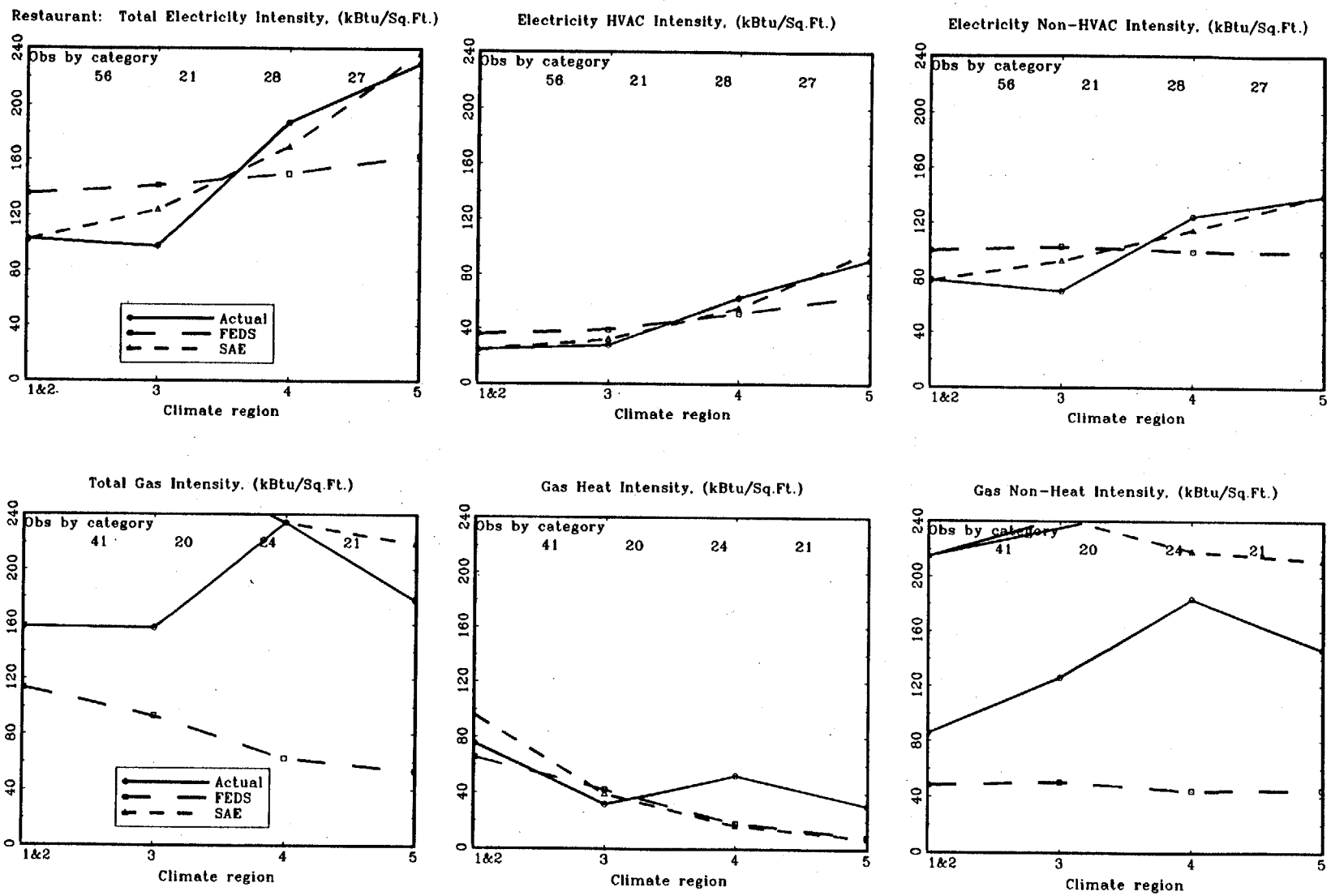

FIGURE D.30. Food Service: Actual, FEDS, and SAE Intensities By Climate Region

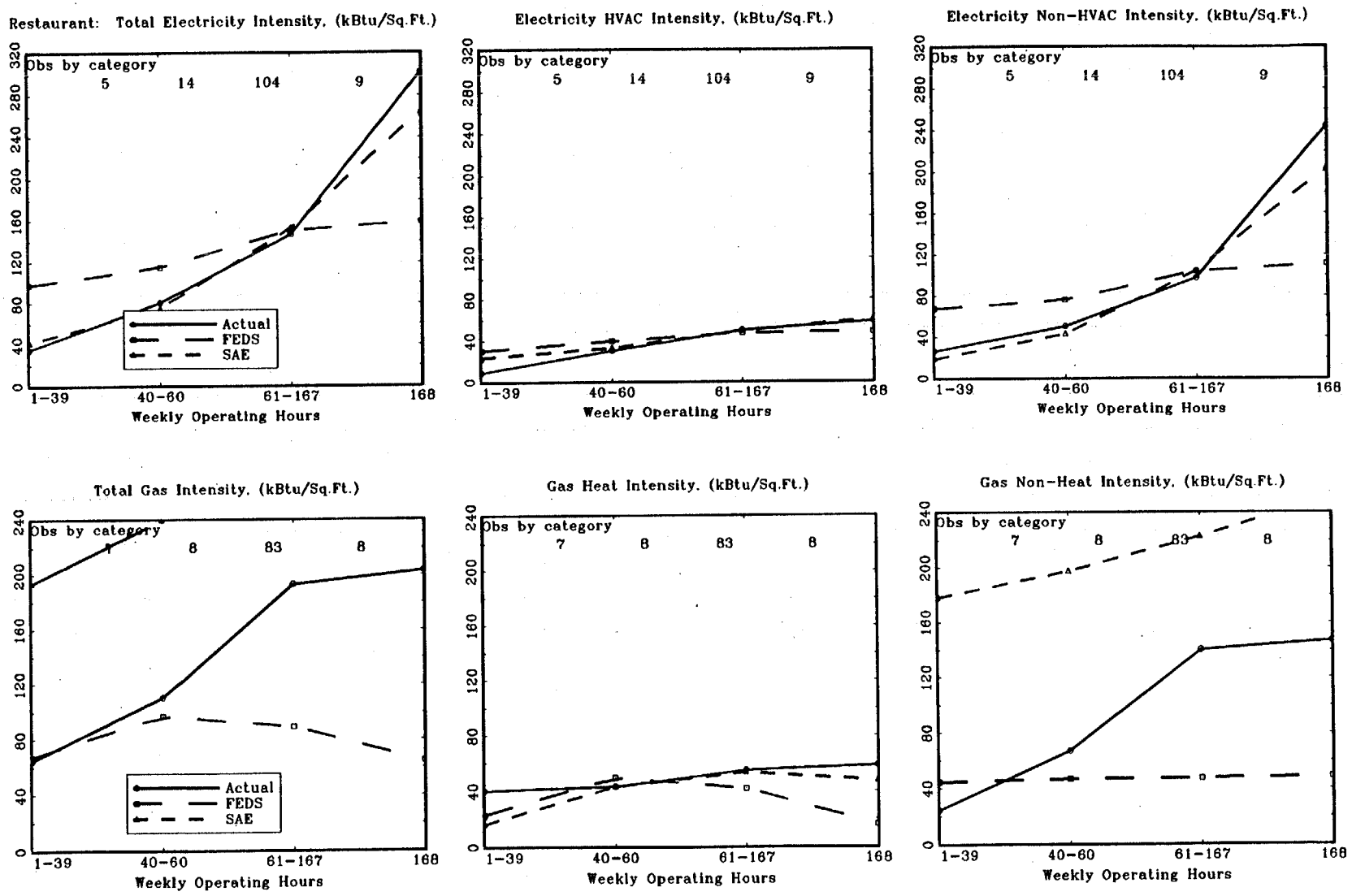

FIGURE D.31. Food Service: Actual, FEDS, and SAE Intensities By Weekly Hours Category

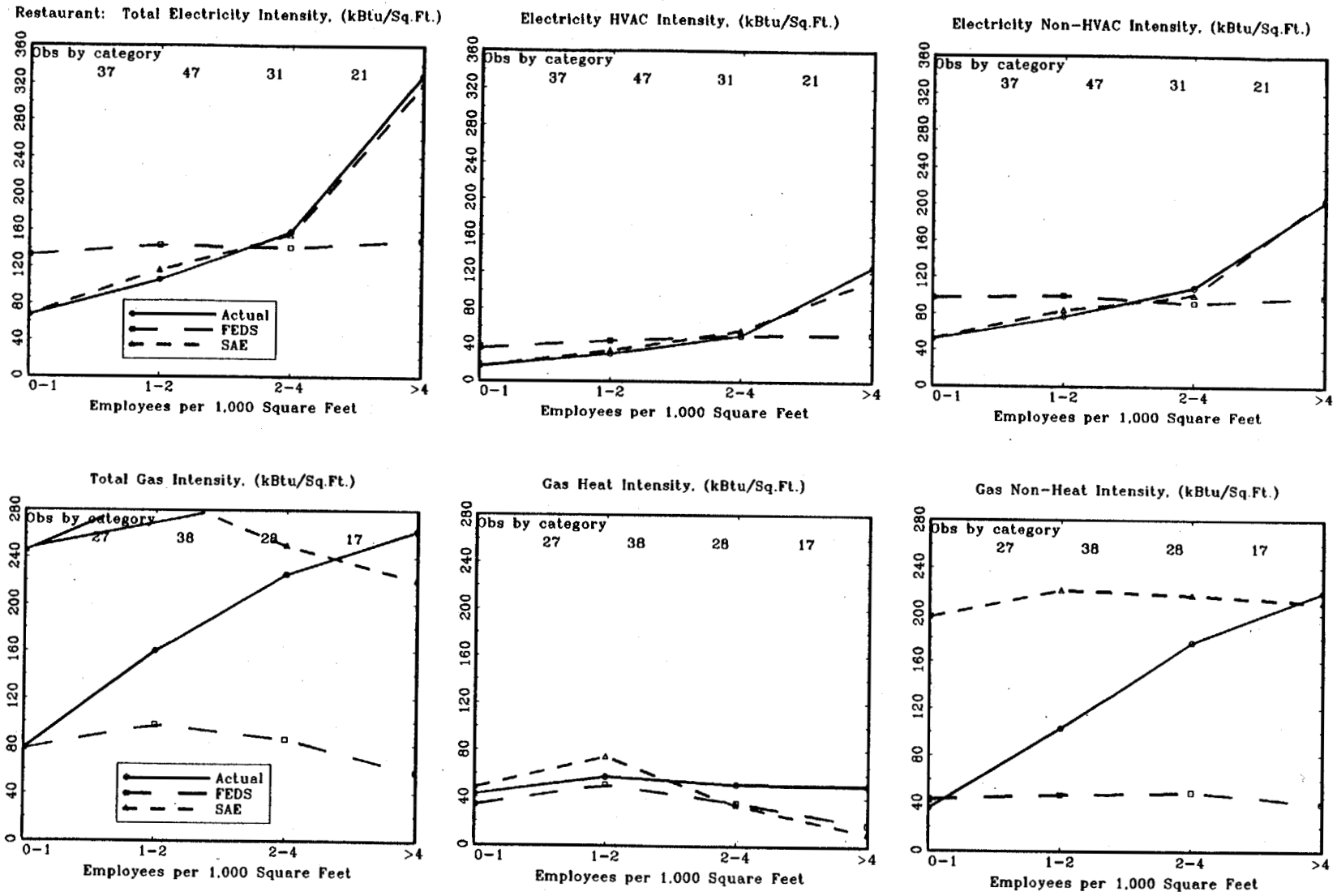

FIGURE D.32. Food Service: Actual, FEDS, and SAE Intensities By Employment Density Category

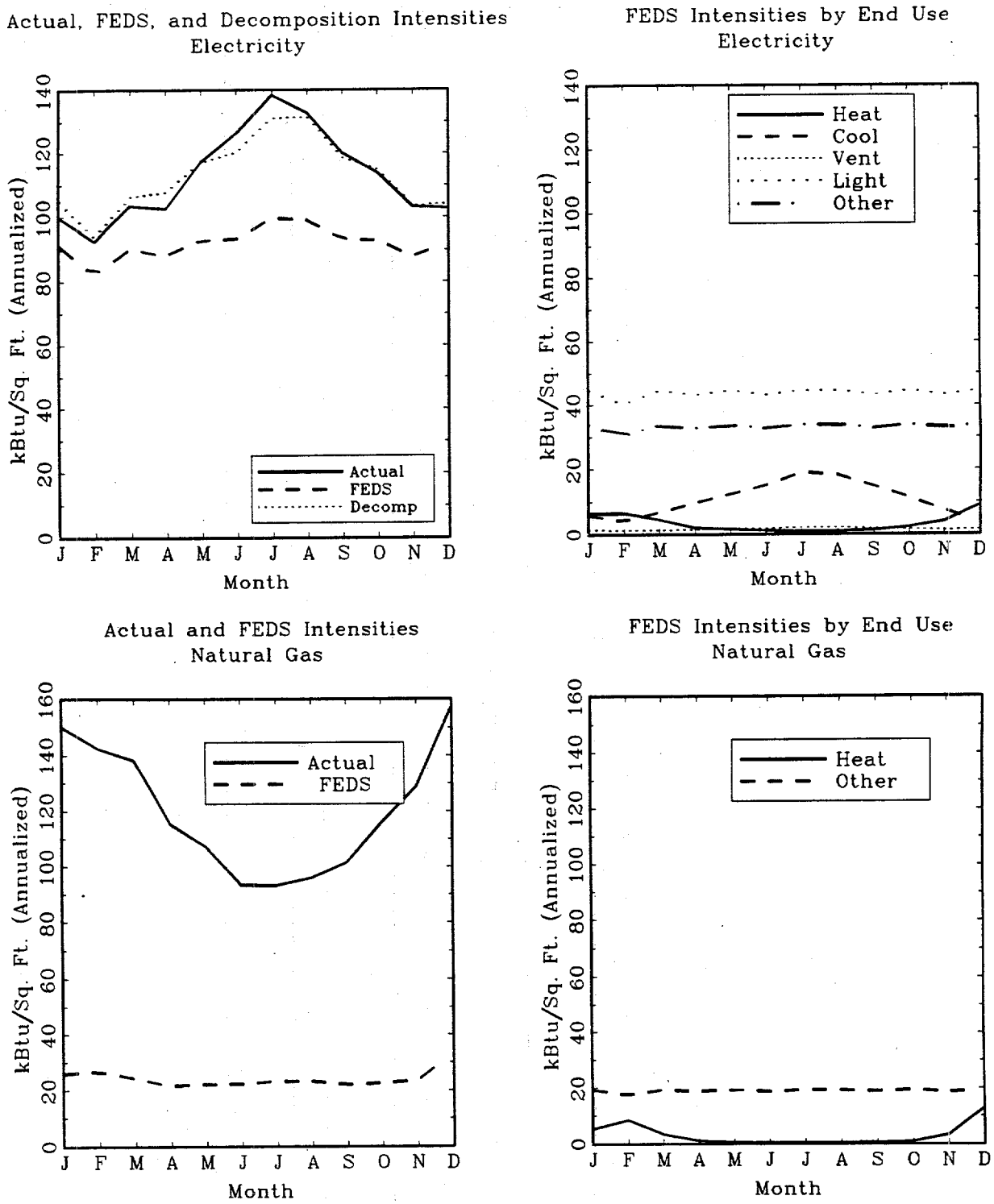

FIGURE D.33. Hospitals: Monthly Average EUIs

HVAC

Valid cases:	69	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	47108.718	Degrees of freedom:	62
R-squared:	0.349	Rbar-squared:	0.286
Residual SS:	30676.034	Std error of est:	22.244
F(7,62):	4.745	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	1.086237	0.096556	11.249834	0.000	1.145497	0.718900
V1*HVf	-0.254142	0.285670	-0.889634	0.377	-0.080247	0.128066
V2*HVf	0.144446	0.418086	0.345494	0.731	0.032929	-0.136544
SQFT*HVf	0.000381	0.000297	1.282848	0.204	0.165835	-0.404103
CDD*HVf	-0.000061	0.000064	-0.949761	0.346	-0.077611	0.204828
HRS*HVf	0.005643	0.001925	2.930887	0.005	0.340819	-0.185207
EMP*HVf	0.237154	0.049921	4.750573	0.000	0.325185	0.343465

NHVAC

Valid cases:	69	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	57345.866	Degrees of freedom:	62
R-squared:	0.046	Rbar-squared:	-0.047
Residual SS:	54720.111	Std error of est:	29.708
F(7,62):	0.425	Probability of F:	0.883

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.009153	0.065187	15.480963	0.000	0.879046	0.859824
V1*NHVf	-0.242478	0.273936	-0.885163	0.379	-0.076359	0.013406
V2*NHVf	0.061474	0.353256	0.174020	0.862	0.015212	-0.023171
SQFT*NHVf	0.000137	0.000176	0.775030	0.441	0.046895	-0.081866
CDD*NHVf	0.000083	0.000078	1.058769	0.294	0.065135	-0.018898
HRS*NHVf	0.006125	0.002640	2.319582	0.024	0.154639	0.159126
EMP*NHVf	0.187745	0.057779	3.249368	0.002	0.183255	0.202168

FIGURE D.34. Hospital: SAE Regression Results for Electricity

Hospital	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	31.80	84.51	31.71	84.83	22.75	43.71	1.00

Hospital	SC	WH	CK	WHCK
Adjustment Coefficients				WH
Baseload	1.00	2.27	11.56	2.56
Non-Baseload	1.00	.24	2.36	.05

Valid cases:	65	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	63614.577	Degrees of freedom:	59
R-squared:	0.072	Rbar-squared:	-0.007
Residual SS:	59043.810	Std error of est:	31.635
F(6,59):	0.761	Probability of F:	0.603

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	4.501847	2.363014	1.905129	0.062	1.318009	0.638301
V1*SHf	-1.796382	1.992828	-0.901423	0.371	-0.503153	0.556993
V2*SHf	1.009716	2.363748	0.427167	0.671	0.071723	0.308085
SQFT*SHf	-0.000002	0.000000	-2.205492	0.031	-0.319494	0.364565
HDD*SHf	0.000184	0.000160	1.149066	0.255	0.342175	0.649323
EMP*SHf	-0.538797	0.340128	-1.584100	0.119	-0.350139	0.521275

FIGURE D.35. Hospital: SAE Regression Results for Natural Gas

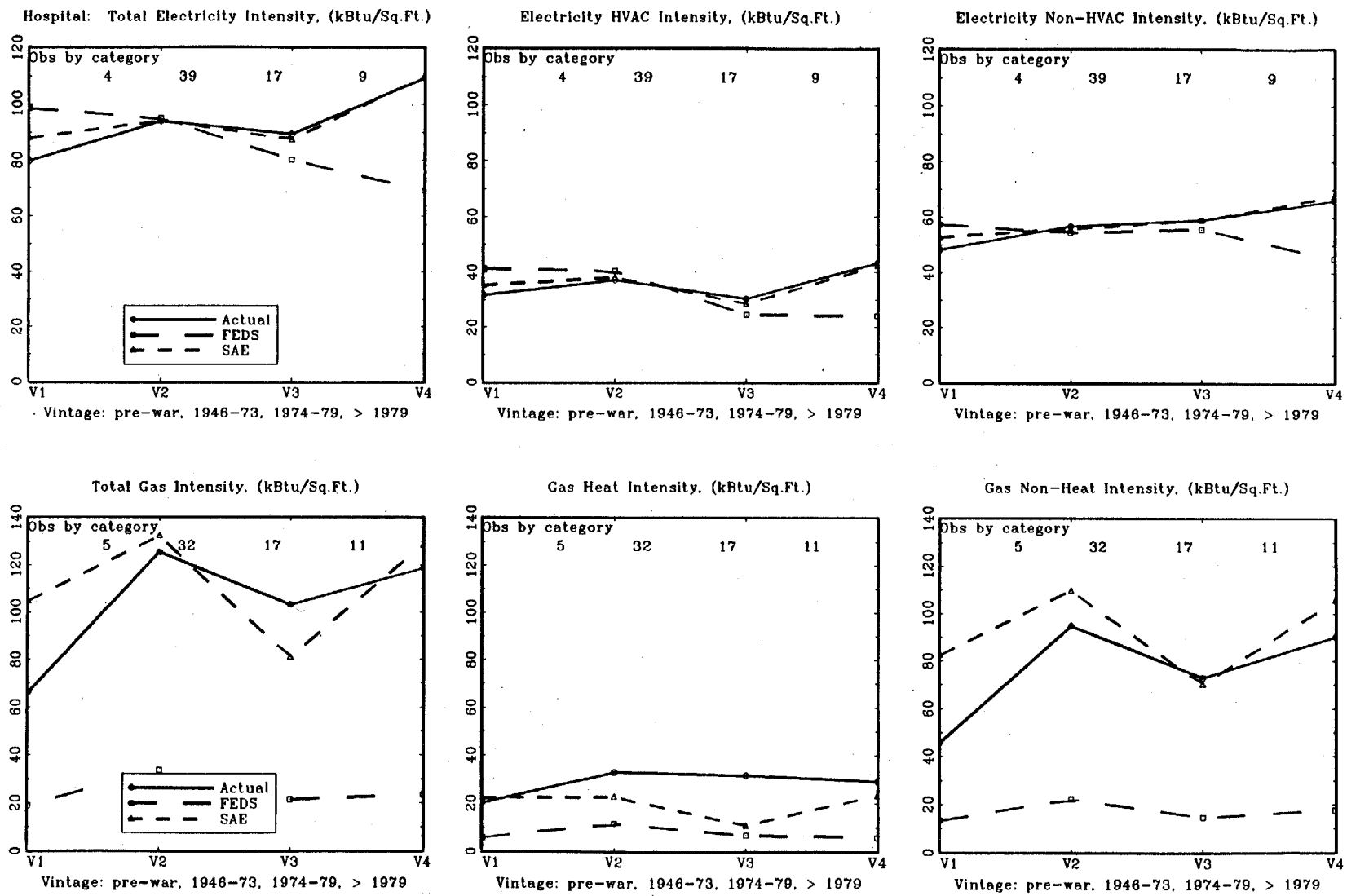

FIGURE D.36. Hospital: Actual, FEDS, and SAE Intensities By Vintage

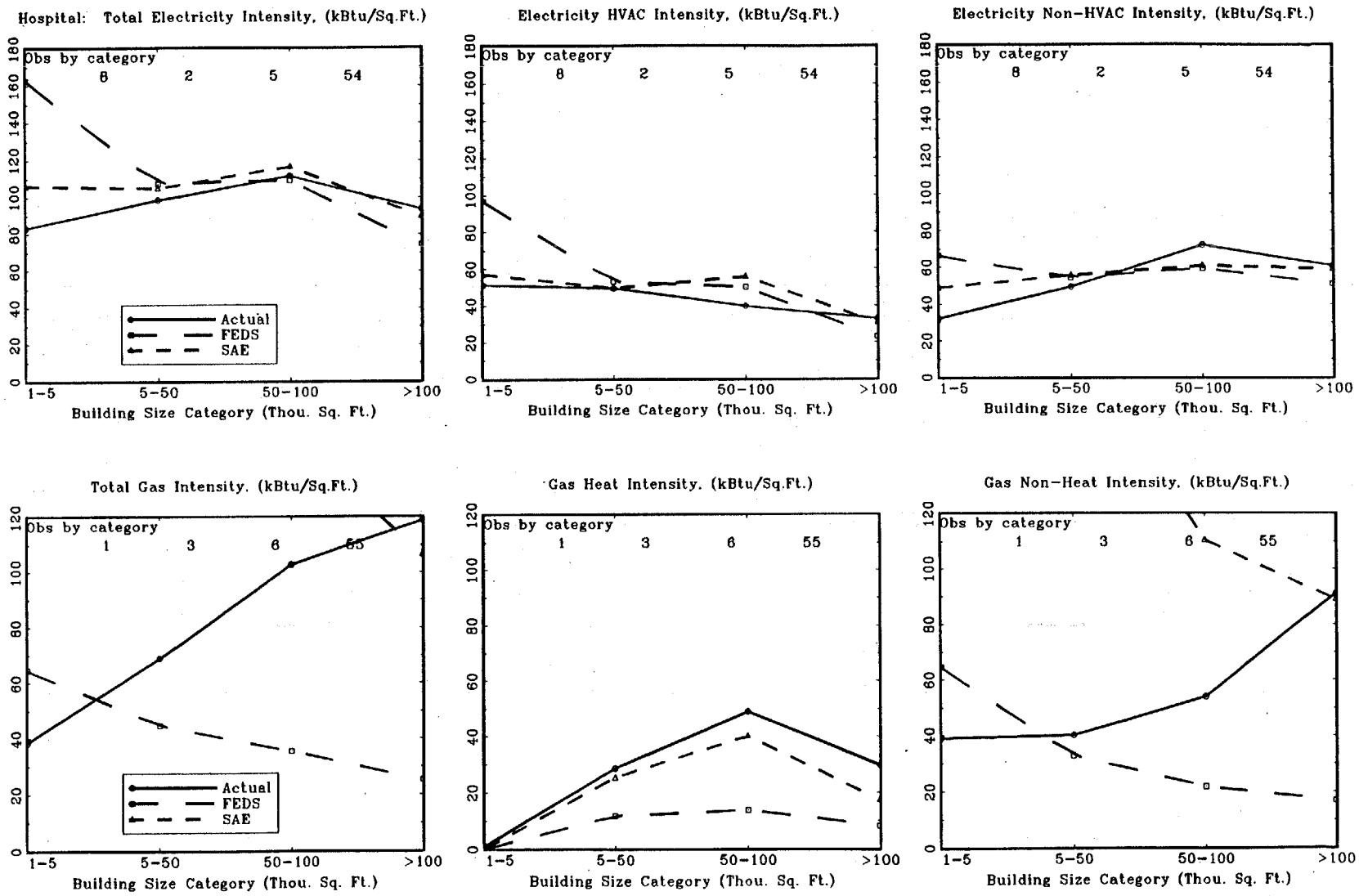

FIGURE D.37. Hospital: Actual, FEDS, and SAE Intensities By Building Size Category

