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D. B. Belzer
L. E. Wrench

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Prepared for the U.S. Department of Energy
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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 of the U.S. Department of Energy, 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 1992 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. Statistical Adjusted Engineering (SAE) models were estimated by building type. The nonlinear 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 (based upon utility billing information). End-use consumption by fuel was estimated for each of the 6751 buildings in the 1992 CBECS. The report displays the summary results for 11 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 of the U.S. Department of Energy, 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 1992 Commercial Building Energy Consumption Survey (CBECS). This work was conducted by Pacific Northwest National Laboratory (PNNL) for the Energy End Use and Integrated Statistics Division (EEUISD) within the Energy Information Administration (EIA). PNNL previously generated estimates of end-use consumption for the 1989 CBECS and published these estimates in 1993.

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 the elements of the 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.

ENGINEERING FRAMEWORK FOR END-USE INTENSITY ESTIMATES

Over the past several years, PNNL has been developing an entirely new building energy consumption estimation tool for the Federal Energy Management Program (FEMP). This tool, the Facility Energy Decision Screening (FEDS) model, estimates building energy consumption for six end uses: heating, cooling, ventilation, interior lighting, service hot water, 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 1992 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 (e.g., information from American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) and IES handbooks was used to develop many heating, ventilation, and air conditioning (HVAC), and lighting assumptions).

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

The characteristics data are used to inform the FEDS model of variables needed for its building-by-building energy simulations. The characteristics data are 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. Out of a total of 6751 buildings in the 1992 CBECS, 3227 buildings had suitable billing data for electricity and 2161 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. The National Oceanic and Atmospheric Administration's TD 3280 weather tapes provided hourly data for 103 weather stations across the U.S. Files with hourly weather profiles were assigned to each of the buildings in the CBECS.

Eleven building types were defined for the engineering and 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

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. 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 provide 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 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.

Revised Approach

Based upon the results of an outside technical review EIA conducted in early 1995, we altered the fundamental SAE approach for the analysis of the 1992 CBECS from the approach used for the 1989 CBECS. The biggest change involves the end-use estimation for electricity, in which the monthly decomposition analysis was replaced by a nonlinear SAE model involving only annual data. The treatment of the natural gas consumption is similar to the 1989 study, although the specification is expanded to consider occupant density and other information which is new to the 1992 CBECS.

The annual specification in this study, however, goes well beyond the simple linear specifications that were first used with the 1989 data. A nonlinear framework, embodying some of the characteristics of EIA's end-use analysis of the Residential Energy Consumption Survey, was implemented. This framework allows greater flexbility in the way that variables such as building size and employment density interact with the engineering estimates of end-use consumption.

Another feature of the SAE specification is that heating use for natural gas is estimated simultaneously with the electricity end uses. The approach was followed in order to provide a more credible picture of electric heating consumption.

END-USE INTENSITY ESTIMATION: ELECTRICITY

The specification used to estimate the electricity EUIs employed employee density and vintage (pre-war [<1946], post-war, and new (>1979) to adjust most of the non-HVAC EUIs. One of the most consistent results across all building types was the significance of the employee density variable. The elasticities with respect to employment density generally ranged between 0.3 and 0.9. As might be reasonable to expect, the elasticities were highest for restaurants and lodging. The restaurant building type covers establishments that range from full service restaurants serving only dinner to fast food establishments. Employment densities in lodging will vary greatly from budget motels to first-class hotels.

With the exception of lodging, warehouses, and miscellaneous buildings, the coefficients on the pre-war categorical variable were all negative and statistically significant. Educational buildings, hospitals, large offices, and retail buildings showed the greatest relative differences between the pre-war and post-war vintages.

The final SAE specification allowed the cross-sectional variation in the lighting intensities to be adjusted, but maintained the same overall mean. The estimation results from the SAE model suggested that a pure engineering approach to the estimation of lighting may overestimate the differences in lighting intensity among buildings within the same building type. A vintage adjustment indicated that in office and retail buildings, lighting intensities in buildings built during the 1980's were somewhat lower than average.

The performance of the adjustment for electric water heating was mixed across building types. In general, the data appear to indicate that the consumption stemming from the engineering model is too low. Small offices and retail showed the largest deviations, with coefficients suggesting an order of magnitude increase from the engineering assumptions. Both may indicate that significantly more hot water is used for clean-up rather than simply domestic use. (The retail building type includes laundromats; however, it is very likely that most of these establishments use gas for water heating).

For cooling, the adjustments varied by building type, with most building types making a downward adjustment from the FEDS value. The actual adjustment to the FEDS cooling values was a function of both a direct scaling coefficient and an effect that varied on the basis of the estimated internal heat load.

For heating, we included terms to adjust the heating consumption for building size and age. For most building types, the estimated size elasticity coefficient was positive. This result stemmed from a tendency in FEDS to reduce heating demands with respect to building size somewhat more than the consumption data indicated.

No clear pattern emerges from the vintage adjustment coefficients. In particular, we were looking to correct any biases within FEDS with regard to buildings built after 1979. Only in assembly buildings was there strong statistical evidence that the model was overpredicting the gas heating consumption for post-1979 buildings. For food sales and large offices, the estimated coefficients indicate that FEDS is underpredicting space heating in newer buildings.

The motivation for estimating gas heating consumption simultaneously with electricity was to better identify space heating loads served by electricity. The empirical results indicate that even after higher (site) energy efficiency is assumed by FEDS for electric space heating, further efficiencies may be widespread in electrically heated buildings. None of the estimated electric space heating adjustment coefficients exceeded 1, although the coefficients in assembly and large offices approached that value. With a large number of observations and a small interaction term, the coefficient for retail buildings was slightly less than 0.8.

EUI ESTIMATION: NATURAL GAS AND OTHER FUELS

For natural gas, the general approach used for the 1989 CBECS was retained for end uses other than heating. The first step in this approach was 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) 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.

The next step was to explain the cross sectional variation in the 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 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.

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 END-USE INTENSITY ESTIMATES

The study generated three full sets of EUIs by building type. The first set was produced from FEDS without adjustment. The second set was the SAE estimates. The third set was termed the calibrated EUIs (referred to as CALIB in the discussion and tables). The calibration was performed on a building-by-building basis in which all of the EUIs were proportionately scaled to match the total consumption as measured either from the billing data or imputed by EIA. Table S.1 shows these three sets of EUIs for all buildings by fuel type. The values in the table are average EUIs in that they include buildings that do not have the particular end use/fuel combination.

TABLE S.1. EUI Estimates for All Buildings

Fuel: Electric	Weighted (by Floorspace) EUIs (kBtu/sf)									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/Cgn	Total
FEDS	1.72	7.28	2.48	18.74	2.60	1.12	0.58	7.09	0.00	41.61
SAE	1.90	6.12	2.31	14.57	2.01	0.62	2.42	5.78	0.16	35.88
CALIB	1.64	6.34	2.42	16.29	2.01	0.54	2.49	6.58	0.11	38.43
Fuel: Gas	Weighted (by Floorspace) EUIs (kBtu/sf)									
FEDS	10.27	0.28	0.00	0.00	0.00	0.35	2.27	0.00	0.00	13.18
SAE	19.46	0.20	0.00	0.00	0.00	2.18	6.43	1.21	1.53	31.01
CALIB	19.65	0.34	0.00	0.00	0.00	2.50	7.14	0.77	1.62	32.02
Fuel: Oil	Weighted (by Floorspace) EUIs (kBtu/sf)									
FEDS	1.94	0.02	0.00	0.00	0.00	0.00	0.46	0.00	0.00	2.42
SAE	3.32	0.00	0.00	0.00	0.00	0.01	1.29	0.00	1.11	5.74
CALIB	2.89	0.00	0.00	0.00	0.00	0.02	0.90	0.01	0.18	4.01
Fuel: Stm	Weighted (by Floorspace) EUIs (kBtu/sf)									
FEDS	0.82	0.07	0.00	0.00	0.00	0.01	0.36	0.00	0.00	1.26
SAE	2.40	0.01	0.00	0.00	0.00	0.09	0.83	0.00	0.01	3.36
CALIB	4.33	0.03	0.00	0.00	0.00	0.13	1.87	0.01	0.04	6.40