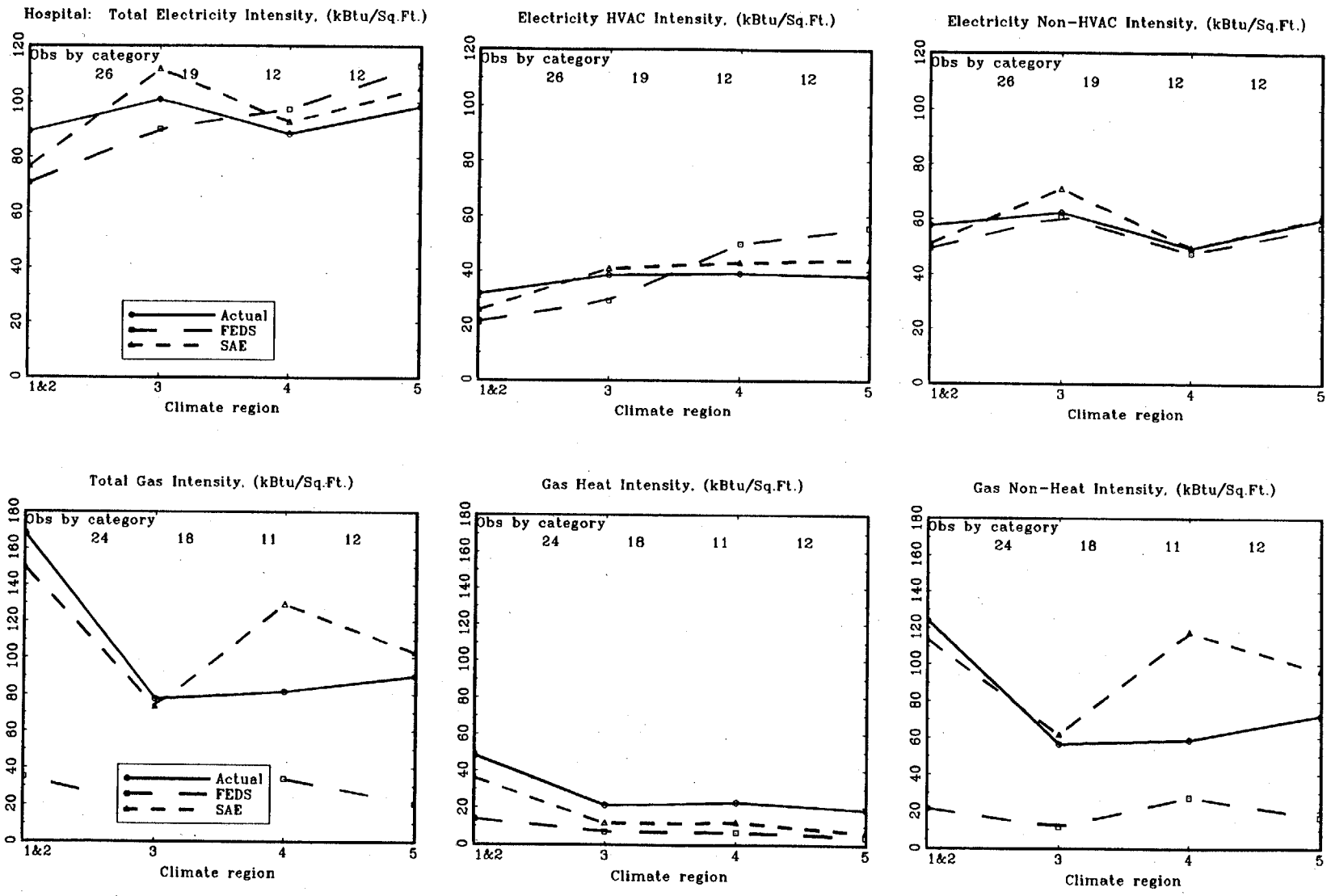

FIGURE D.38. Hospital: Actual, FEDS, and SAE Intensities By Climate Region

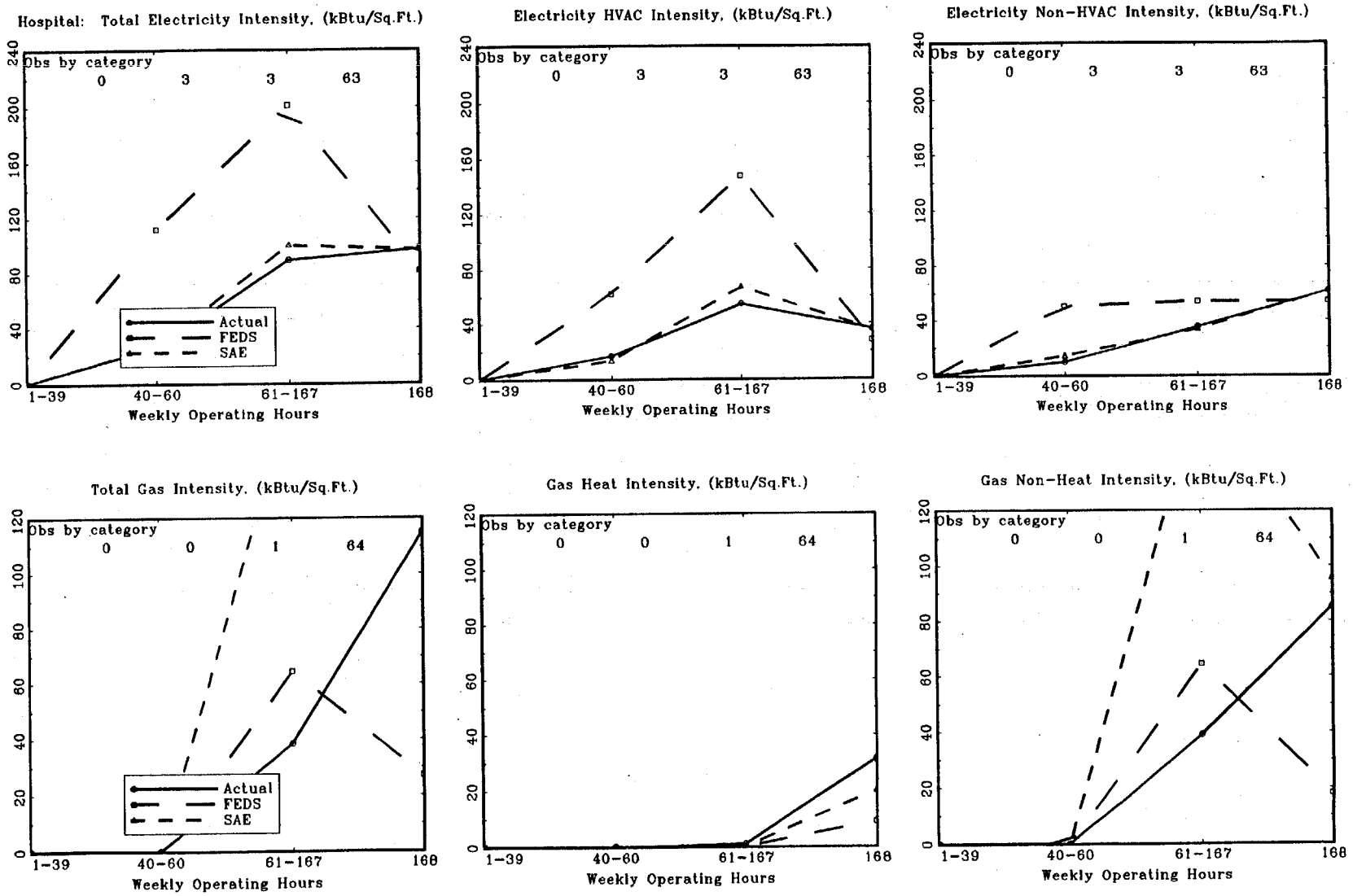

FIGURE D.39. Hospital: Actual, FEDS, and SAE Intensities By Weekly Hours Category

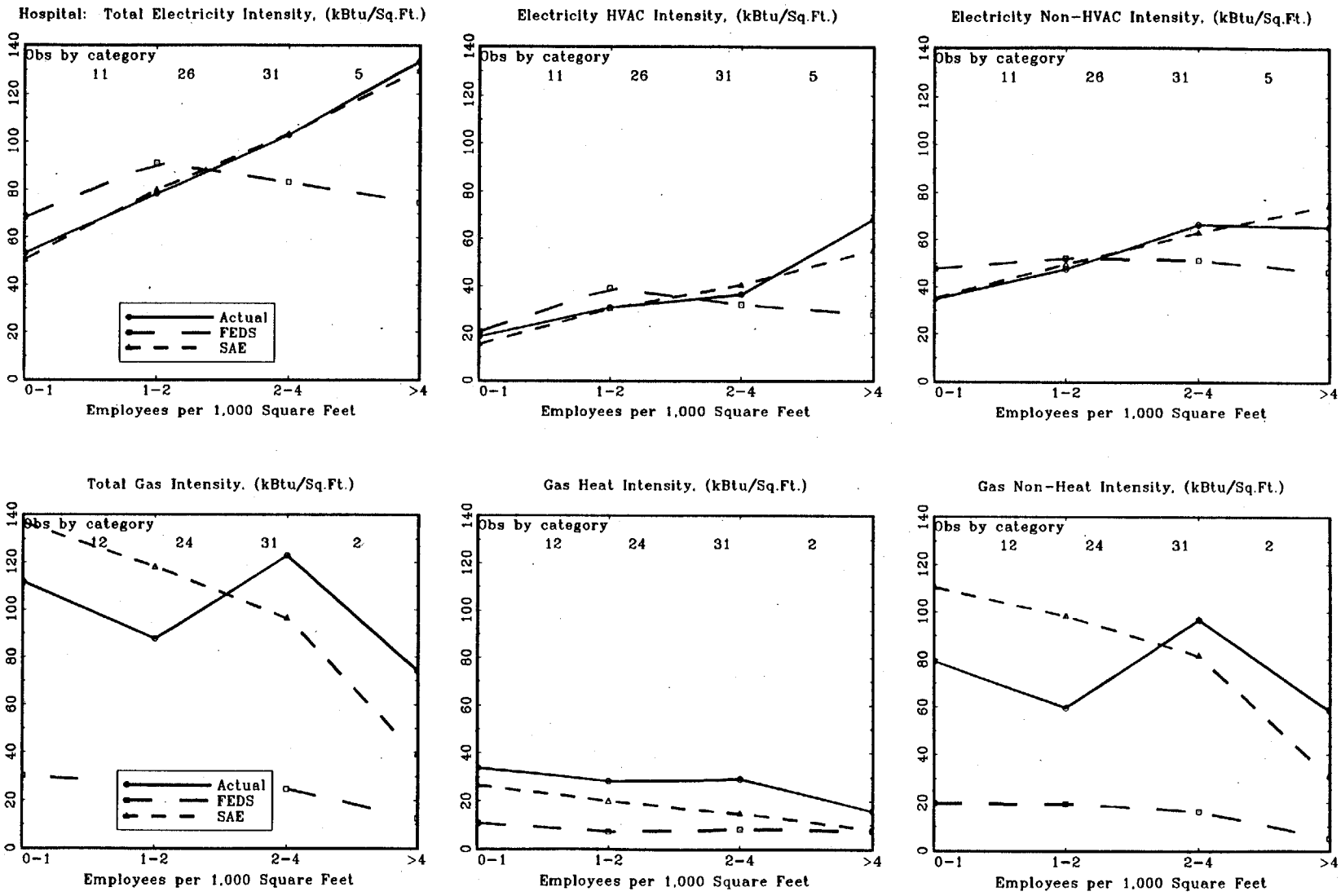

FIGURE D.40. Hospital: Actual, FEDS, and SAE Intensities By Employment Density Category

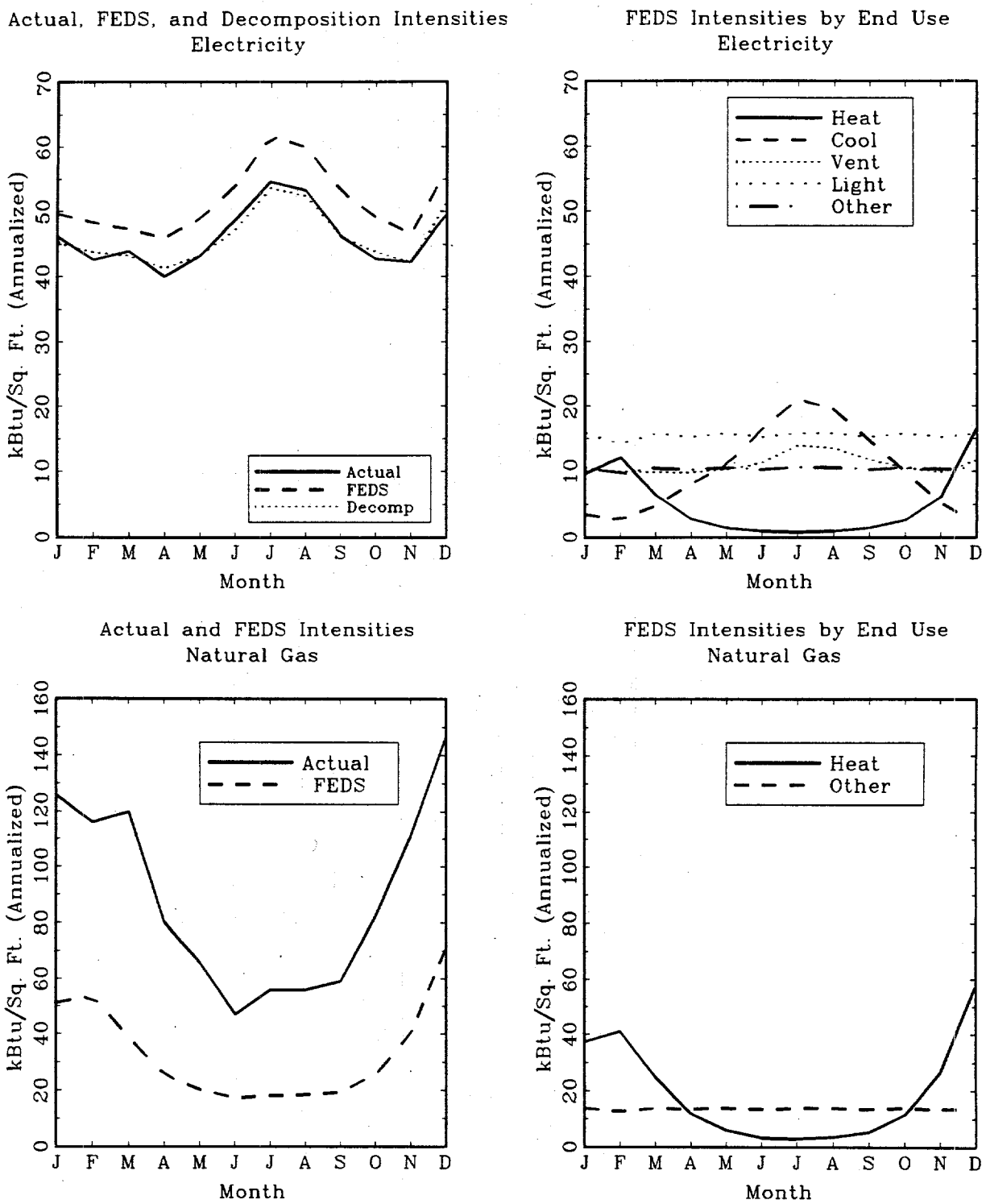

FIGURE D.41. Lodging: Monthly Average EUIs

HVAC

Valid cases:	114	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	32384.696	Degrees of freedom:	107
R-squared:	0.212	Rbar-squared:	0.168
Residual SS:	25515.430	Std error of est:	15.442
F(7,107):	4.115	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.586139	0.073257	8.001131	0.000	0.758272	0.788086
V1*HVf	0.149108	0.168437	0.885244	0.378	0.095247	0.134609
V2*HVf	0.263841	0.179694	1.468277	0.145	0.153813	0.063173
SQFT*HVf	-0.000668	0.000955	-0.699575	0.486	-0.056296	-0.548512
CDD*HVf	0.000018	0.000048	0.368972	0.713	0.025658	0.221077
HRS*HVf	0.000170	0.002426	0.070065	0.944	0.004753	-0.011788
EMP*HVf	0.013323	0.017762	0.750111	0.455	0.054545	-0.431348

NHVAC

Valid cases:	114	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	51918.341	Degrees of freedom:	106
R-squared:	-0.296	Rbar-squared:	-0.382
Residual SS:	67284.779	Std error of est:	25.194
F(8,106):	-3.026	Probability of F:	.

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	0.889164	0.085292	10.424949	0.000	0.756241	0.693997
V1*NHVf	0.223125	0.225156	0.990980	0.324	0.094577	0.009635
V2*NHVf	0.370336	0.248210	1.492030	0.139	0.142556	0.090538
SQFT*NHVf	0.001828	0.000762	2.399467	0.018	0.167547	-0.021894
CDD*NHVf	-0.000012	0.000090	-0.131585	0.896	-0.009731	0.013733
HRS*NHVf	-0.004163	0.005705	-0.729668	0.467	-0.053027	0.101201
EMP*NHVf	0.007695	0.010850	0.709164	0.480	0.048425	-0.089823
ElcMan	-2.428454	25.939055	-0.093622	0.926	-0.006453	0.030721

FIGURE D.42. Lodging: SAE Regression Results for Electricity

Lodging	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	53.12	82.61	9.68	47.47	1.00	1.00	10.13

Lodging	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	4.53	4.85	1.87	.22
Non-Baseload	1.00	.95	1.17	1.40	.16

Valid cases:	94	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	261522.602	Degrees of freedom:	87
R-squared:	0.121	Rbar-squared:	0.061
Residual SS:	229780.472	Std error of est:	51.392
F(7,87):	1.717	Probability of F:	0.115

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.341775	1.126407	0.303420	0.762	0.230245	0.629415
V1*SHf	0.102119	0.333609	0.306103	0.760	0.056345	0.534372
V2*SHf	-0.618029	0.647630	-0.954293	0.343	-0.092231	0.144044
SQFT*SHf	0.000005	0.000002	2.470531	0.015	0.234130	0.381777
HDD*SHf	0.000069	0.000073	0.947533	0.346	0.281918	0.644311
HRS*SHf	0.000244	0.006507	0.037488	0.970	0.026495	0.624313
EMP*SHf	0.022109	0.028551	0.774346	0.441	0.063289	0.186290

FIGURE D.43. Lodging: SAE Regression Results for Natural Gas

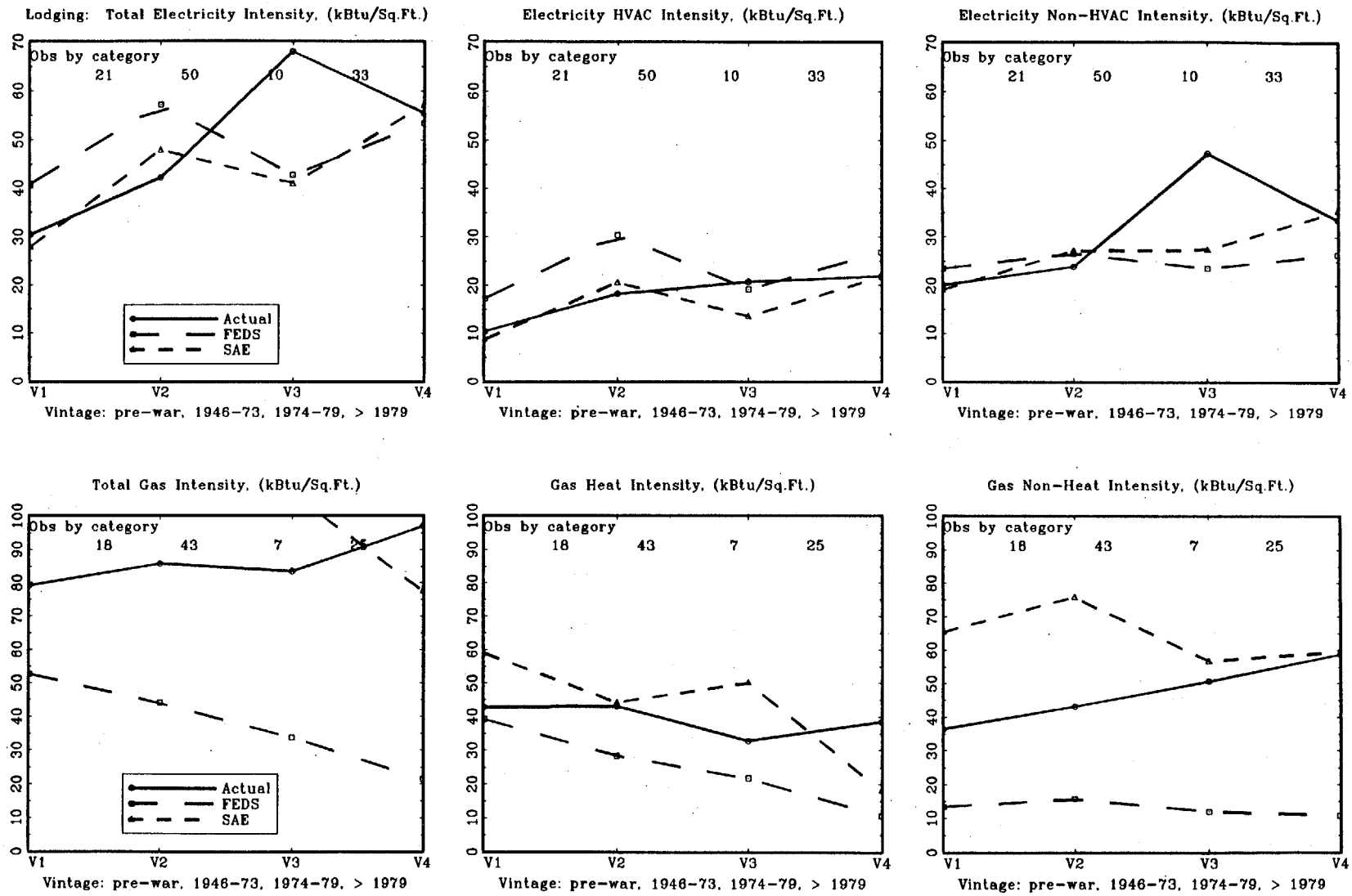

FIGURE D.44. Lodging: Actual, FEDS, and SAE Intensities By Vintage

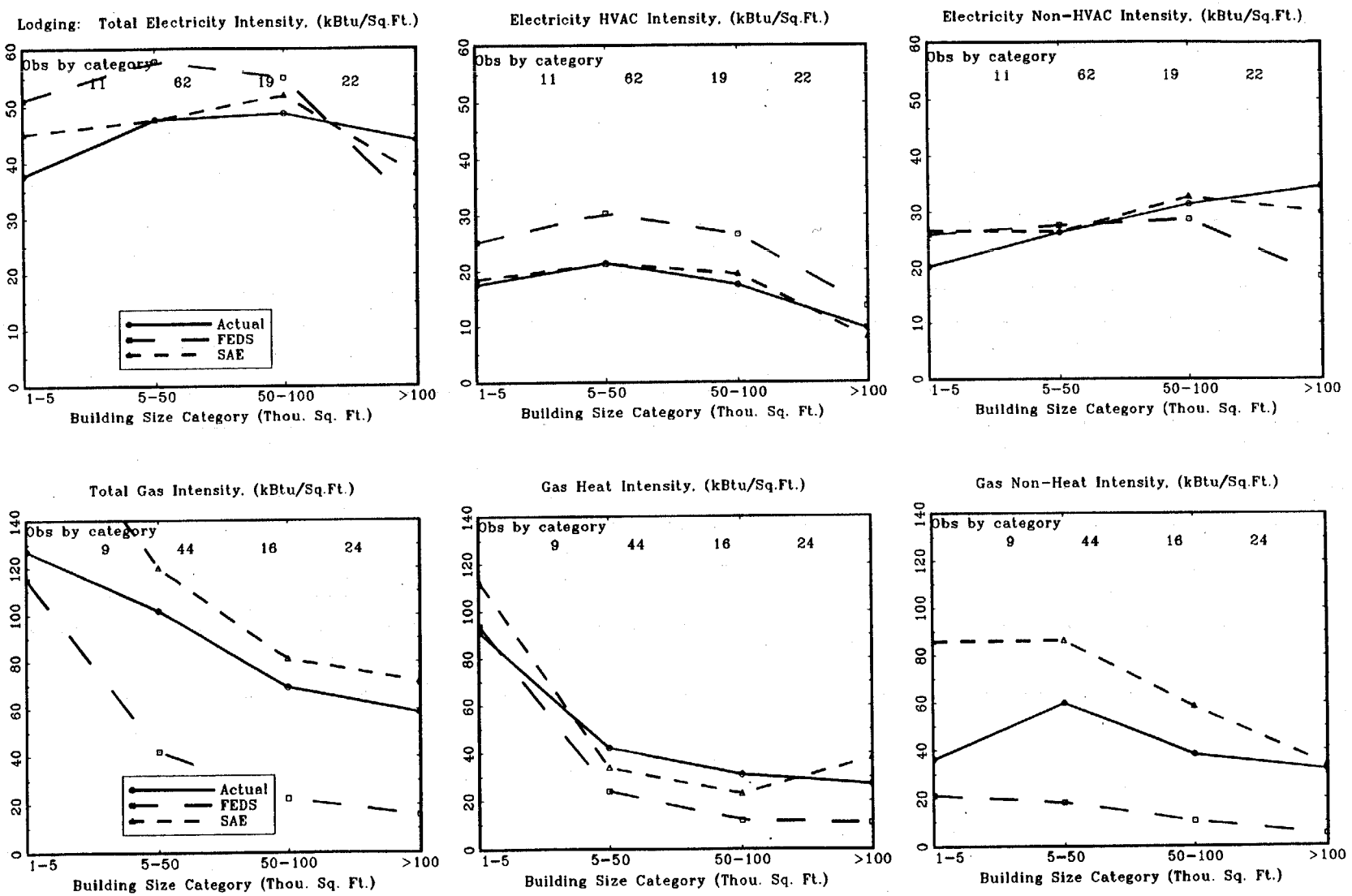

FIGURE D.45. Lodging: Actual, FEDS, and SAE Intensities By Building Size Category