Key:
- Heat: Heating
- Cool: Cooling
- Vent: Ventilation
- Light: Lighting
- Refrg: Refrigeration
- Cook: Cooking
- HotWt: Hot Water
- Misc: Miscellaneous
- M/Cgn: Manufacturing and cogeneration.

For electricity, the weighted average EUI values across all buildings are fairly comparable across all three EUI sources--FEDS, SAE, and CALIB. The largest difference from the FEDS values is for hot water. As discussed in the previous chapter, the estimation of a separate adjustment factor for electric water heating yields considerably higher consumption estimates for most building types. For heating and cooling, all three estimates are roughly comparable. The all-buildings average EUI for lighting is adjusted downward from the FEDS simulated values.

For natural gas, it is clear that FEDS is underpredicting total consumption by a considerable degree. As noted earlier, the underprediction for heating varies by building type. The EUIs for cooking and water heating are also increased substantially from the FEDS values.

When examining these intensities by fuel, one should keep in mind that the EUIs cannot be expected to represent the amount of fuel needed 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 than for electricity. For buildings with high demands for these end uses (e.g., restaurants, laundromats, hospitals), gas is the less expensive fuel. Nevertheless, additional work may be required to better rationalize the differences in EUIs found in this study.

The values of the average intensities can be used to determine the fractions of end use consumption by fuel. Consistent with EIA's use of these estimates for the NEMS, we use the weighted average CALIB figures. For electricity, lighting is the largest end use, composing about 43% (16.29/38.43) of total consumption. At 16%, the next single largest use is cooling, followed closely by miscellaneous uses (office equipment, task lighting, task lighting, etc.) which make up about 17% of total consumption.

As would be expected, heating is the 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.1 and S.2 display the end-use shares of commercial consumption after aggregation across fuels. Figure S.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 less than that for heating.

Figure S.2 shows the composition of energy as expressed in primary energy. On this basis, electricity is converted to Btu by a factor of