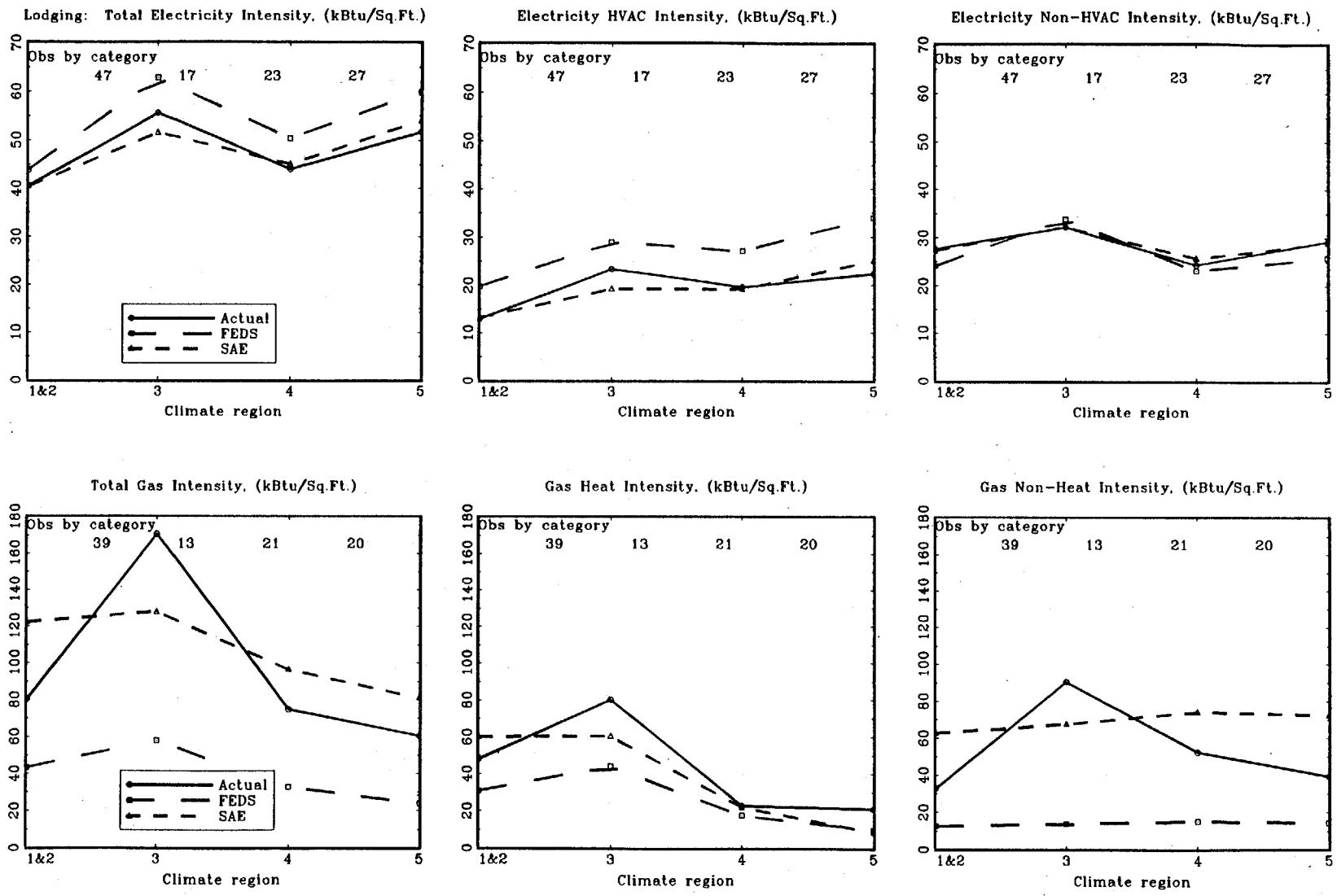

FIGURE D.46. Lodging: Actual, FEDS, and SAE Intensities By Climate Region

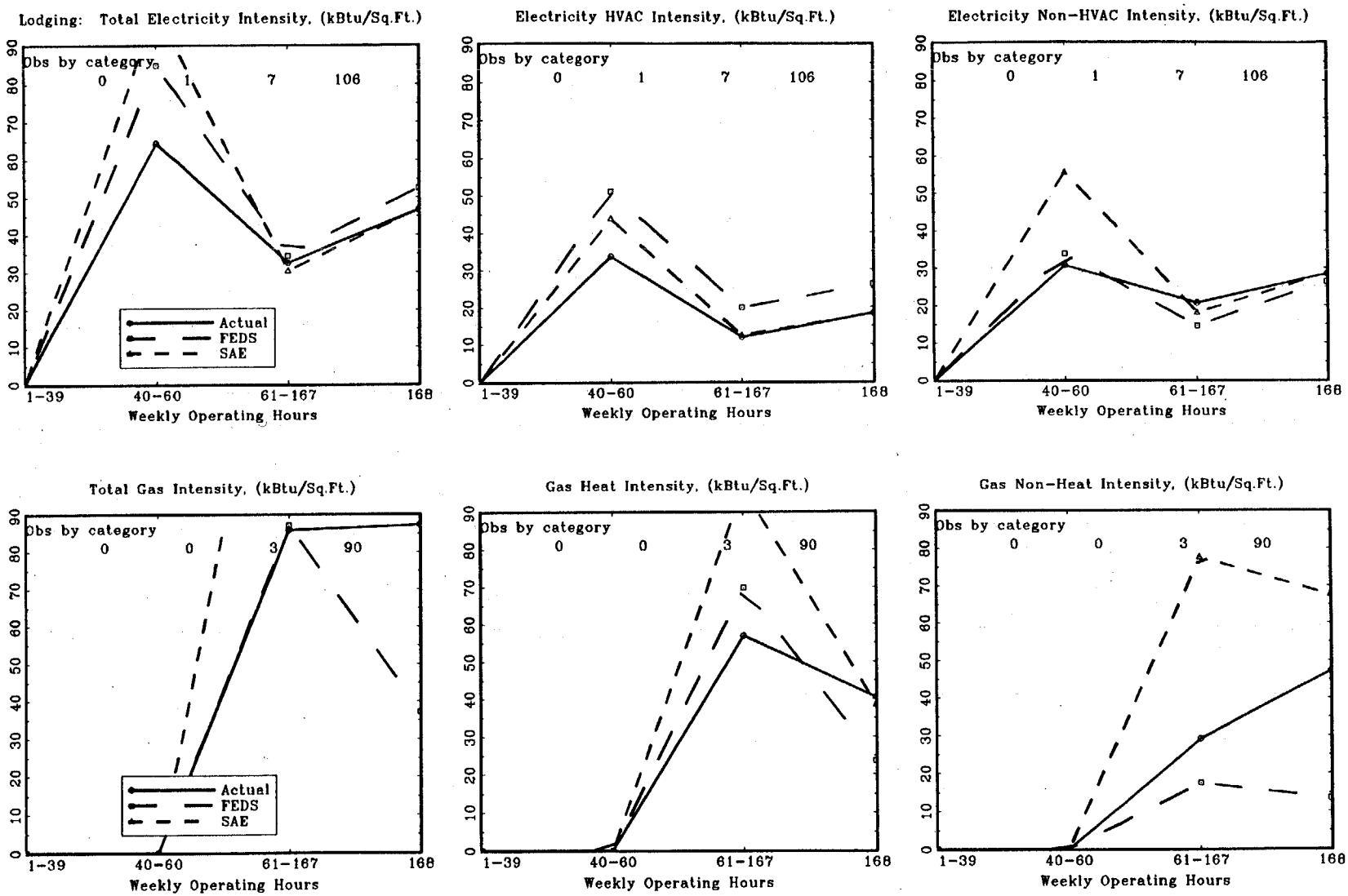

FIGURE D.47. Lodging: Actual, FEDS, and SAE Intensities By Weekly Hours Category

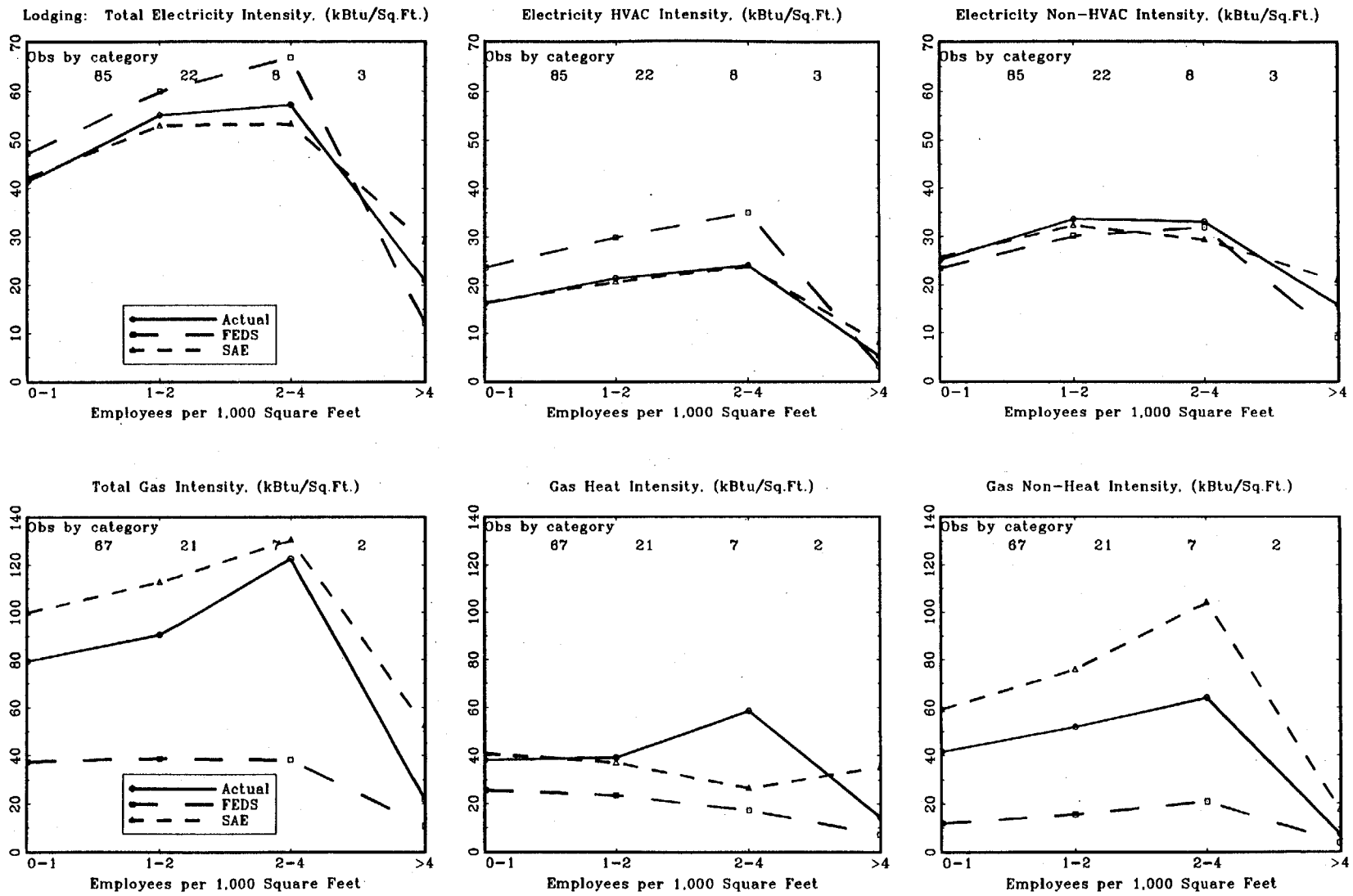

FIGURE D.48. Lodging: Actual, FEDS, and SAE Intensities By Employment Density Category

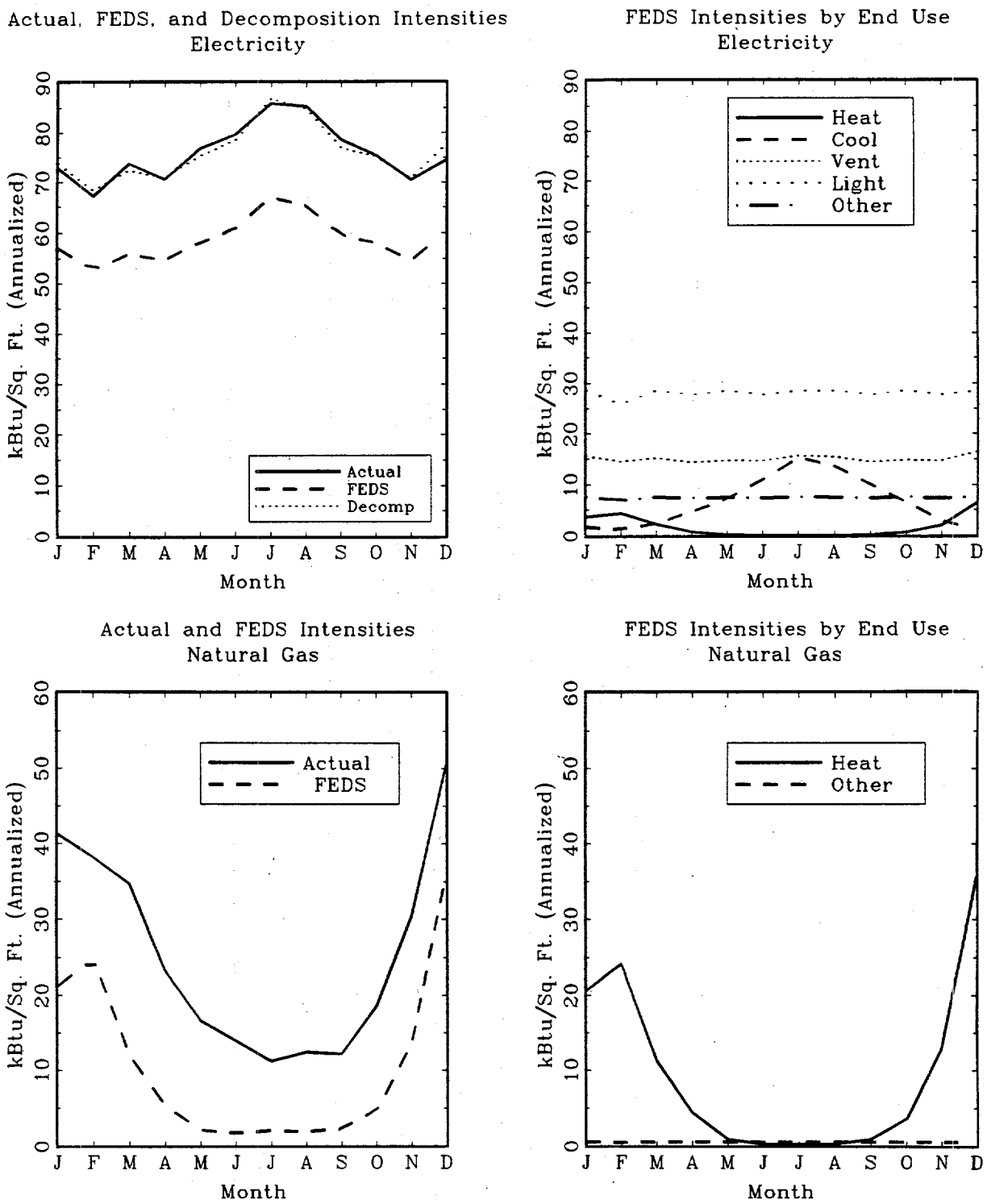

FIGURE D.49. Large Office: Monthly Average EUIs

HVAC

Valid cases:	283	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	141759.066	Degrees of freedom:	276
R-squared:	-0.044	Rbar-squared:	-0.066
Residual SS:	147964.944	Std error of est:	23.154
F(7,276):	-1.654	Probability of F:	.

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	1.125864	0.059563	18.902229	0.000	0.775457	0.771521
V1*HVf	0.335789	0.199829	1.680381	0.094	0.115466	0.091935
V2*HVf	0.142236	0.206823	0.687720	0.492	0.047576	-0.034665
SQFT*HVf	0.000076	0.000157	0.483827	0.629	0.019093	-0.150970
CDD*HVf	-0.000039	0.000048	-0.816279	0.415	-0.031470	0.073391
HRS*HVf	-0.000065	0.001497	-0.043320	0.965	-0.001736	0.213803
EMP*HVf	0.025758	0.020422	1.261294	0.208	0.048283	0.070290

NHVAC

Valid cases:	283	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	985581.668	Degrees of freedom:	275
R-squared:	0.003	Rbar-squared:	-0.022
Residual SS:	982675.771	Std error of est:	59.778
F(8,275):	0.102	Probability of F:	0.999

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.450071	0.112303	12.912156	0.000	0.635595	0.634866
V1*NHVf	0.480622	0.329030	1.460723	0.145	0.104982	0.141430
V2*NHVf	0.015001	0.350765	0.042765	0.966	0.003091	-0.136096
SQFT*NHVf	0.000202	0.000237	0.853185	0.394	0.039573	0.106222
CDD*NHVf	-0.000041	0.000110	-0.372998	0.709	-0.017311	-0.010481
HRS*NHVf	-0.005506	0.002620	-2.101444	0.037	-0.101420	0.108117
EMP*NHVf	0.052839	0.036715	1.439162	0.151	0.066445	0.114519
ElcMan	26.903428	17.679739	1.521710	0.129	0.070903	0.172706

FIGURE D.50. Large Office: SAE Regression Results for Electricity

Large Office	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	19.35	7.01	1.08	6.59	74.88	50.54	2.63

Large Office	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	8.43	5.11	4.45	.80
Non-Baseload	1.00	12.29	1.60	2.44	.44

Valid cases:	168	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	116327.376	Degrees of freedom:	161
R-squared:	0.210	Rbar-squared:	0.181
Residual SS:	91874.613	Std error of est:	23.888
F(7,161):	6.122	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	1.613303	0.594402	2.714159	0.007	0.928807	0.578816
V1*SHf	-0.432332	0.312071	-1.385363	0.168	-0.190226	0.455307
V2*SHf	-0.760849	0.349780	-2.175221	0.031	-0.216179	0.196200
SQFT*SHf	-0.000000	0.000000	-0.598212	0.551	-0.048242	0.304432
HDD*SHf	0.000014	0.000055	0.250338	0.803	0.056091	0.556355
HRS*SHf	-0.011096	0.006799	-1.631974	0.105	-0.386779	0.531078
EMP*SHf	0.153588	0.073151	2.099602	0.037	0.288818	0.566314