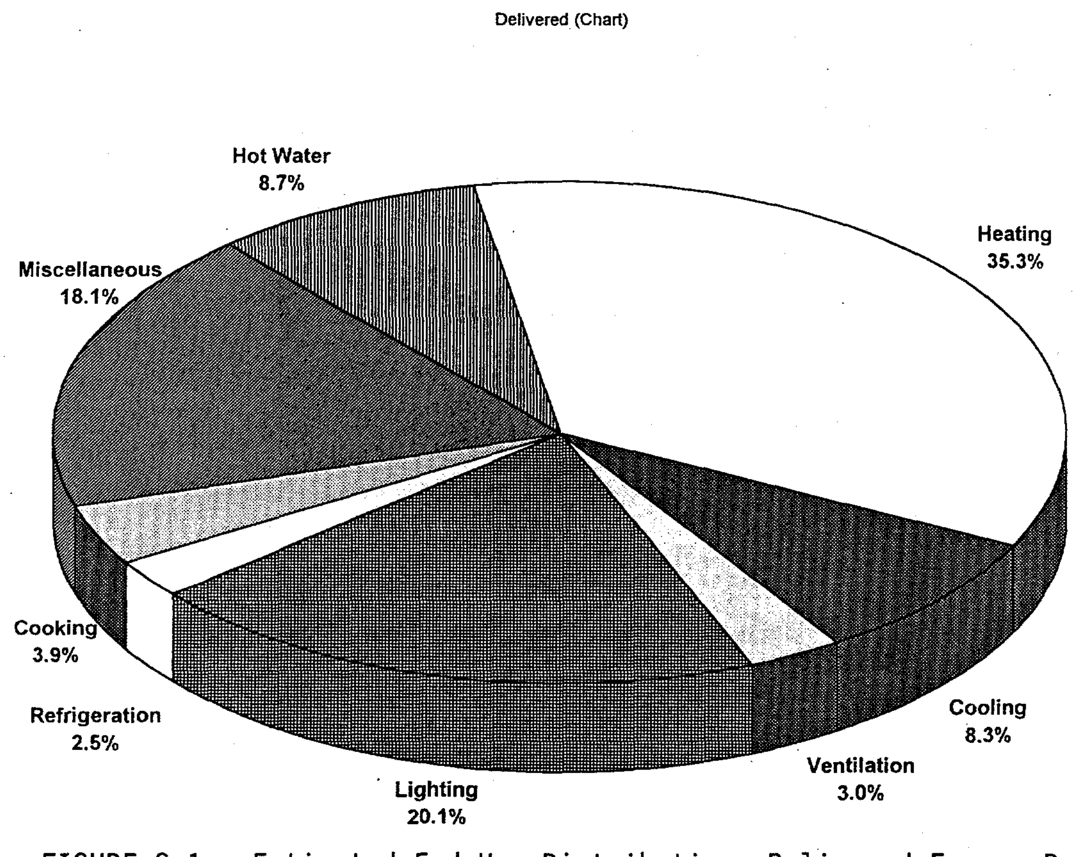

FIGURE S.1. Estimated End-Use Distribution, Delivered Energy Basis

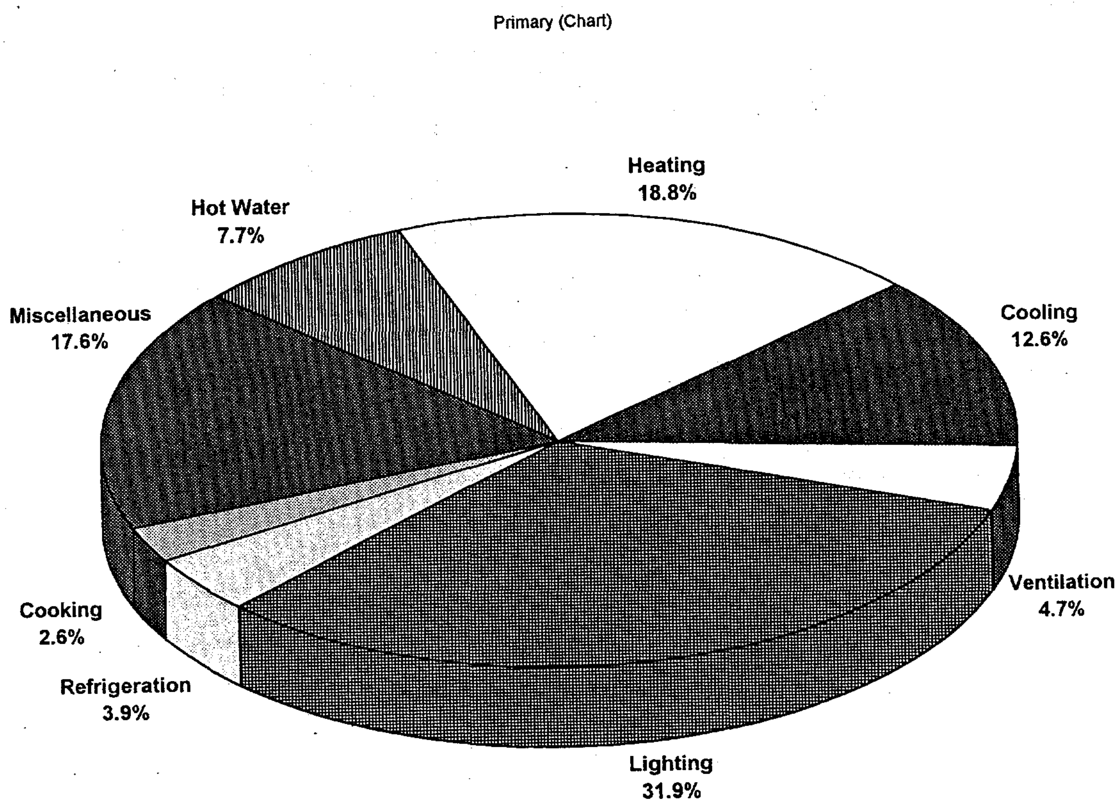

FIGURE S.2. Estimated End-Use Distribution, Primary Energy Basis

11,500 Btu/kWh to account for the generation and transmission losses associated with electricity.[a] On a primary energy basis, lighting becomes the largest single end use with 32% of total energy consumption. Heating and miscellaneous use follow, both with about an 18% share. Cooling is the fourth largest end use, consuming nearly 13% of primary energy.

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 non-HVAC end uses. The second area involves additional modifications of the input

(a) This factor is derived from the ratio of electrical system energy losses to electricity sales for the commercial sector for 1992 as published in the State Energy Data Report 1993, DOE/EIA-0214(93), July 1995.

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 use a building engineering model, along with monthly billing data, as a means of estimating end-use consumption for a national sample of commercial buildings. Nevertheless, this study still leaves a number of unresolved issues. Some of the key issues are briefly discussed below.

More Detailed SAE Models for Electricity

On the HVAC side, additional work is still required to validate and refine the estimates of electric space heating. While the nonlinear annual cross-section approach increases the estimates of electric space heating over the 1993 study using the 1989 CBECS, the intensity estimates are still substantially lower than those for natural gas. Not all of this difference can be attributed simply to differences in weather and vintages of the buildings. A resolution may involve obtaining more detailed knowledge of the type of HVAC systems installed and whether these system effects are biased in favor of higher efficiencies with electric space heating.

Further analysis is also needed to examine the estimates of electric water heating. The estimates still 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.

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 method for splitting the non-heating uses can be further improved.

Improved Treatment of High-Intensity Cases