FIGURE D.51. Large Office: SAE Regression Results for Natural Gas

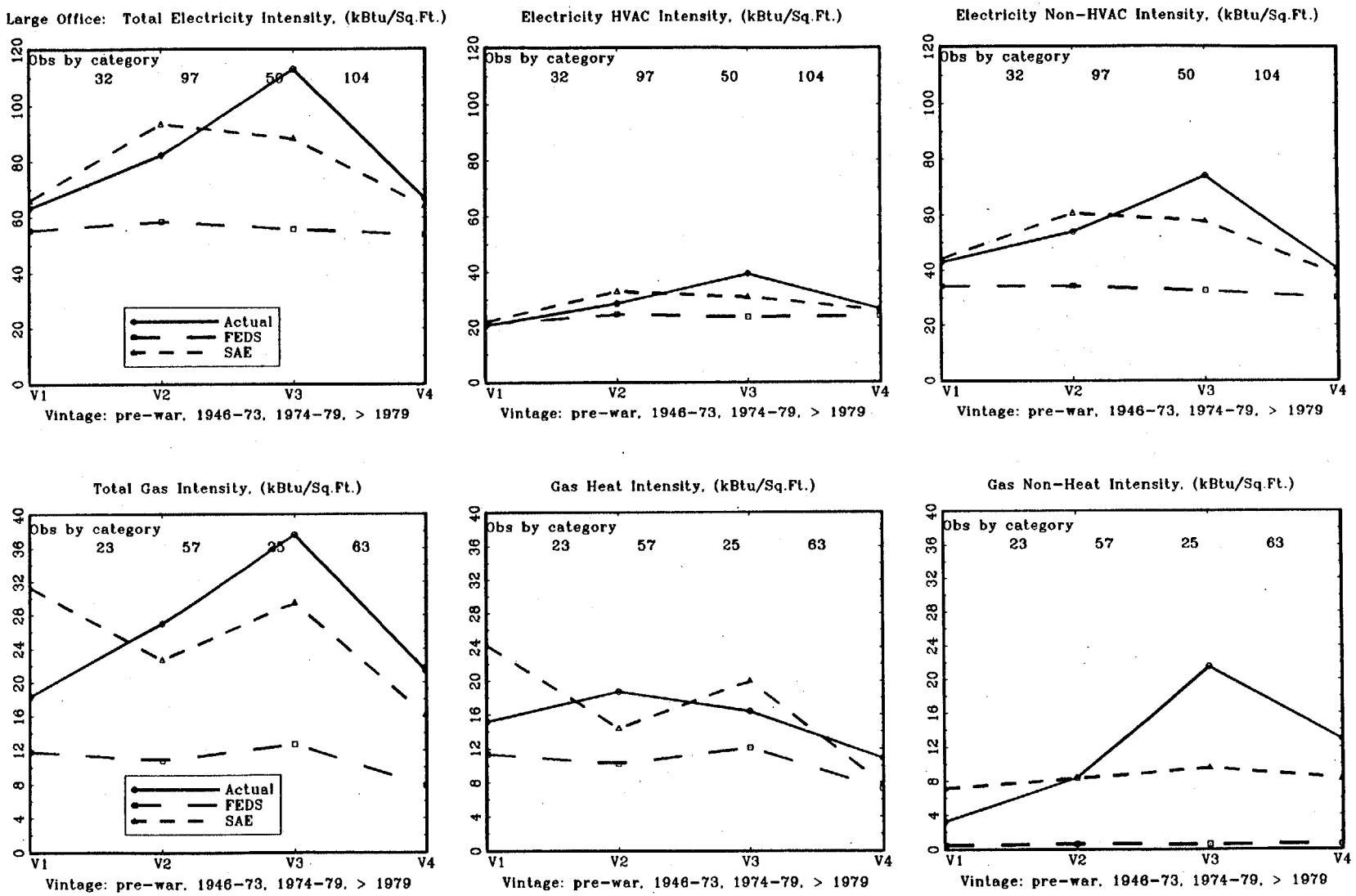

FIGURE D.52. Large Office: Actual, FEDS, and SAE Intensities By Vintage

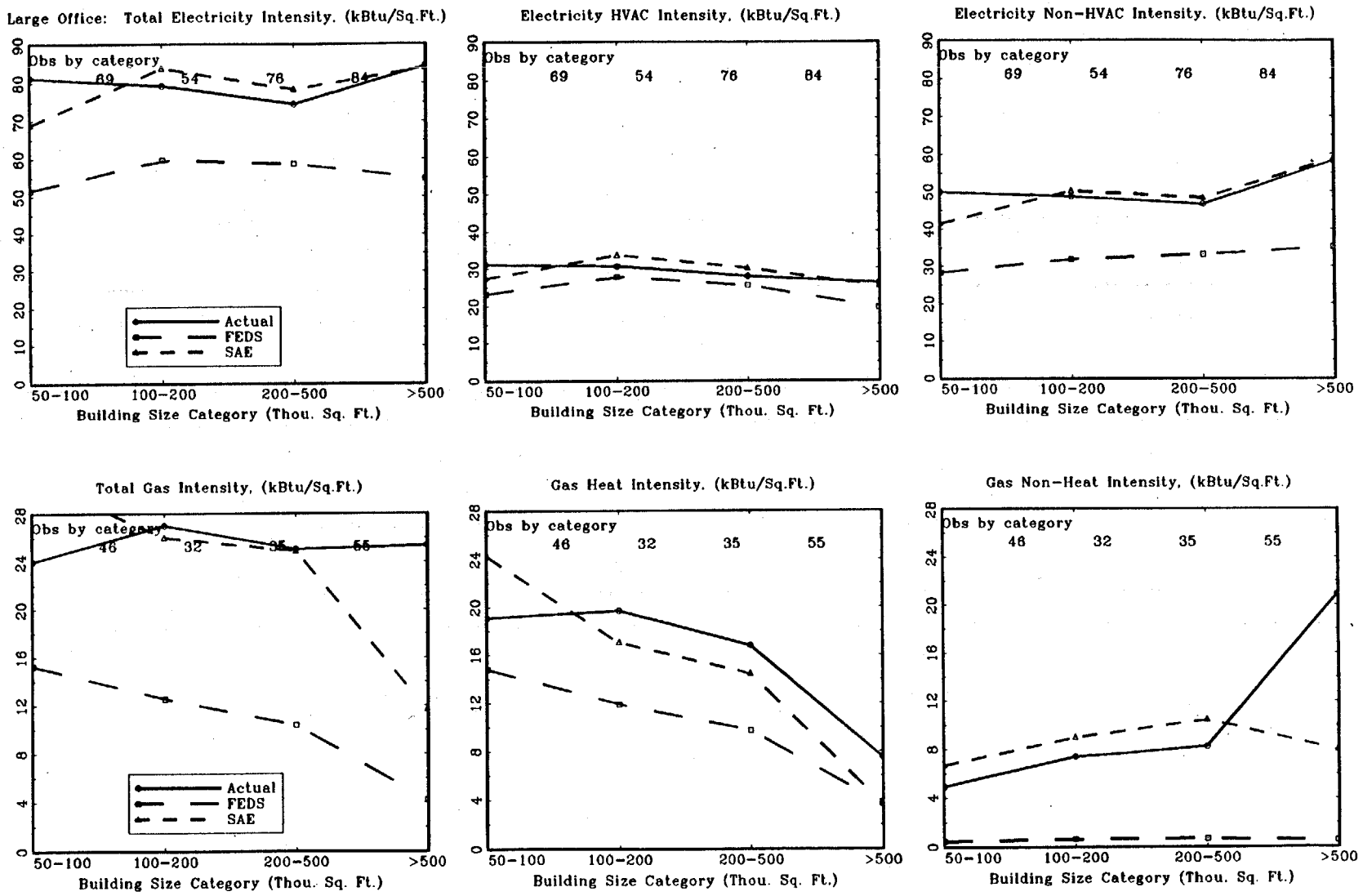

FIGURE D.53. Large Office: Actual, FEDS, and SAE Intensities By Building Size Category

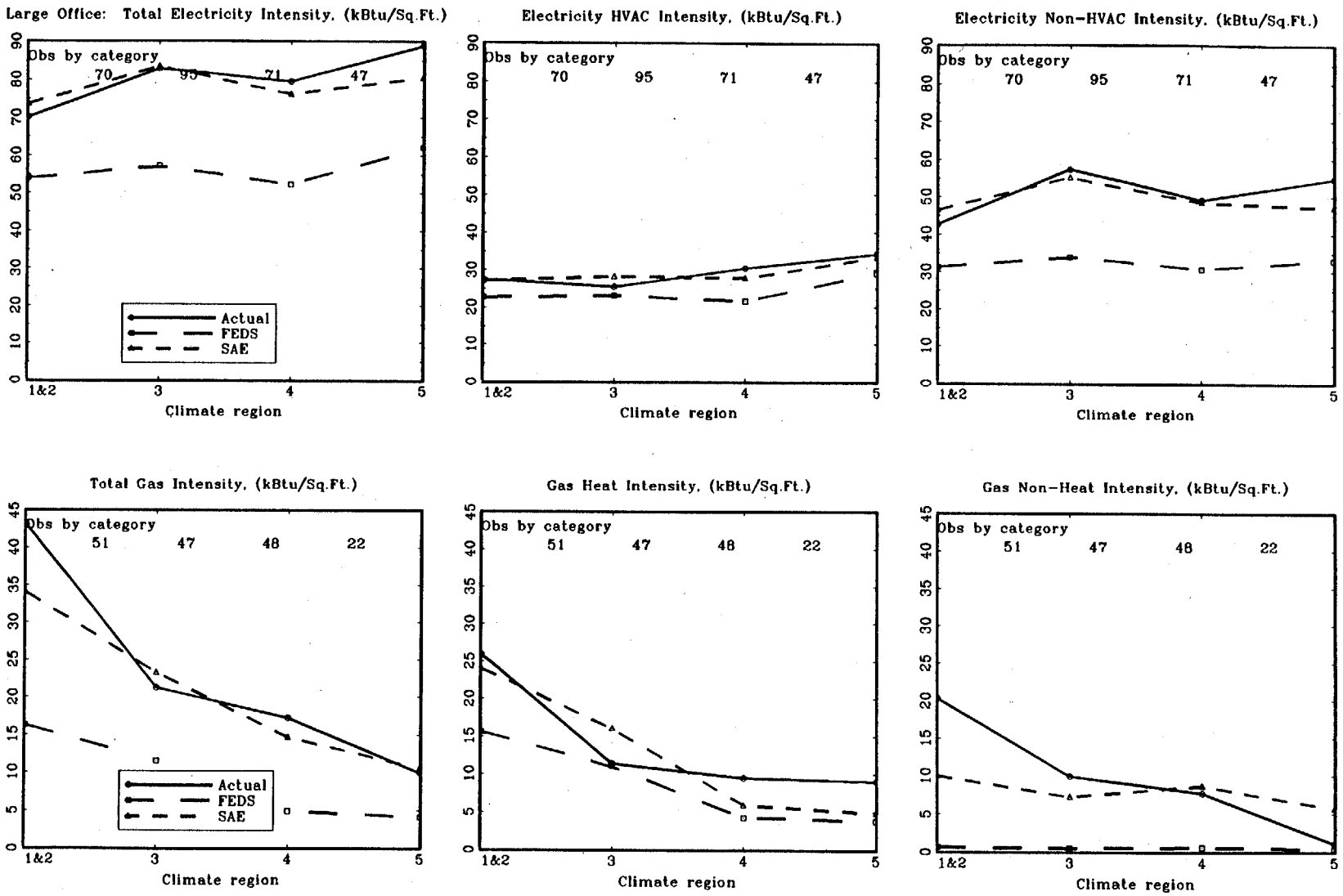

FIGURE D.54. Large Office: Actual, FEDS, and SAE Intensities By Climate Region

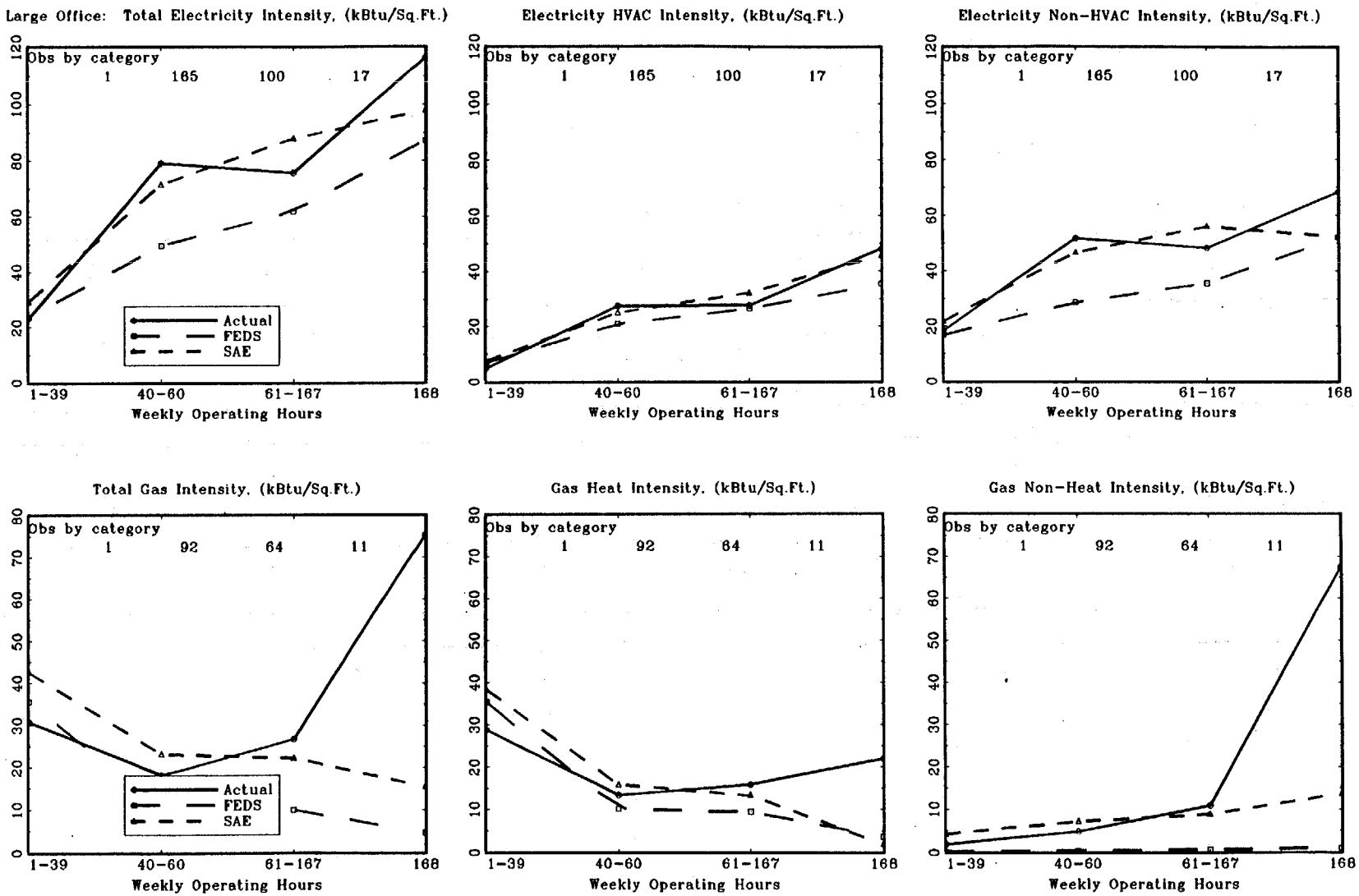

FIGURE D.55. Large Office: Actual, FEDS, and SAE Intensities By Weekly Hours Category

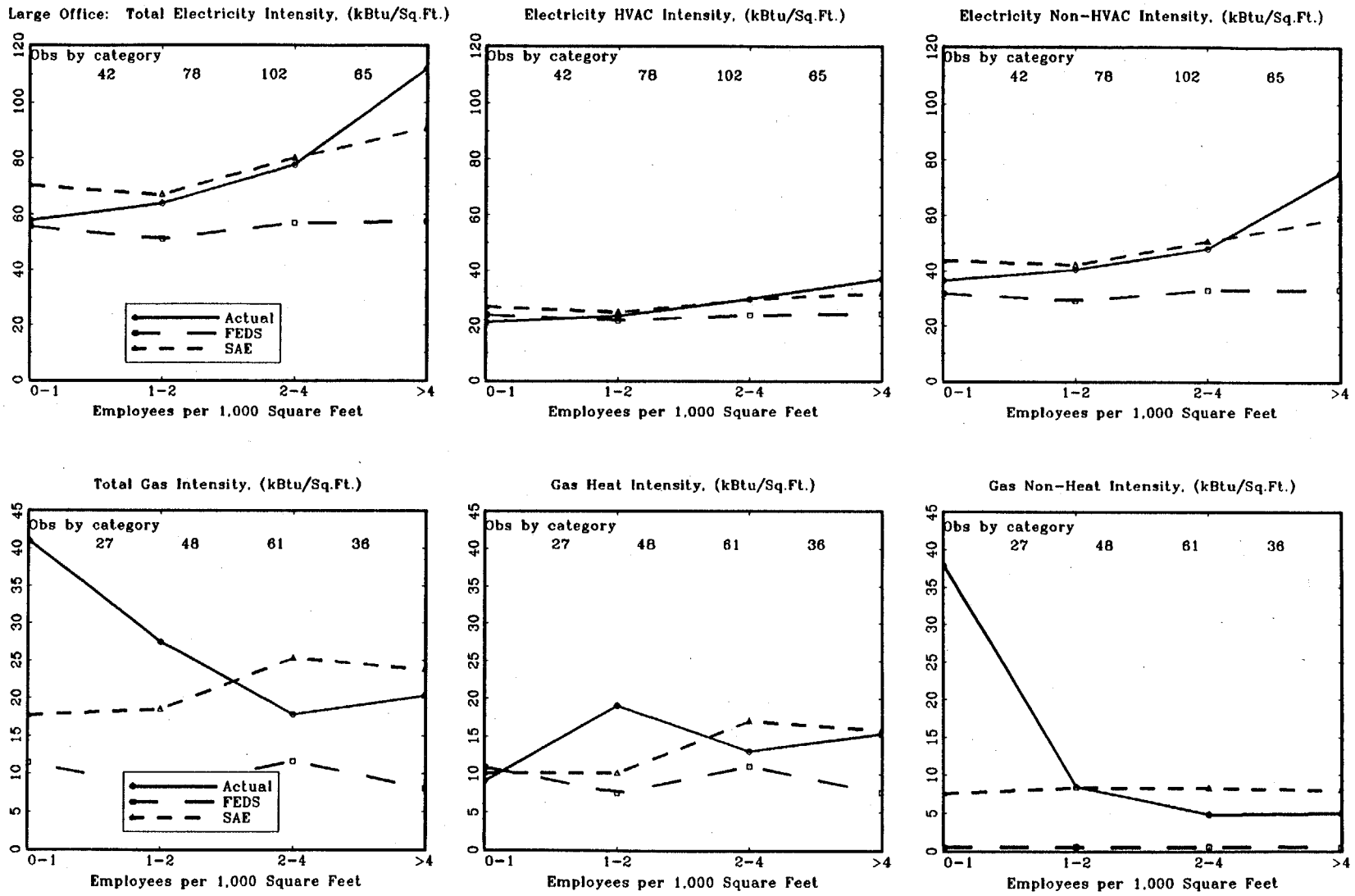

FIGURE D.56. Large Office: Actual, FEDS, and SAE Intensities By Employment Density Category

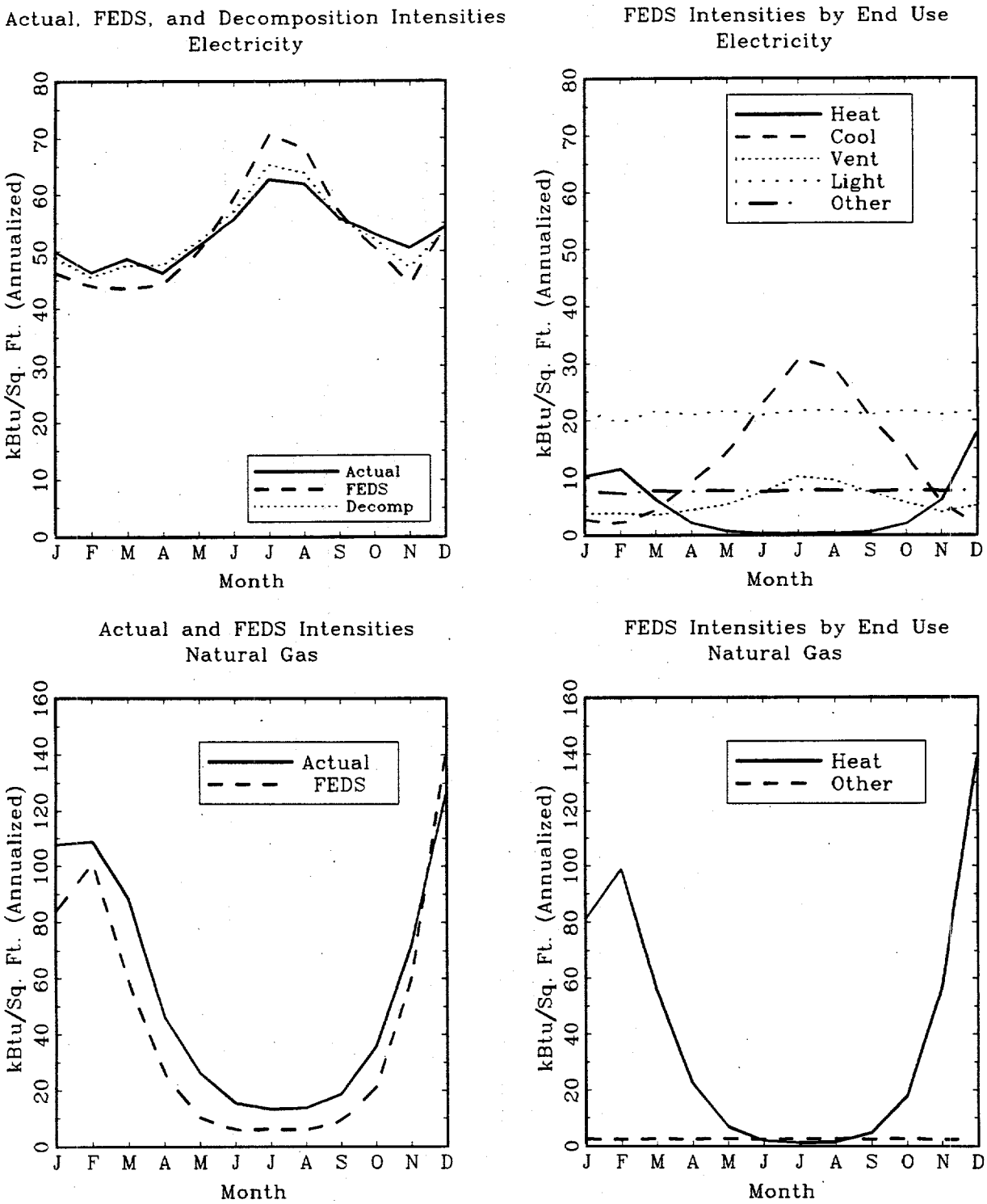

FIGURE D.57. Small Office: Monthly Average EUIs

HVAC

Valid cases:	477	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	155913.211	Degrees of freedom:	470
R-squared:	0.189	Rbar-squared:	0.179
Residual SS:	126455.533	Std error of est:	16.403
F(7,470):	15.641	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.483098	0.029518	16.366310	0.000	0.610888	0.667430
V1*HVf	0.057235	0.072615	0.788205	0.431	0.035967	0.142449
V2*HVf	0.124990	0.085791	1.456910	0.146	0.066542	-0.065238
SQFT*HVf	0.001558	0.002505	0.621980	0.534	0.022290	-0.212718
CDD*HVf	0.000080	0.000023	3.520145	0.000	0.123889	0.348744
HRS*HVf	0.003250	0.001241	2.618164	0.009	0.086826	0.089944
EMP*HVf	0.066506	0.012495	5.322773	0.000	0.176564	0.279727

NHVAC

Valid cases:	477	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	1131834.779	Degrees of freedom:	469
R-squared:	0.115	Rbar-squared:	0.101
Residual SS:	1002094.679	Std error of est:	46.224
F(8,469):	7.590	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.156661	0.071651	16.143048	0.000	0.575764	0.633205
V1*NHVf	-0.015850	0.183577	-0.086341	0.931	-0.003941	-0.020390
V2*NHVf	0.351540	0.203951	1.723652	0.085	0.078719	0.073304
SQFT*NHVf	0.012686	0.005444	2.330430	0.020	0.081324	0.113072
CDD*NHVf	-0.000094	0.000081	-1.158265	0.247	-0.039932	-0.056678
HRS*NHVf	0.006221	0.002007	3.099275	0.002	0.111506	0.319519
EMP*NHVf	0.147678	0.036115	4.089123	0.000	0.139753	0.186134
ElcMan	35.911308	12.327043	2.913214	0.004	0.101526	0.221753

FIGURE D.58. Small Office: SAE Regression Results for Electricity

Small Office	sh	wh	ck	whck	mf	cg	ms
Conditional Demand Coefficients	47.17	11.73	8.05	18.36	1.00	39.35	8.40

Small Office	sc	wh	ck	whck	
Adjustment Coefficients				wh	ck
Baseload	1.00	1.74	1.74	1.42	2.31
Non-Baseload	1.00	1.92	1.74	1.42	2.31

Valid cases:	293	Dependent variable:	EUI^{NBL}
Missing cases:	0	Deletion method:	None
Total SS:	875082.801	Degrees of freedom:	286
R-squared:	0.135	Rbar-squared:	0.117
Residual SS:	757073.672	Std error of est:	51.450
F(7,286):	6.369	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.154883	0.256940	0.602796	0.547	0.132741	0.674119
V1*SHf	-0.099061	0.112960	-0.876958	0.381	-0.064254	0.509373
V2*SHf	-0.165530	0.181919	-0.909913	0.364	-0.048885	0.206668
SQFT*SHf	0.000009	0.000006	1.407646	0.160	0.073224	0.432345
HDD*SHf	0.000051	0.000033	1.543854	0.124	0.288402	0.669252
HRS*SHf	0.005704	0.002057	2.772820	0.006	0.283858	0.660317
EMP*SHf	0.012550	0.027093	0.463219	0.644	0.037024	0.558383

FIGURE D.59. Small Office: SAE Regression Results for Natural Gas

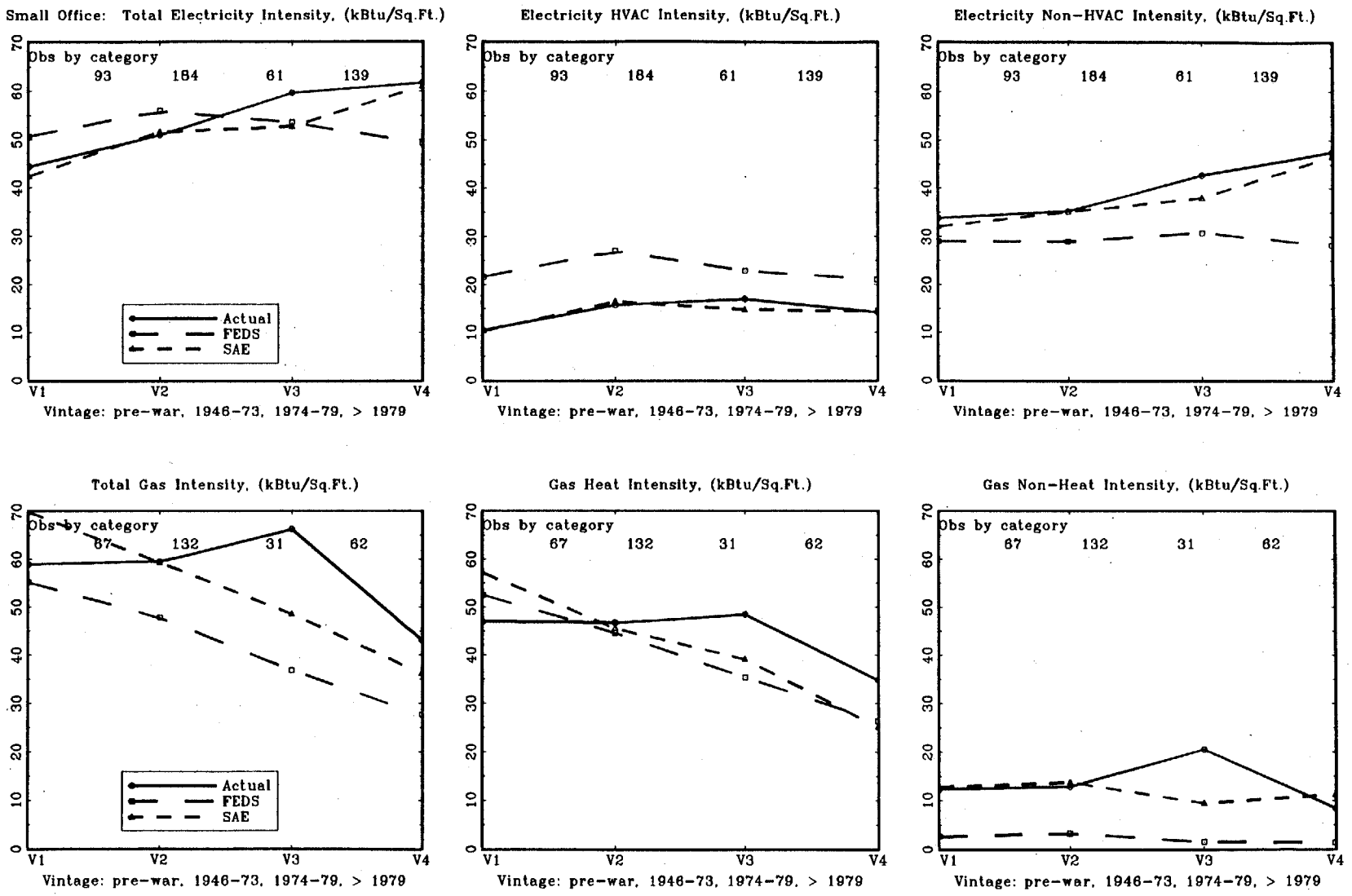

FIGURE D.60. Small Office: Actual, FEDS, and SAE Intensities By Vintage

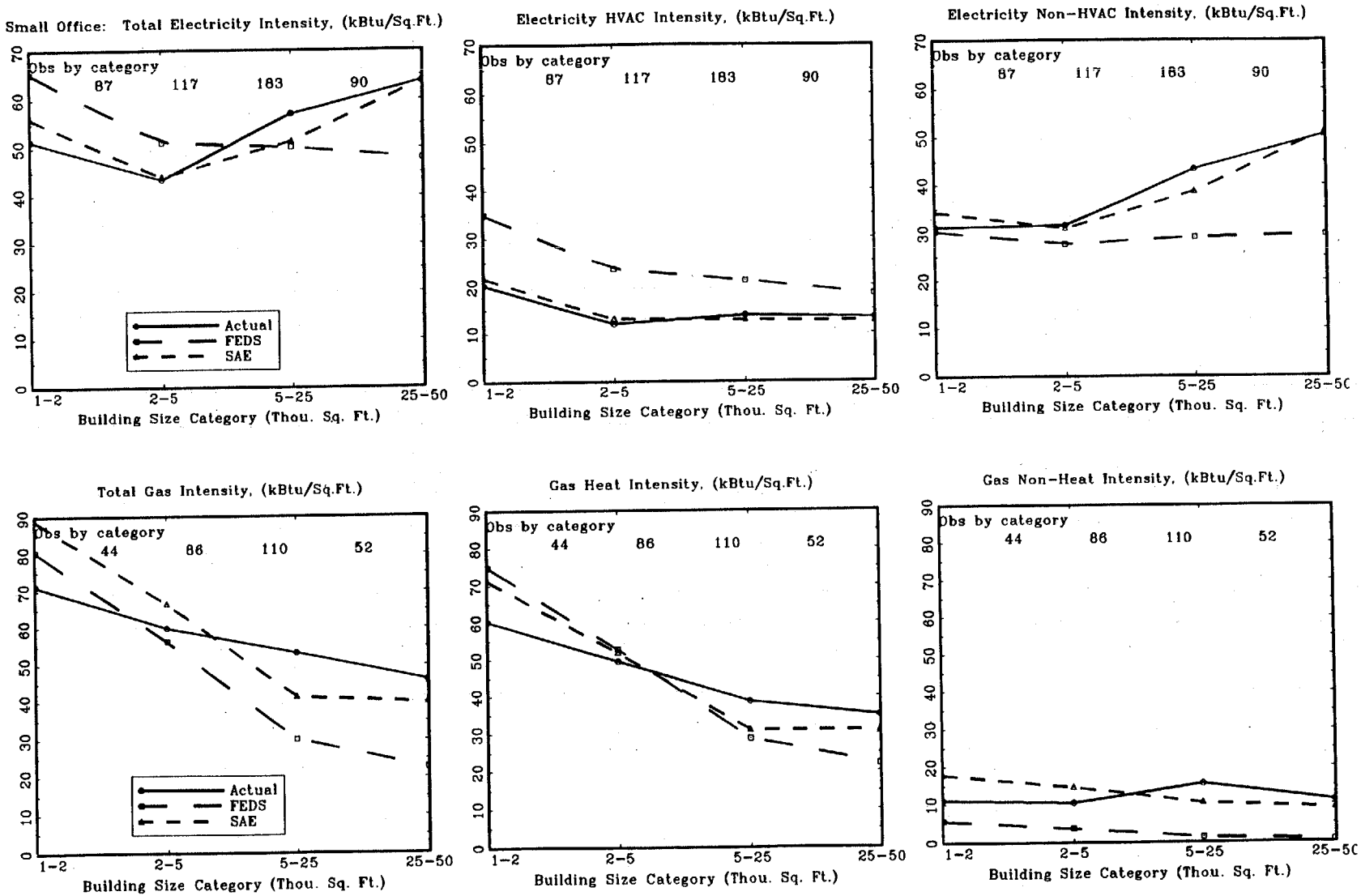

FIGURE D.61. Small Office: Actual, FEDS, and SAE Intensities By Building Size Category

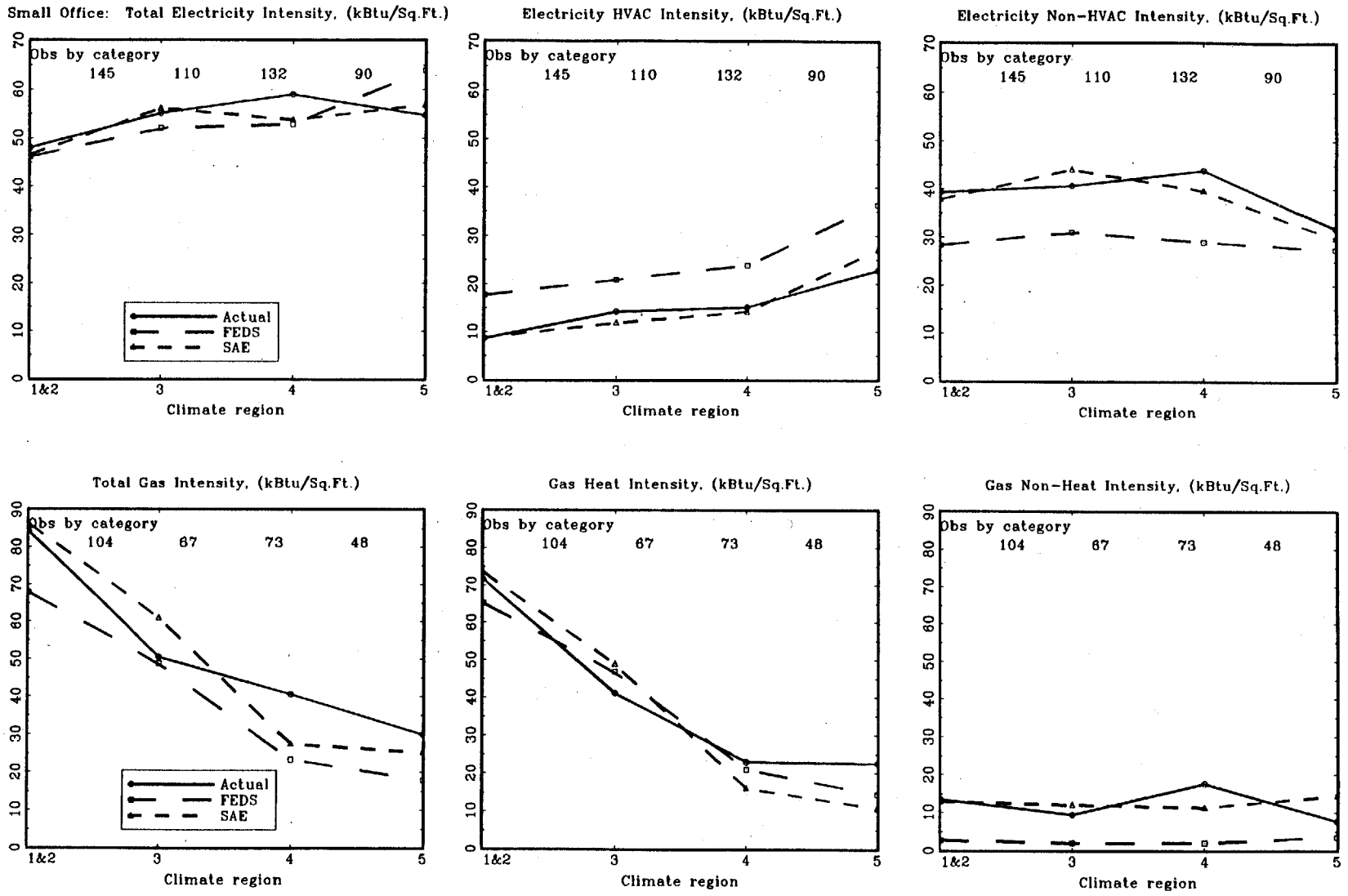

FIGURE D.62. Small Office: Actual, FEDS, and SAE Intensities By Climate Region

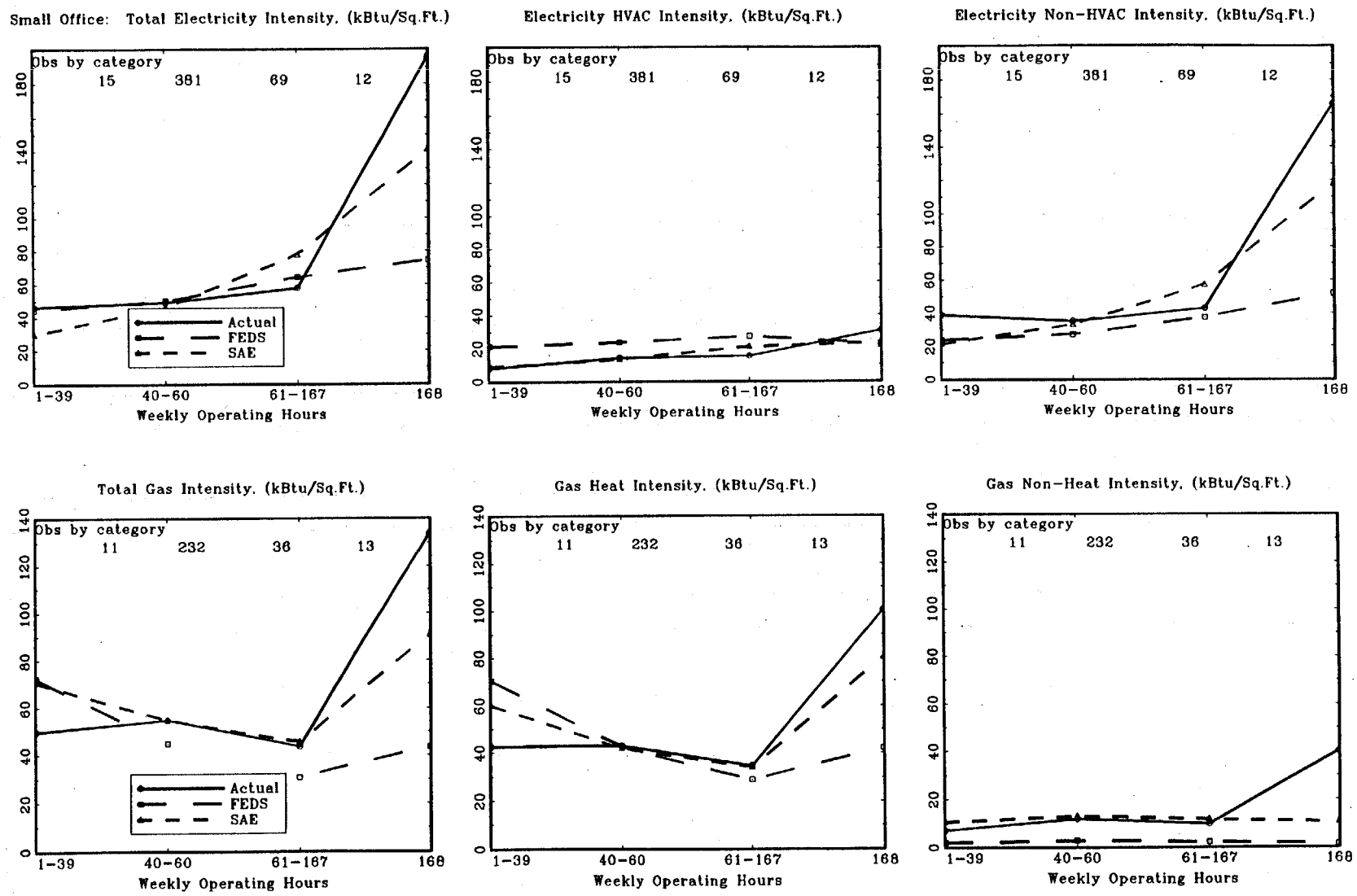

FIGURE D.63. Small Office: Actual, FEDS, and SAE Intensities By Weekly Hours Category

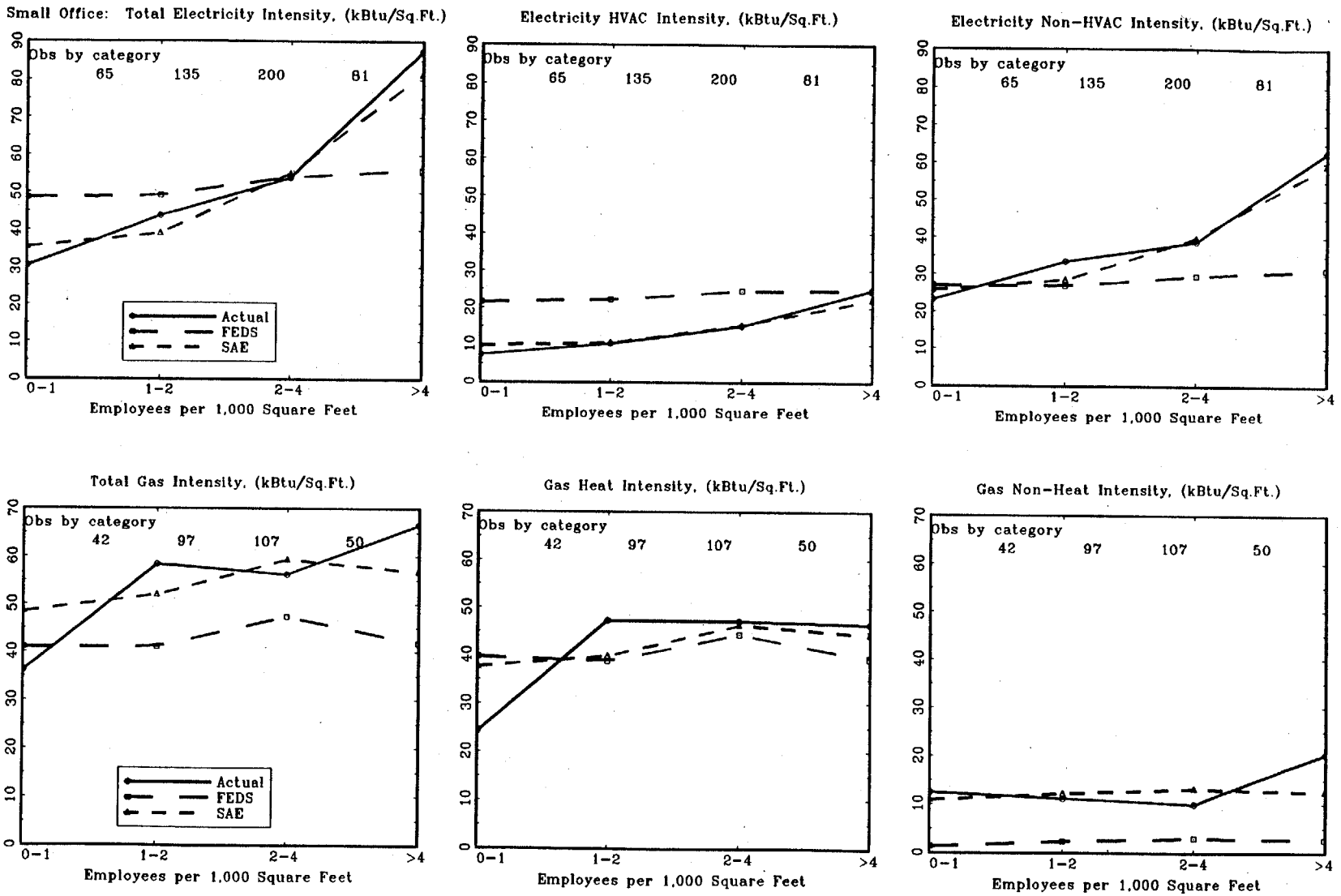

FIGURE D.64. Small Office: Actual, FEDS, and SAE Intensities By Employment Density Category

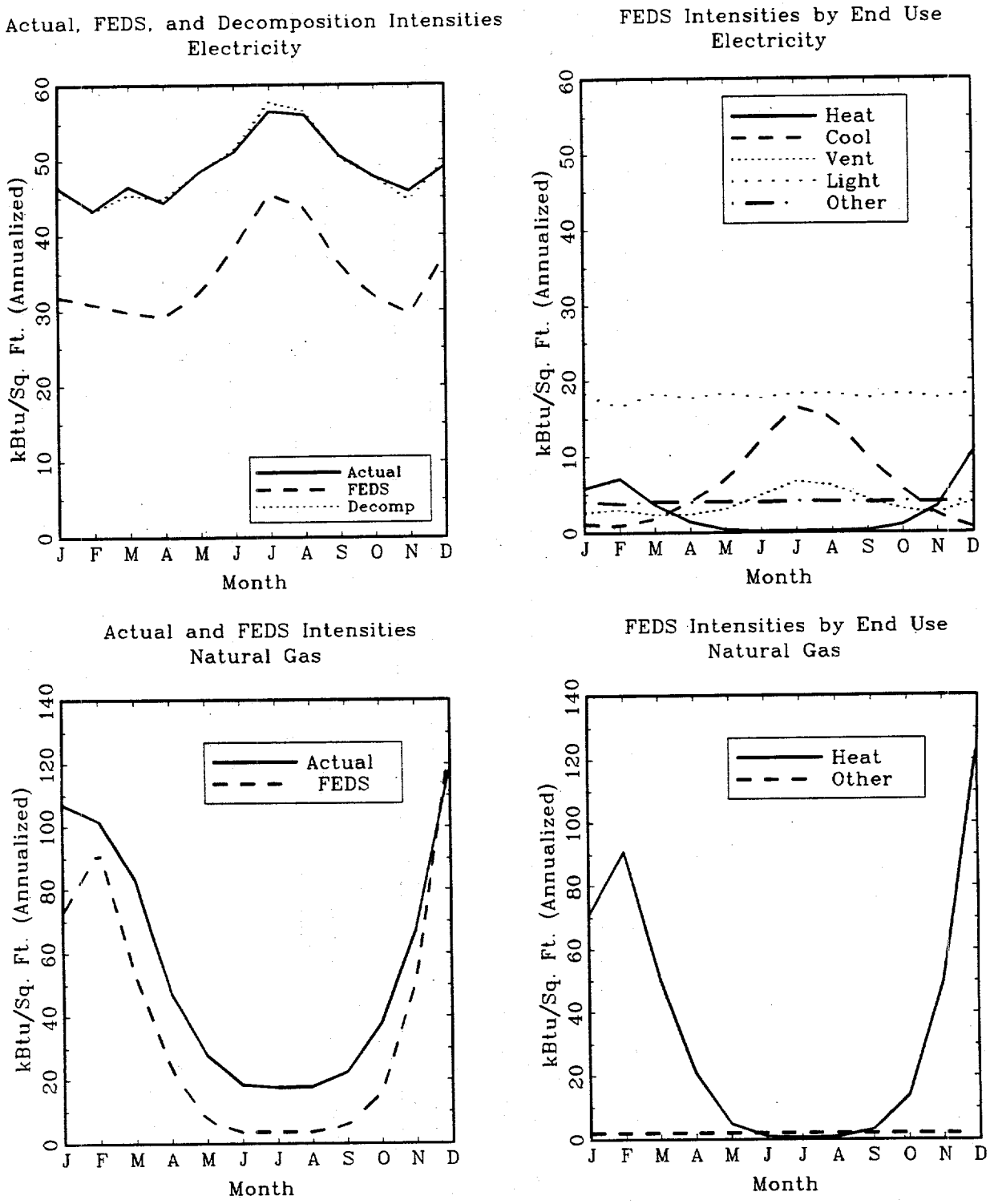

FIGURE D.65. Retail Service: Monthly Average EUIs

HVAC

Valid cases:	820	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	265041.471	Degrees of freedom:	813
R-squared:	0.335	Rbar-squared:	0.330
Residual SS:	176236.916	Std error of est:	14.723
F(7,813):	58.524	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.552022	0.031594	17.472202	0.000	0.502593	0.609759
V1*HVf	0.299323	0.082066	3.647331	0.000	0.129312	0.201808
V2*HVf	0.117837	0.098675	1.194195	0.233	0.041503	-0.042296
SQFT*HVf	0.000187	0.000255	0.732592	0.464	0.020114	-0.229807
CDD*HVf	0.000169	0.000025	6.656904	0.000	0.173180	0.305392
HRS*HVf	0.003686	0.000715	5.152990	0.000	0.139389	0.298844
EMP*HVf	0.179712	0.025121	7.153945	0.000	0.189894	0.348114

NHVAC

Valid cases:	820	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	3190061.572	Degrees of freedom:	812
R-squared:	0.245	Rbar-squared:	0.238
Residual SS:	2409425.960	Std error of est:	54.473
F(8,812):	32.885	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.472783	0.085588	17.207827	0.000	0.482010	0.573350
V1*NHVf	0.856732	0.205602	4.166942	0.000	0.134250	0.123445
V2*NHVf	1.249983	0.272394	4.588882	0.000	0.148510	0.023825
SQFT*NHVf	-0.000997	0.000279	-3.566573	0.000	-0.092925	0.000507
CDD*NHVf	0.000152	0.000098	1.552145	0.121	0.041289	-0.038933
HRS*NHVf	0.017356	0.001974	8.792217	0.000	0.243719	0.433414
EMP*NHVf	0.659069	0.074870	8.802863	0.000	0.226955	0.301014
ElcMan	16.760630	9.499201	1.764425	0.078	0.045659	0.116600

FIGURE D.66. Retail/Service: SAE Regression Results for Electricity

Retail	sh	wh	ck	whck	mf	cg	ms
Conditional Demand Coefficients							
Baseload (w/Heating)	44.53	28.10	7.83	21.09	35.51	45.63	9.97
Baseload (wo/Heating)	NA	51.55	6.92	13.21	35.51	45.63	9.97