An unresolved problem in analyzing the CBECS--in both the current study and well as the 1993 effort--is how to treat high-intensity cases. As in previous surveys, both the 1989 and 1992 CBECS contain a number of buildings that display 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. 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 both the current and the previous study, we assumed that any consumption over the FEDS-defined limit fell into the miscellaneous equipment category. Future work should be devoted to exploring available audit data sets and perhaps to reinterviewing CBECS sample buildings to attempt to generalize some basic reasons for this phenomenon.

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.

In spite of the improvements that were introduced in FEDS between the 1993 and 1995 studies, the current approach still relies heavily upon an SAE methodology. 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 building-specific engineering calibration and requires embedding the building simulation code 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. 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.

ACRONYMS

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
CBECS	1989 Commercial Building Energy Consumption Survey
CD	Conditional Demand
EEUISD	Energy End Use and Integrated Statistics Division
EIA	Energy Information Administration
ELCAP	End-Use Load and Consumption Assessment Program
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, ventilation, and air conditioning
IES	Illuminating Engineering Society
NEMS	National Energy Modeling System
NHVAC	non-HVAC
NOAA	National Oceanic and Atmospheric Administration
PNNL	Pacific Northwest National Laboratory
PRISM	Princeton Scorekeeping Method
REMP	Regional End Use Monitoring Program
RMSE	Root Mean Squared Error
SAE	Statistically Adjusted Engineering
SHW	Service Hot Water
UA	thermal conductivity of the building shell

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The authors gratefully acknowledge the guidance, counsel, and patience of Eugene Burns, technical program monitor for this study at the Energy Information Administration. In the course of translating our statistical adjustment procedures into an alternative software framework, Dr. Burns pointed out various omissions and discrepancies between our initial documentation and the numerical estimates of end-use energy intensities. This report and the final set of end-use estimates have benefitted from his careful review and effort to replicate the statistical results.