Retail - 9	sc	wh	ck	whck	
				wh	ck
Baseload (w/Heating)	1.00	4.15	20.57	13.07	5.08
Baseload (wo/Heating)	1.00	9.71	19.52	14.61	5.68
Non-Baseload	1.00	8.05	10.45	4.17	1.62

Valid cases:	508	Dependent variable:	EUI^{NBL}
Missing cases:	0	Deletion method:	None
Total SS:	1459387.762	Degrees of freedom:	501
R-squared:	0.243	Rbar-squared:	0.234
Residual SS:	1105163.083	Std error of est:	46.967
F(7,501):	22.940	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.218748	0.216493	1.010417	0.313	0.173743	0.656822
V1*SHf	0.212348	0.086758	2.447599	0.015	0.129710	0.533204
V2*SHf	0.404799	0.157539	2.569507	0.010	0.090709	0.279104
SQFT*SHf	0.000000	0.000000	0.296563	0.767	0.009388	0.120057
HDD*SHf	0.000007	0.000028	0.270558	0.787	0.040597	0.651140
HRS*SHf	0.000661	0.001640	0.403292	0.687	0.034329	0.627732
EMP*SHf	0.228649	0.028192	8.110453	0.000	0.383855	0.667624

FIGURE D.67. Retail/Service: SAE Regression Results for Natural Gas

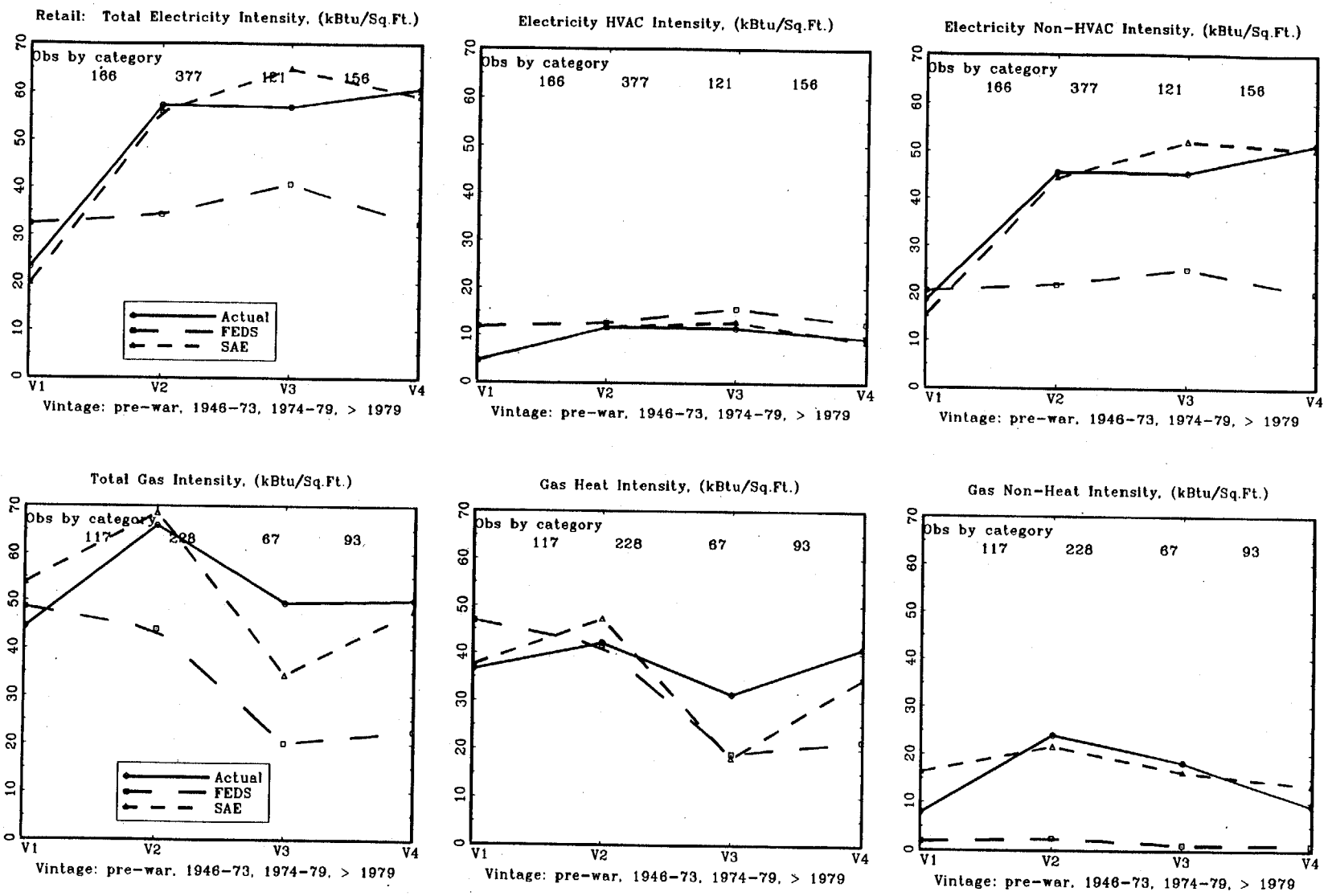

FIGURE D.68. Retail/Service: Actual, FEDS, and SAE Intensities By Vintage

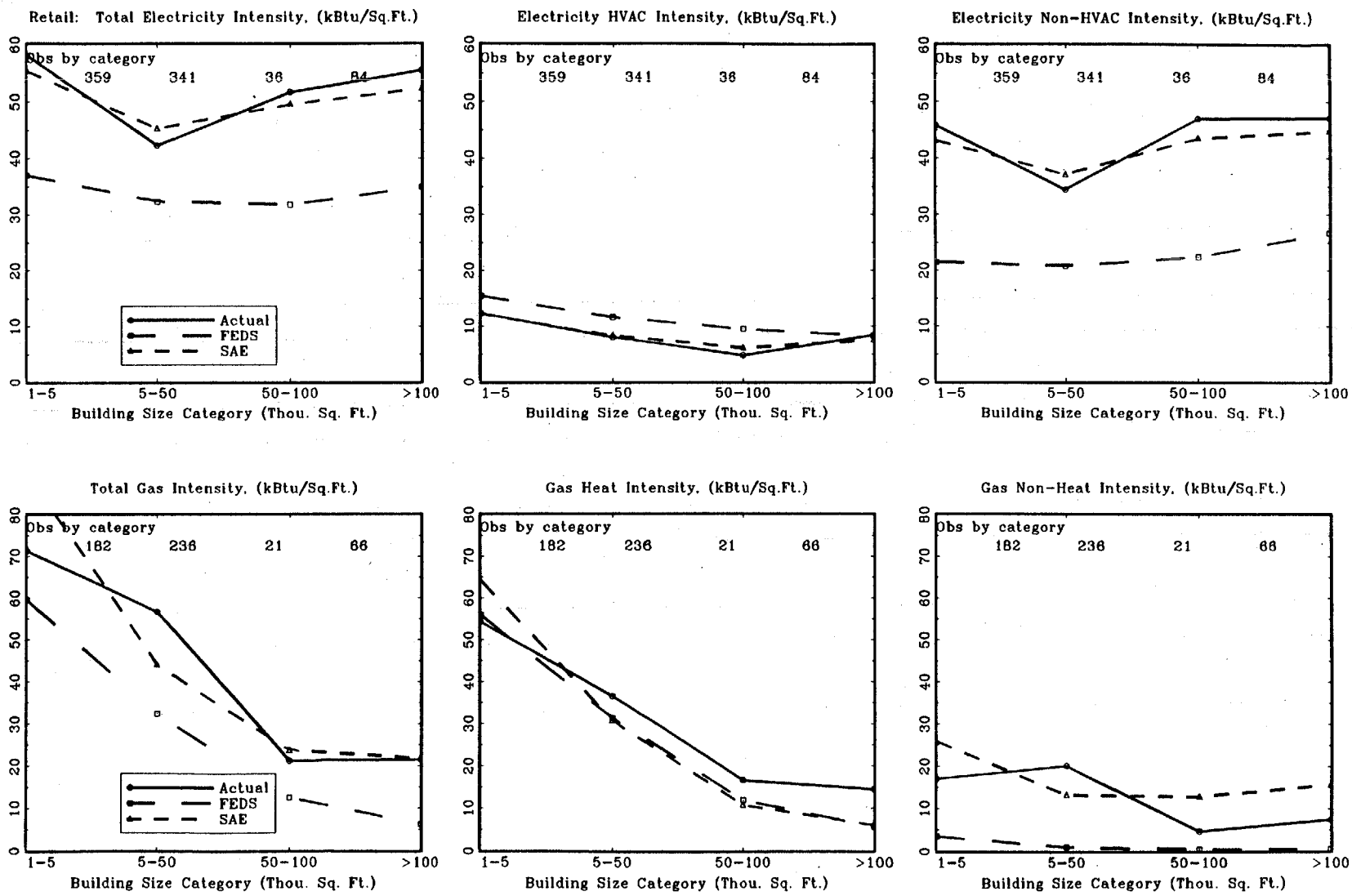

FIGURE D.69. Retail/Service: Actual, FEDS, and SAE Intensities By Building Size Category

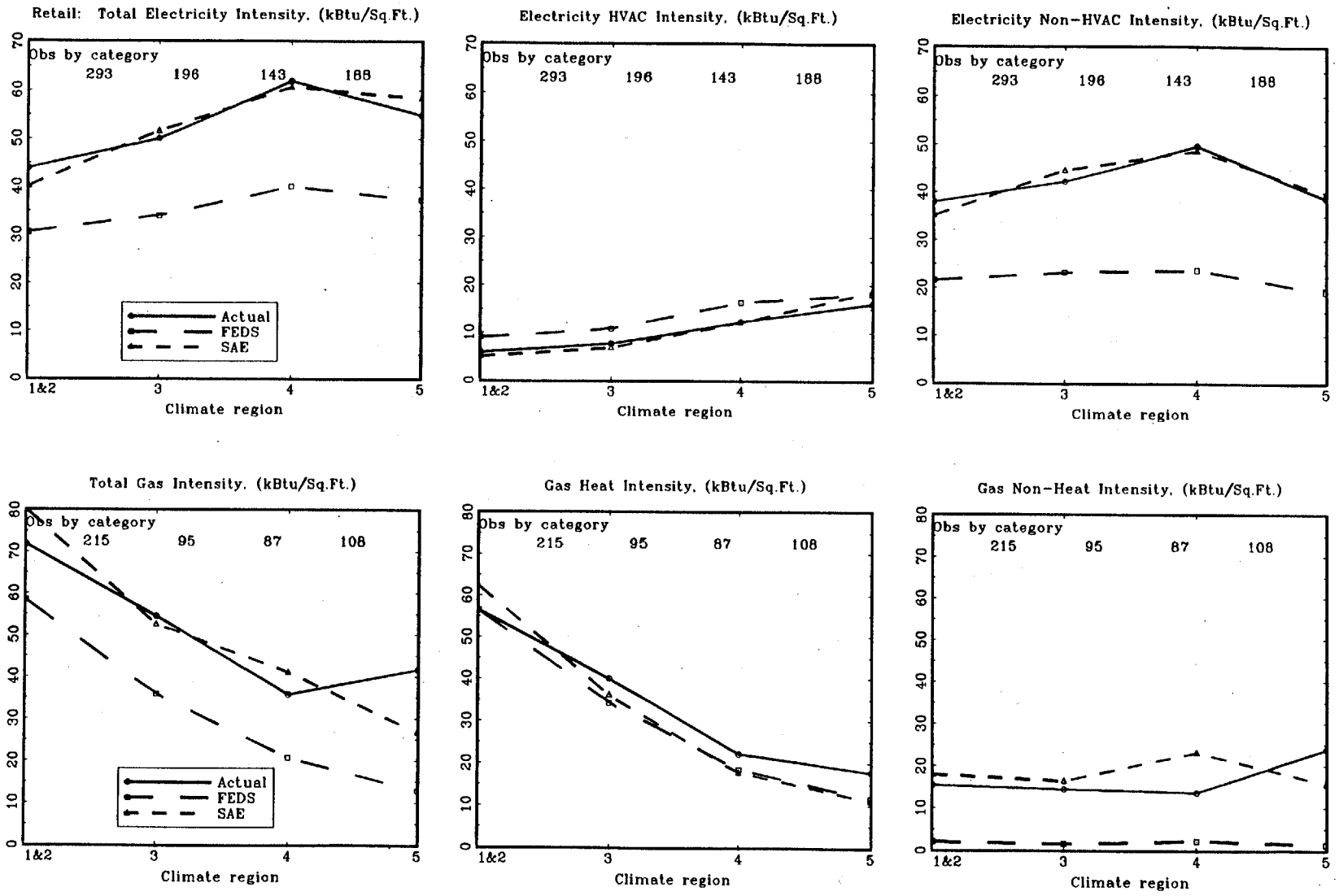

FIGURE D.70. Retail/Service: Actual, FEDS, and SAE Intensities By Climate Region

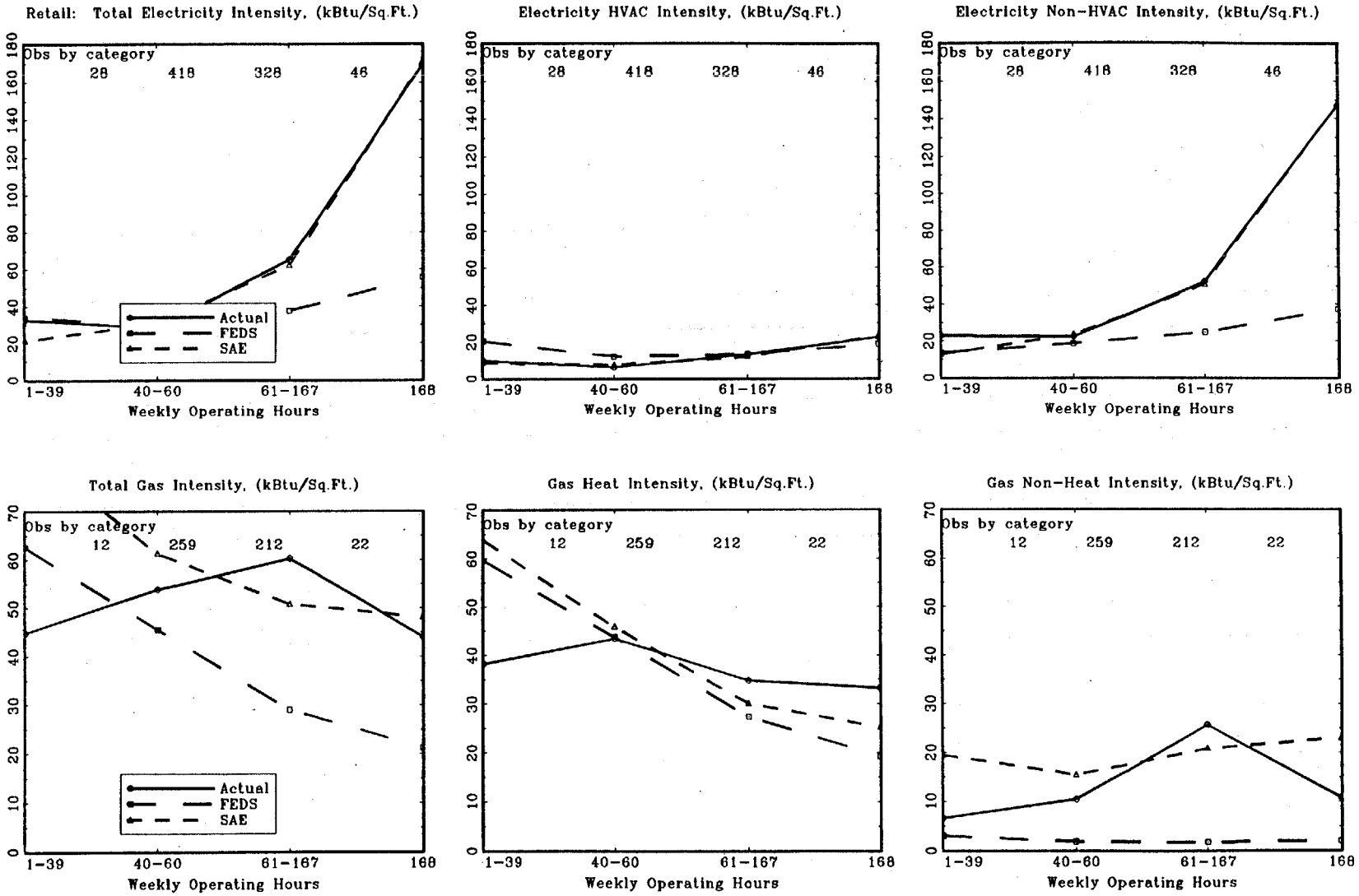

FIGURE D.71. Retail/Service: Actual, FEDS, and SAE Intensities By Weekly Hours Category

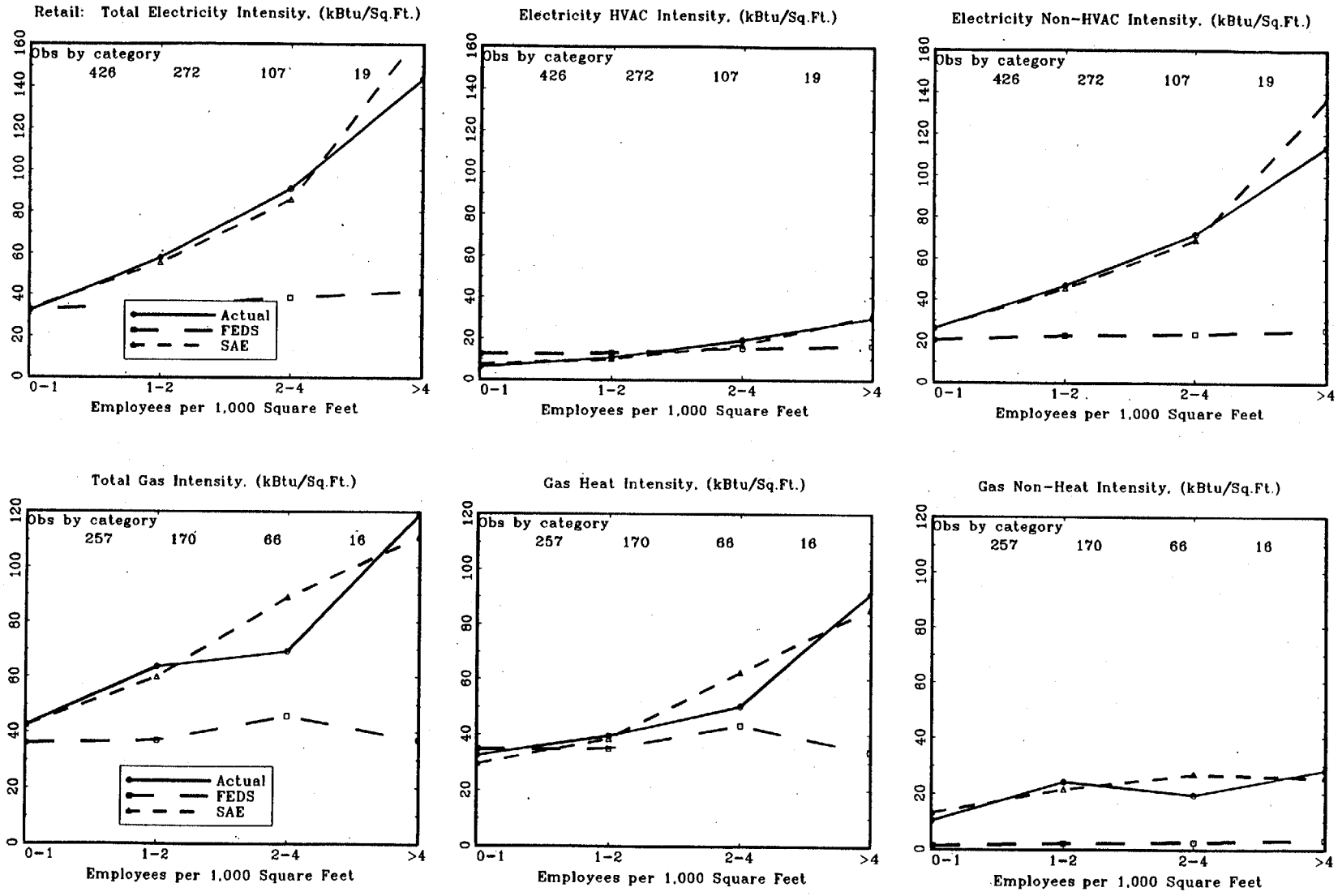

FIGURE D.72. Retail/Service: Actual, FEDS, and SAE Intensities By Employment Density Category

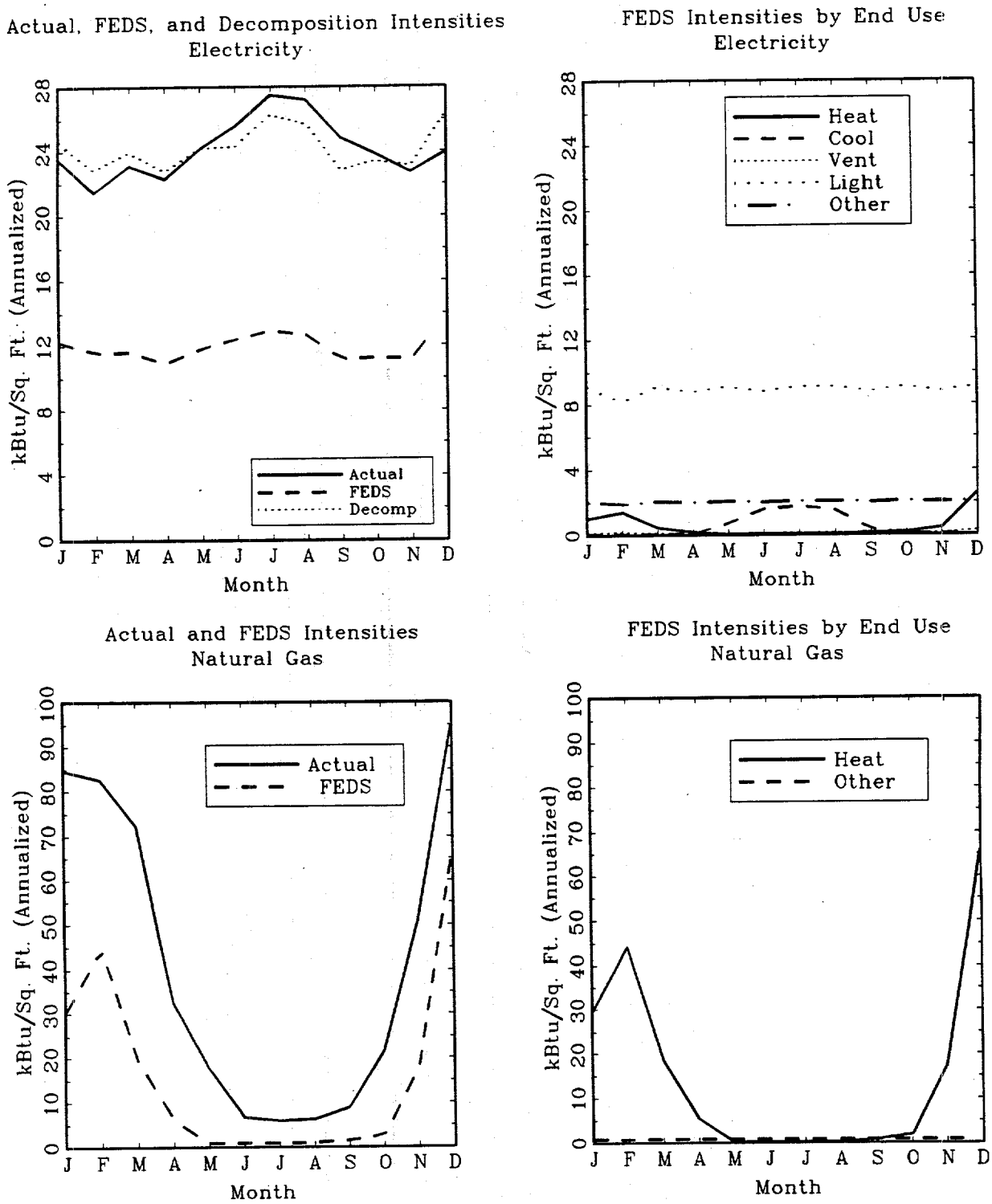

FIGURE D.73. Warehouse: Monthly Average EUIs

HVAC

Valid cases:	436	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	2958.039	Degrees of freedom:	429
R-squared:	-0.046	Rbar-squared:	-0.061
Residual SS:	3094.023	Std error of est:	2.686
F(7,429):	-2.694	Probability of F:	.

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.425108	0.058991	7.206366	0.000	0.578028	0.344375
V1*HVf	0.221679	0.168206	1.317901	0.188	0.140931	-0.026489
V2*HVf	0.477984	0.187069	2.555125	0.011	0.273851	0.138331
SQFT*HVf	0.000980	0.000459	2.137791	0.033	0.117390	-0.023932
CDD*HVf	-0.000066	0.000036	-1.817344	0.070	-0.140888	0.249022
HRS*HVf	0.005766	0.001818	3.171270	0.002	0.195985	-0.056565
EMP*HVf	0.000542	0.020928	0.025886	0.979	0.001647	0.105736

NHVAC

Valid cases:	436	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	711013.751	Degrees of freedom:	428
R-squared:	0.331	Rbar-squared:	0.320
Residual SS:	475861.117	Std error of est:	33.344
F(8,428):	26.438	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.071468	0.096904	11.056954	0.000	0.467074	0.432186
V1*NHVf	0.023998	0.251257	0.095512	0.924	0.004786	0.106260
V2*NHVf	0.337911	0.351005	0.962695	0.336	0.050044	-0.026126
SQFT*NHVf	0.000294	0.000625	0.469611	0.639	0.016709	0.055959
CDD*NHVf	0.000015	0.000095	0.154328	0.877	0.005766	-0.095214
HRS*NHVf	0.001127	0.001613	0.698571	0.485	0.026098	0.190330
EMP*NHVf	1.072178	0.125125	8.568851	0.000	0.317829	0.254751
Refrig	98.859782	9.028001	10.950351	0.000	0.395420	0.518637

FIGURE D.74. Warehouse: SAE Regression Results for Electricity

Warehouse	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	36.30	3.12	1.20	4.72	76.89	45.11	5.65

Warehouse	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	2.08	8.25	3.95	1.39
Non-Baseload	1.00	4.28	8.25	3.95	1.39

Valid cases:	249	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	405192.055	Degrees of freedom:	242
R-squared:	-0.001	Rbar-squared:	-0.026
Residual SS:	405626.523	Std error of est:	40.941
F(7,242):	-0.037	Probability of F:	.

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	0.806773	0.702785	1.147965	0.252	0.382808	0.530674
V1*SHf	0.438323	0.242349	1.808641	0.072	0.170210	0.464016
V2*SHf	1.315181	0.602860	2.181571	0.030	0.119509	0.234804
SQFT*SHf	0.000005	0.000002	2.602487	0.010	0.147505	0.326401
HDD*SHf	-0.000163	0.000091	-1.789428	0.075	-0.552262	0.505702
HRS*SHf	0.015507	0.004492	3.451853	0.000	0.418852	0.564223
EMP*SHf	0.260527	0.116014	2.245653	0.026	0.150584	0.424282

FIGURE D.75. Warehouse: SAE Regression Results for Natural Gas

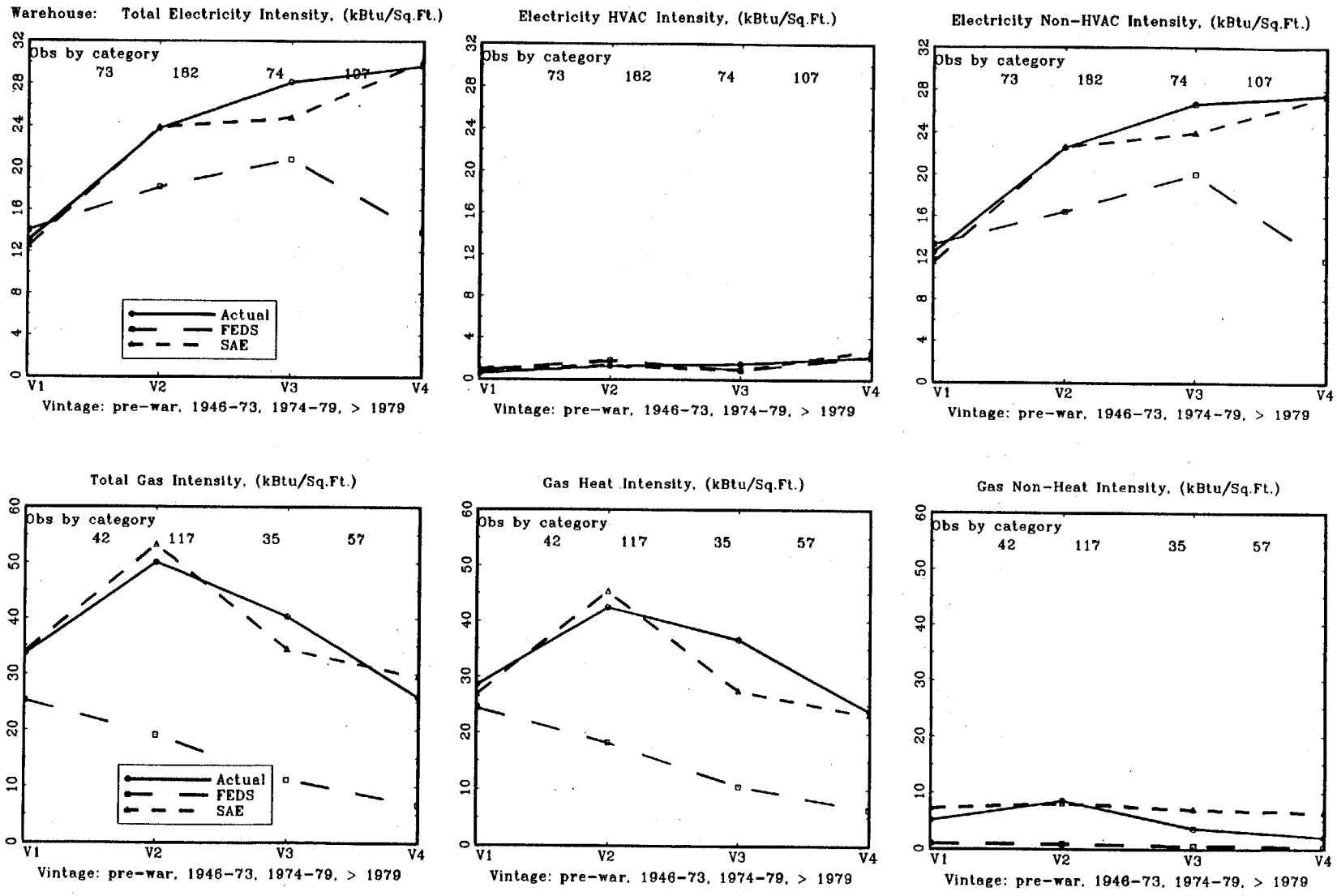

FIGURE D.76. Warehouse: Actual, FEDS, and SAE Intensities By Vintage

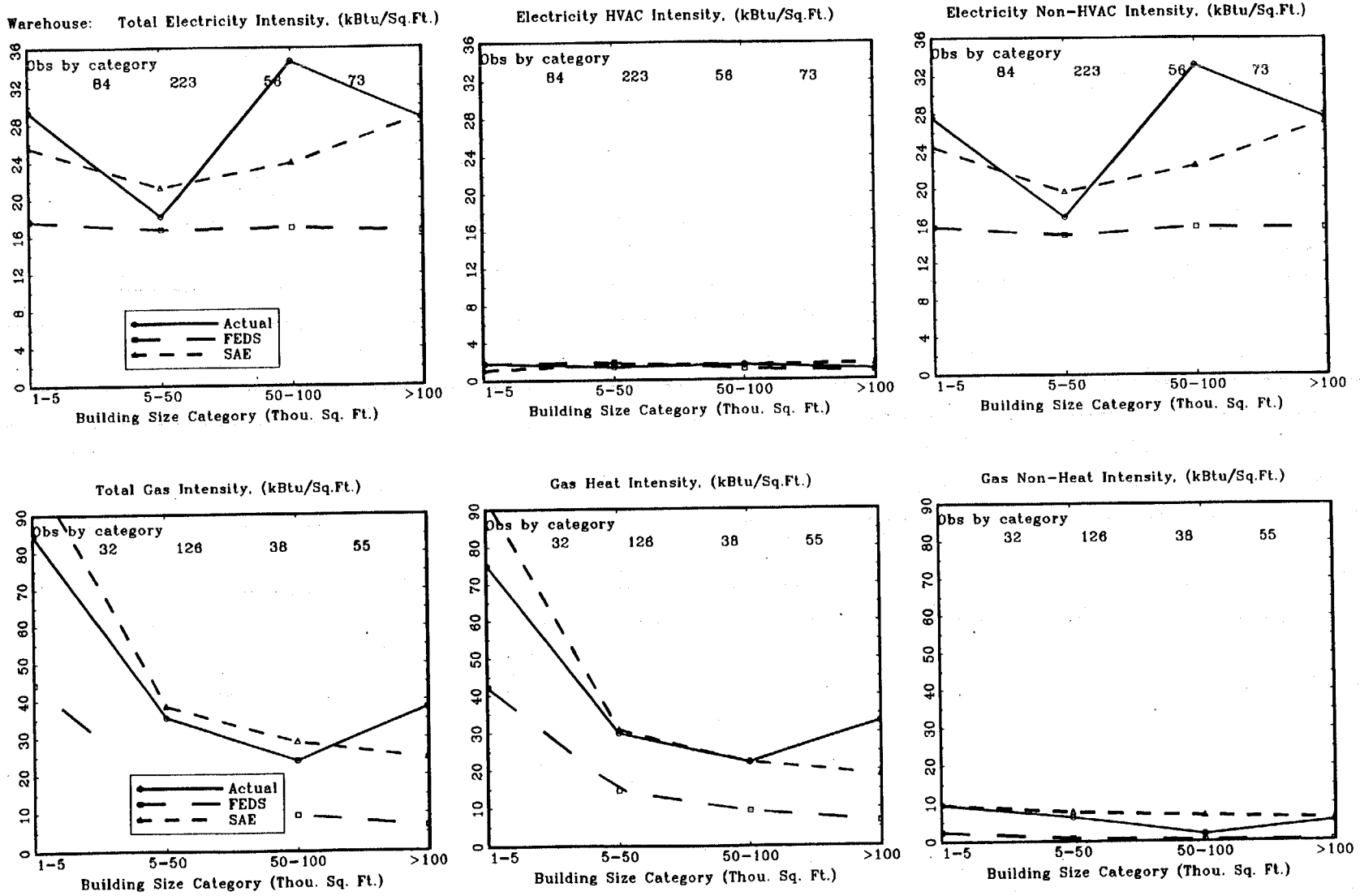

FIGURE D.77. Warehouse: Actual, FEDS, and SAE Intensities By Building Size Category

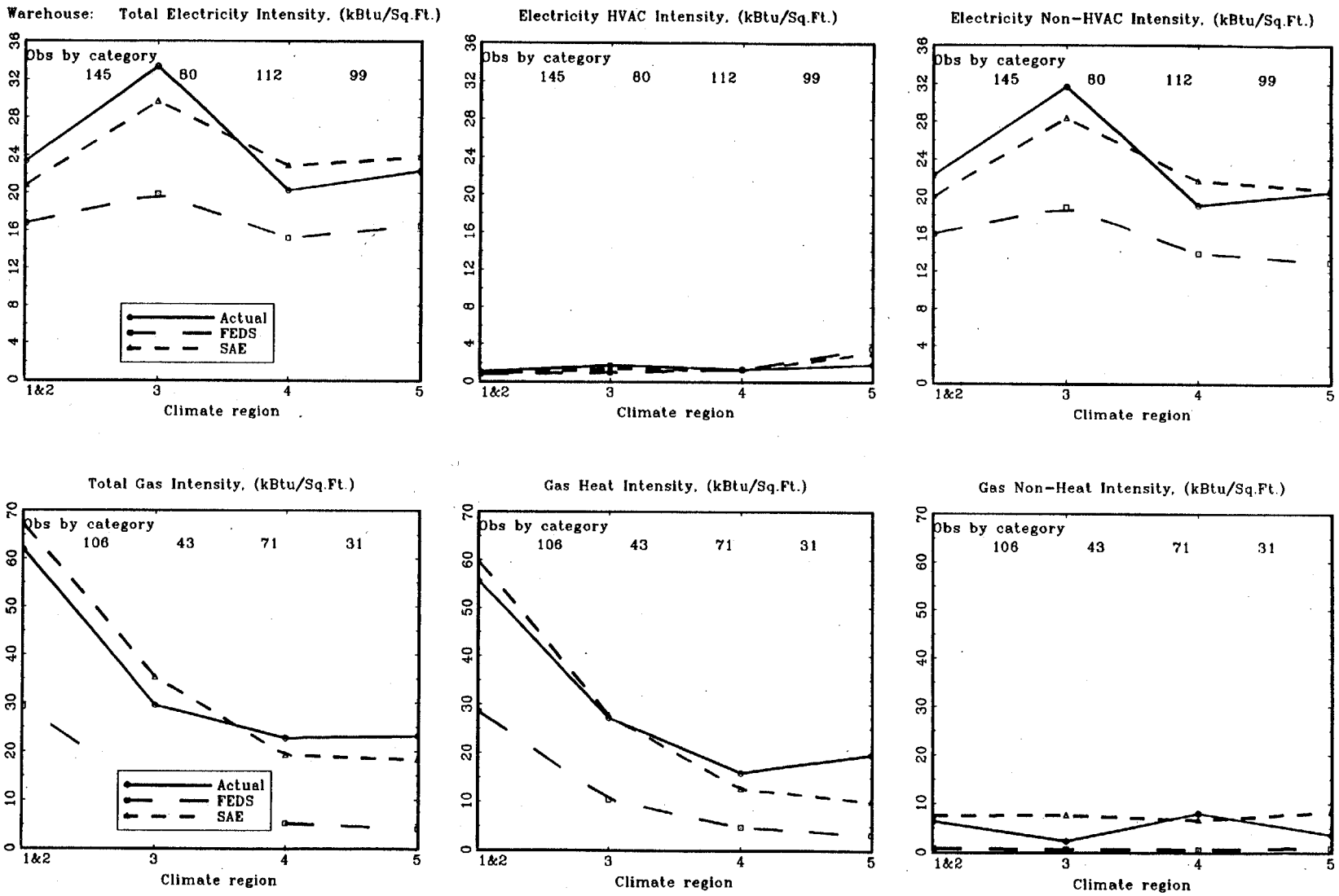

FIGURE D.78. Warehouse: Actual, FEDS, and SAE Intensities By Climate Region

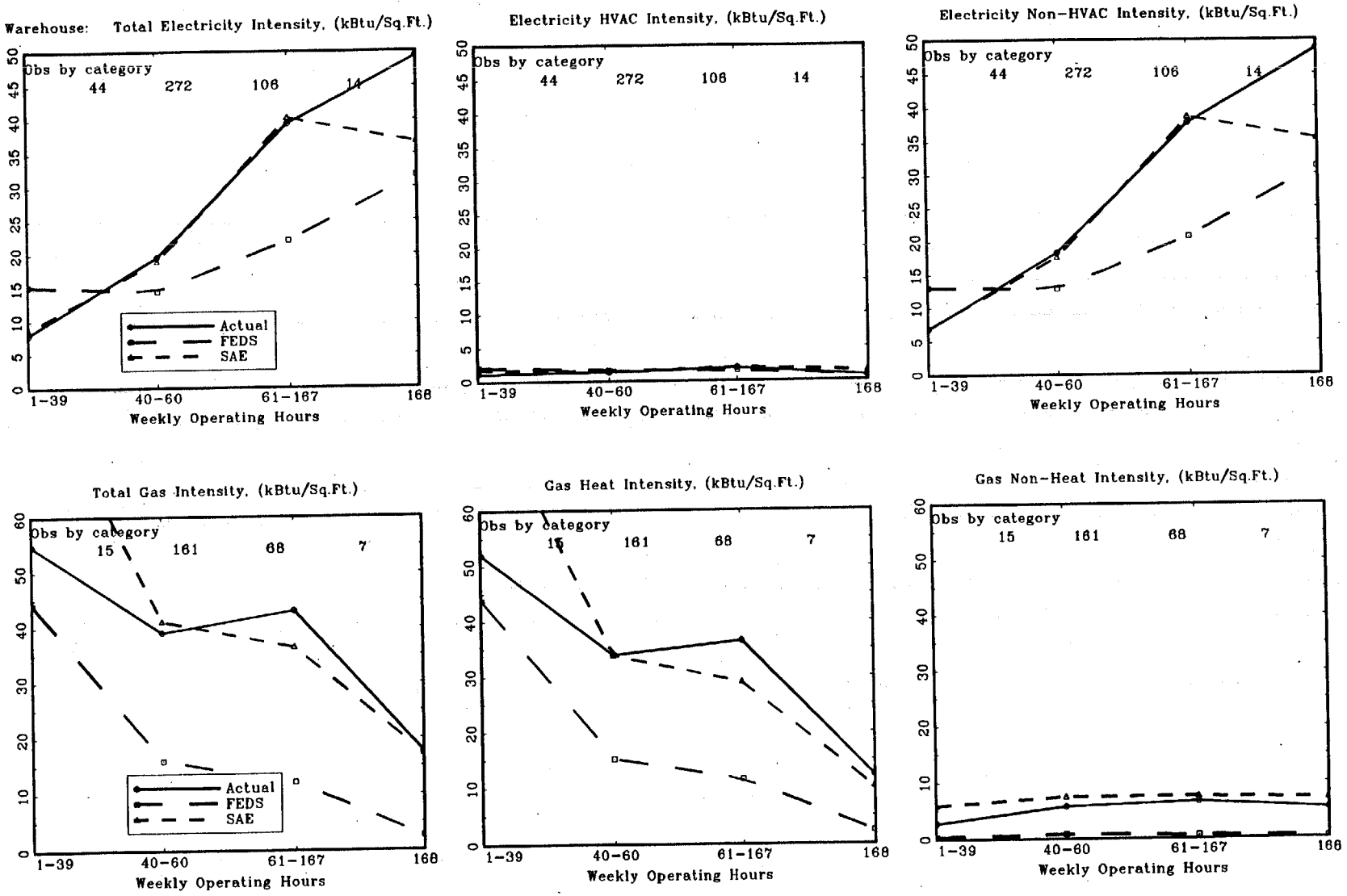

FIGURE D.79. Warehouse: Actual, FEDS, and SAE Intensities By Weekly Hours Category

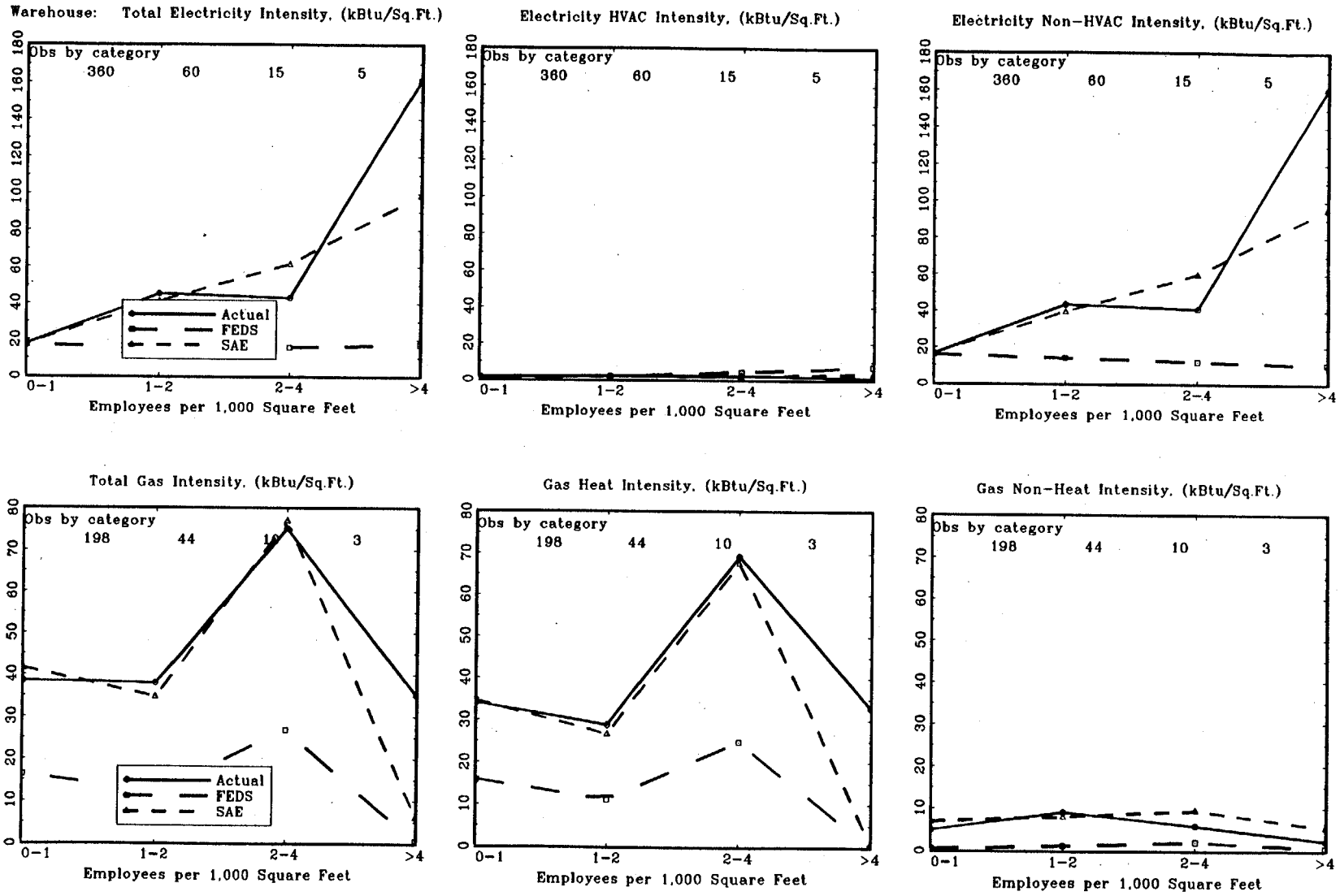

FIGURE D.80. Warehouse: Actual, FEDS, and SAE Intensities By Employment Density Category

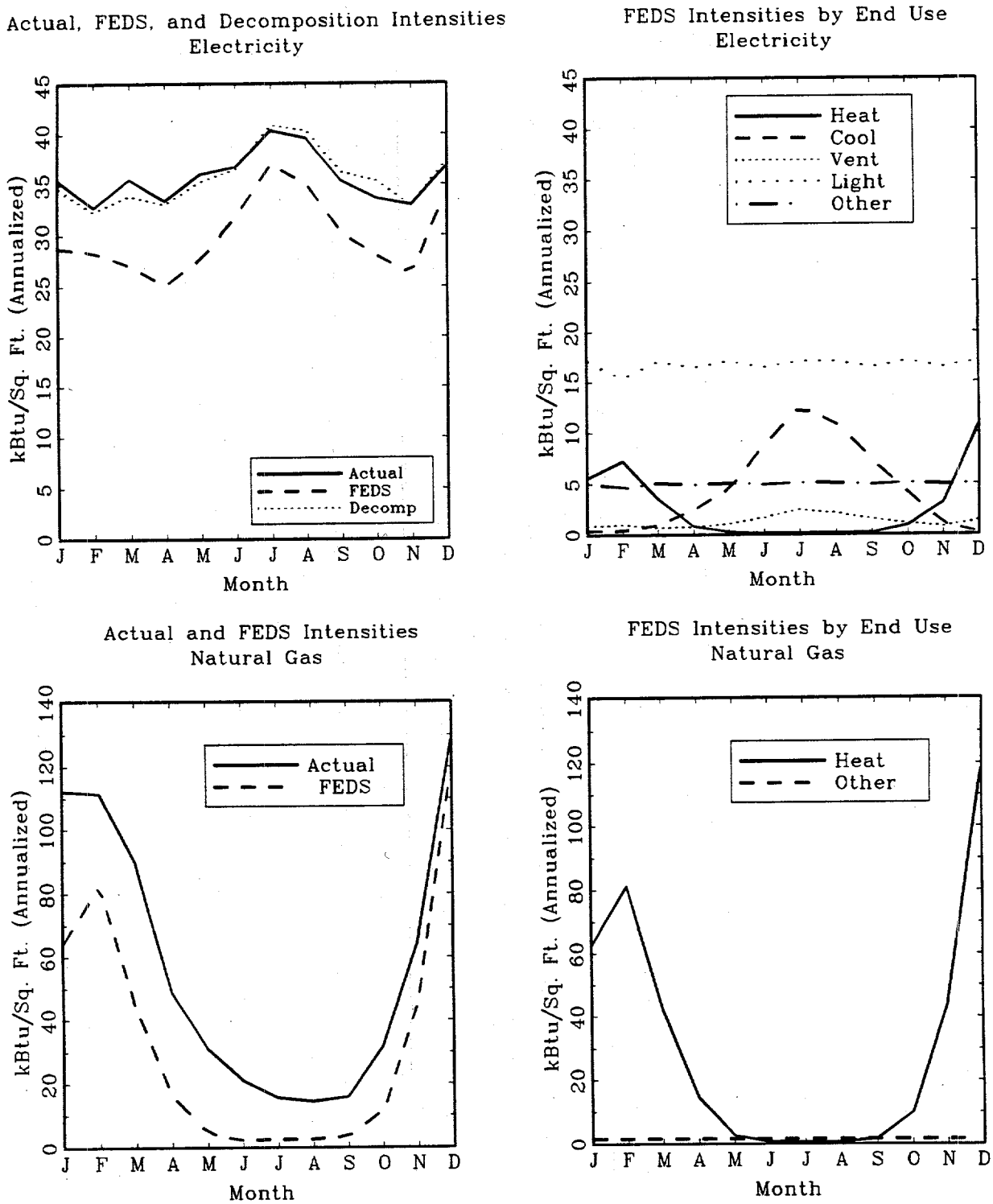

FIGURE D.81. Misc. Buildings: Monthly Average EUIs

HVAC

Valid cases:	245	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	25227.057	Degrees of freedom:	238
R-squared:	0.311	Rbar-squared:	0.293
Residual SS:	17385.150	Std error of est:	8.547
F(7,238):	15.336	Probability of F:	0.000

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
HVf	0.522970	0.052799	9.904960	0.000	0.761620	0.520902
V1*HVf	0.129505	0.084196	1.538135	0.125	0.094617	0.050831
V2*HVf	0.443749	0.124215	3.572437	0.000	0.217197	-0.001551
SQFT*HVf	0.002767	0.000525	5.274852	0.000	0.360306	-0.137294
CDD*HVf	-0.000017	0.000037	-0.449009	0.654	-0.025492	0.176237
HRS*HVf	0.002372	0.000628	3.777773	0.000	0.210022	0.044143
EMP*HVf	0.078422	0.021514	3.645218	0.000	0.224624	0.381843

NHVAC

Valid cases:	245	Dependent variable:	Y
Missing cases:	0	Deletion method:	None
Total SS:	683621.586	Degrees of freedom:	237
R-squared:	0.098	Rbar-squared:	0.071
Residual SS:	616669.959	Std error of est:	51.010
F(8,237):	3.216	Probability of F:	0.002

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
NHVf	1.146418	0.165376	6.932168	0.000	0.508824	0.480879
V1*NHVf	0.273672	0.272002	1.006140	0.315	0.060635	0.070835
V2*NHVf	0.702397	0.378687	1.854821	0.065	0.114963	-0.014739
SQFT*NHVf	0.001214	0.000792	1.533124	0.127	0.089551	0.177056
CDD*NHVf	-0.000182	0.000156	-1.168927	0.244	-0.068017	-0.031360
HRS*NHVf	-0.004853	0.002239	-2.167395	0.031	-0.153372	0.171691
EMP*NHVf	0.211131	0.071219	2.964527	0.003	0.171851	0.279916
ElcMan	34.011698	12.595071	2.700397	0.007	0.150786	0.262616

FIGURE D.82. Misc. Buildings: SAE Regression Results for Electricity

Other	SH	WH	CK	WHCK	MF	CG	MS
Conditional Demand Coefficients	54.82	18.53	13.22	16.41	106.87	1.00	7.78

Other	SC	WH	CK	WHCK	
Adjustment Coefficients				WH	CK
Baseload	1.00	2.62	51.35	1.83	.19
Non-Baseload	1.00	4.28	51.35	.41	.04

Valid cases:	131	Dependent variable:	EUI
Missing cases:	0	Deletion method:	None
Total SS:	828422.708	Degrees of freedom:	124
R-squared:	0.098	Rbar-squared:	0.055
Residual SS:	747074.659	Std error of est:	77.620
F(7,124):	1.929	Probability of F:	0.070

Variable	Estimate	Standard Error	t-value	Prob >|t|	Standardized Estimate	Cor with Dep Var
SHf	1.194043	0.703903	1.696317	0.092	0.671995	0.565192
V1*SHf	0.106792	0.332262	0.321409	0.748	0.052032	0.486658
V2*SHf	0.490450	0.654925	0.748864	0.455	0.064054	0.140027
SQFT*SHf	-0.000000	0.000005	-0.090283	0.928	-0.007043	0.190860
HDD*SHf	-0.000097	0.000095	-1.020155	0.310	-0.389182	0.540128
HRS*SHf	0.004465	0.002672	1.671051	0.097	0.179821	0.498319
EMP*SHf	0.092034	0.068160	1.350273	0.179		

FIGURE D.83. Misc. Buildings: SAE Regression Results for Natural Gas

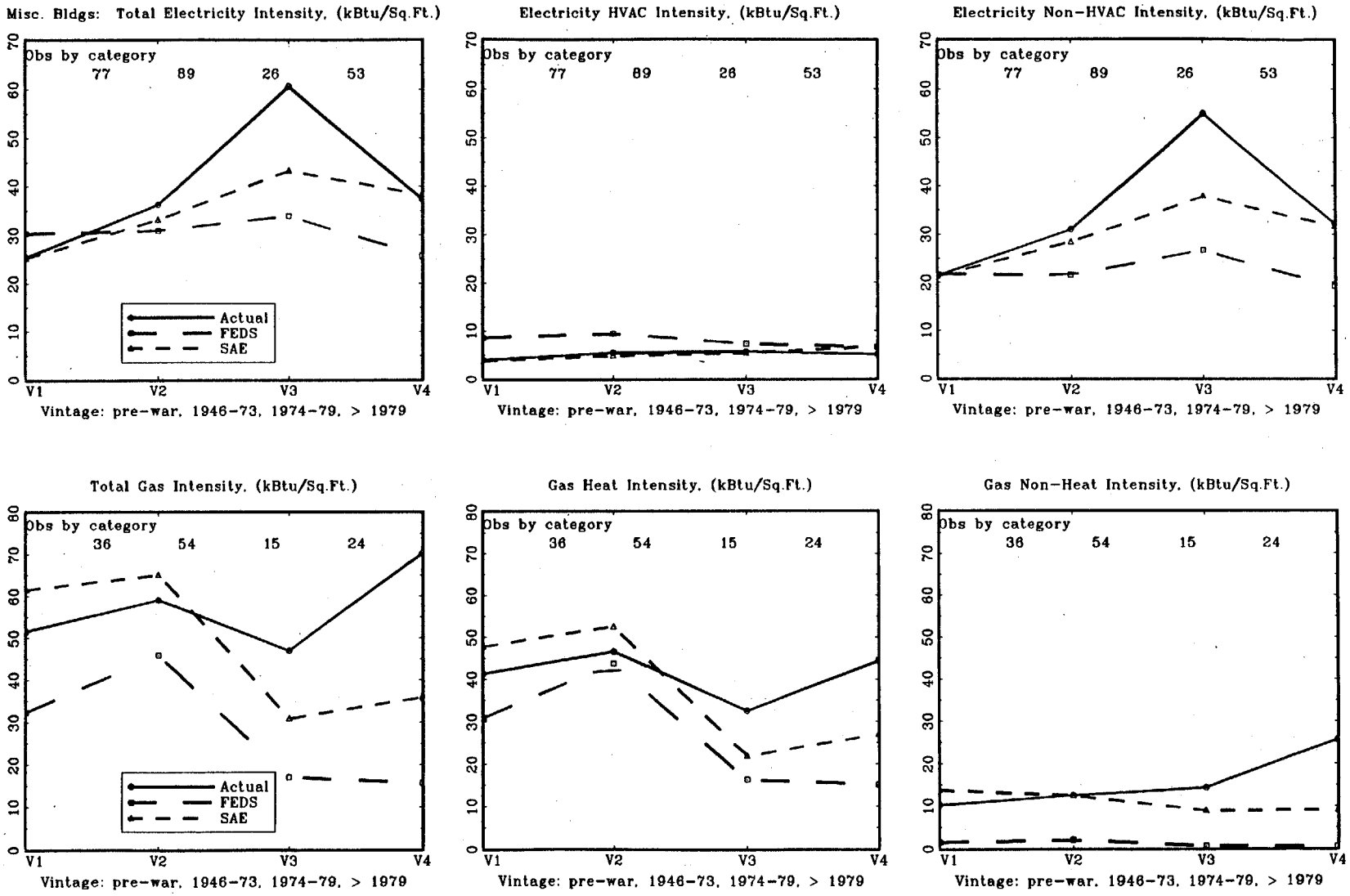

FIGURE D.84. Misc. Buildings: Actual, FEDS, and SAE Intensities By Vintage

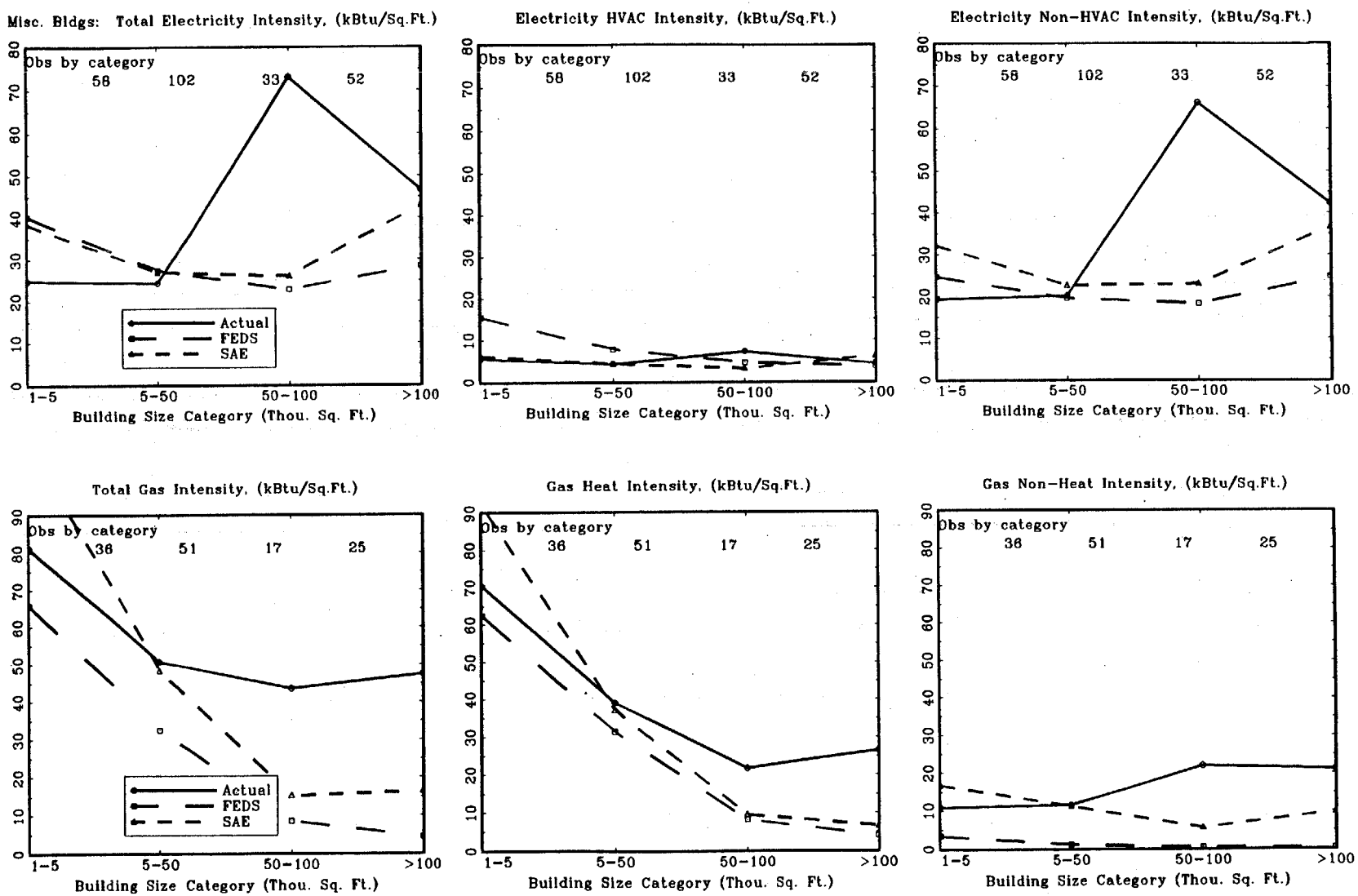

FIGURE D.85. Misc. Buildings: Actual, FEDS, and SAE Intensities By Building Size Category

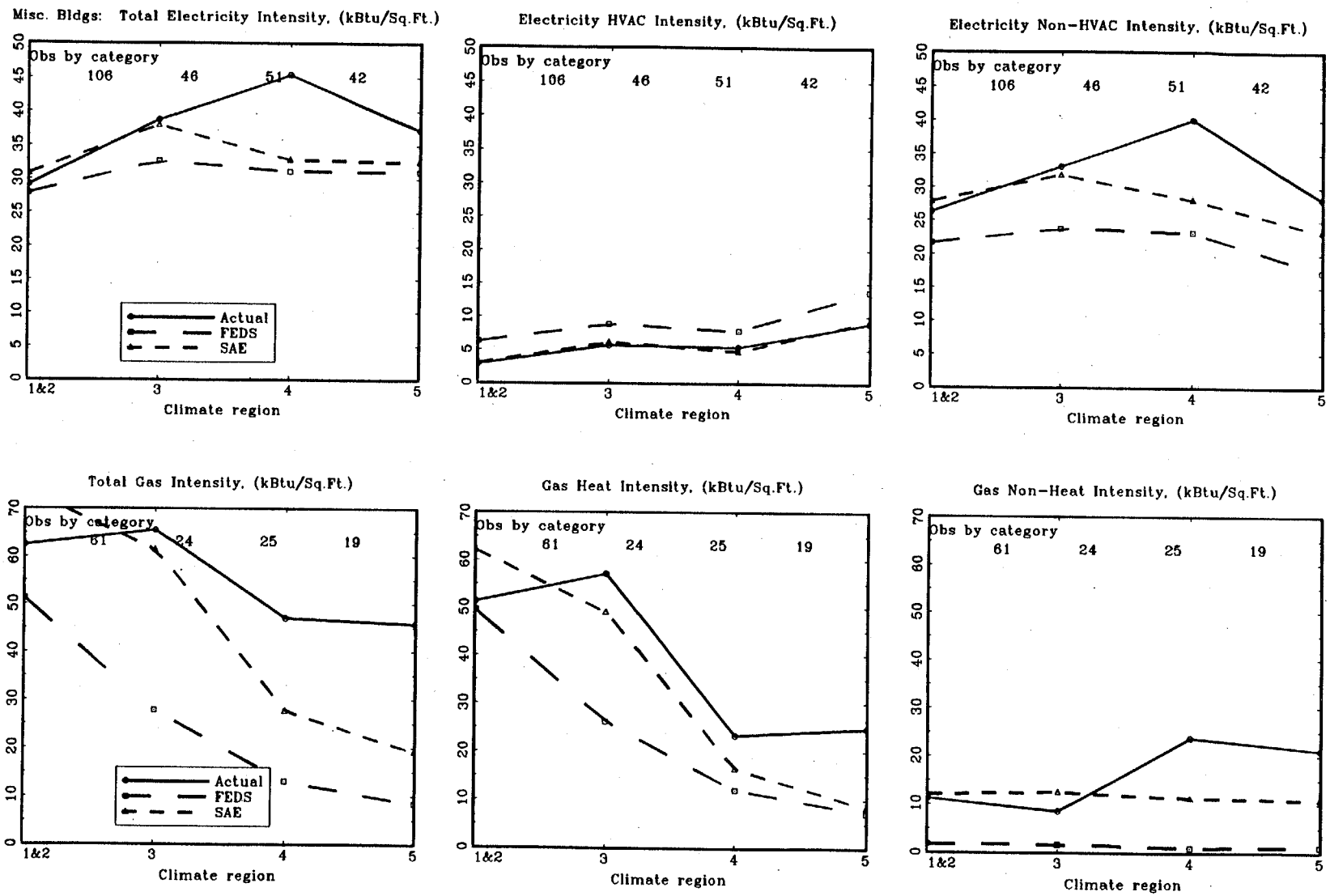

FIGURE D.86. Misc. Buildings: Actual, FEDS, and SAE Intensities By Climate Region

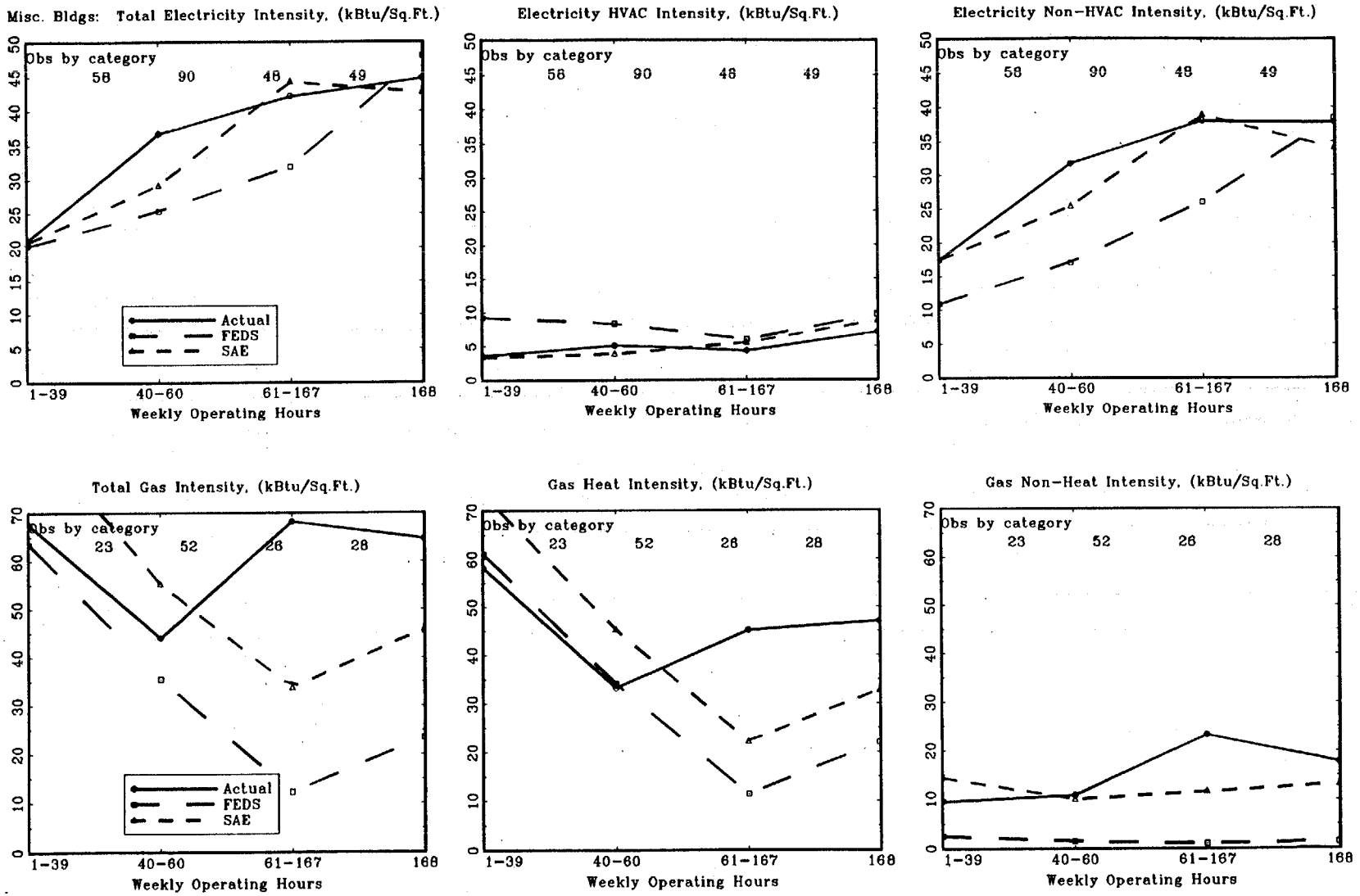

FIGURE D.87. Misc. Buildings: Actual, FEDS, and SAE Intensities By Weekly Hours Category

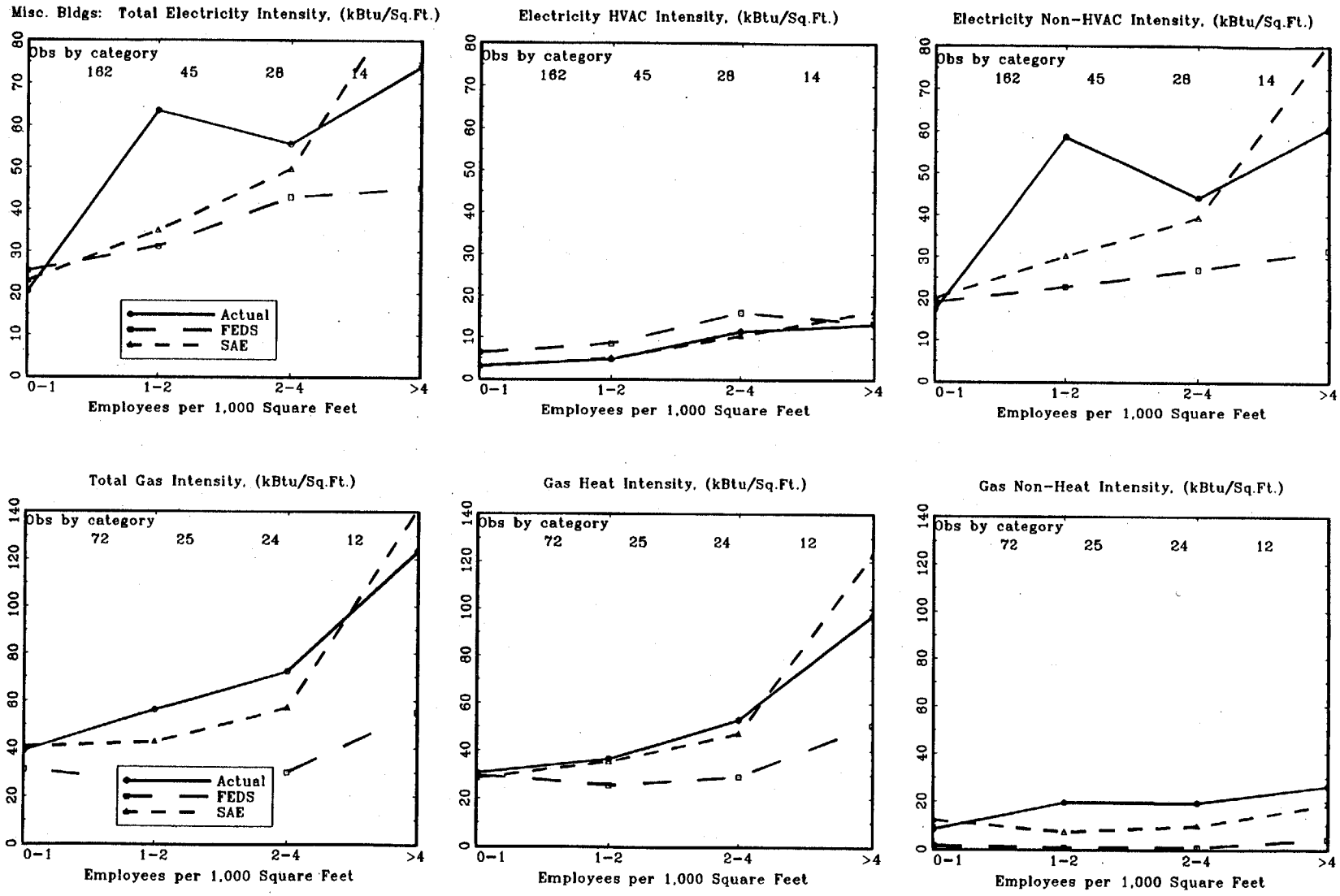

FIGURE D.88. Misc. Buildings: Actual, FEDS, and SAE Intensities By Employment Density Category

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