CONTENTS

FIGURES

TABLES

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 1992 Commercial Building Energy Consumption Survey (CBECS) (Energy Information Administration [EIA] 1994a, 1995). Pacific Northwest National Laboratory (PNNL)[a] conducted this study for the Energy End Use and Integrated Statistics Division (EEUISD) within the Energy Information Administration (EIA). This study builds upon prior PNNL work in developing end-use consumption estimates for the preceding (1989) CBECS (Belzer et al. 1993).

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 as part of the National Energy Modeling System (NEMS) (EIA 1994b). The second role is to augment the statistical summary information published by EEUISD. Although EIA published the estimates as a companion report to the 1989 Commercial Buildings Energy Consumption and Expenditures Report, no separate end-use report is planned for the 1992 survey. However, tables and public use data will be made available through the Internet.

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

1.1 GENERAL APPROACHES

As discussed in Belzer et al. (1993), development of end-use intensities for buildings can follow three general approaches: direct metering, conditional demand analysis, and engineering simulations. Direct metering provides the most accurate approach, but is expensive to implement. The metering studies 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

$$E(i) = a1 * EUP(1, i) + a2 * EUP(2, i) + \ldots + aM * EUP(M, i) + e \quad (1.2)$$

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 *ai* 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 as in the 1993 effort. In undertaking the SAE approach, however, we remained cognizant of these interaction effects mentioned above. To the extent feasible, we pursued a limited engineering calibration as we used the regression-based adjustment factors to influence our engineering assumptions in an iterative process. As compared to the 1993 study, much more attention was given to selecting engineering assumptions that yielded engineering results more consistent with the available electricity and gas billing data.

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

1. Map 1992 CBECS data (and weather) into engineering model.

2. Run initial engineering model.

3. Estimate SAE models for electricity and natural gas for buildings with complete annual billing data, by building type

4. Compare predicted and actual consumption patterns; revise engineering model accordingly. Repeat steps 3 and 4 as allowed by time and budget constraints.

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.

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 with respect to the 1992 CBECS. A considerable effort was made to extract as much information as possible from the special monthly utility billing files that were made available for this study.

Chapter 4 lays out the SAE framework used to generate EUIs by building type. The SAE framework has been substantially revised from the 1993 study, and we discuss the most important differences between the two studies.

Chapters 5 and 6 discuss the detailed estimation methodologies and empirical results. Chapter 5 is concerned with electricity end uses as well as natural gas used for heating. Chapter 6 details the SAE models used to estimate the non-heating end uses for natural gas.

End-use estimates on an aggregate basis are summarized in Chapter 7. A set of tables is shown that compares the raw engineering results with the final SAE end-use results.

Chapter 8, the final chapter of the report, discusses extensions of the analysis undertaken for this report. Several improvements in the SAE models that would refine the estimates made in this study are indicated. Further modifications in the engineering model are also suggested.

2.0 ENGINEERING FRAMEWORK FOR END-USE INTENSITY ESTIMATES

As in the prior PNNL study, the approach used to estimate the 1992 end-use intensities is based on a deterministic model developed using accepted engineering algorithms for calculating building energy use. During the past several years, PNNL has been developing a new building energy consumption estimation tool as part of the Facility Energy Decision Screening System (FEDS) for the Federal Energy Management Program (FEMP). This tool is known as the FEDS 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

As in the previous PNNL study that developed end-use estimates for the 1989 CBECS, the engineering model used here is the loads calculation portion of the FEDS building model.[a] The specific version of the model used in this study is Release 3, which was formally distributed in May 1995.[b] 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.

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

(b) Appendix A describes some of the key differences in the version of the FEDS model used in the prior study and the most recent version of the model used in this study. A detailed technical description of the most recent version of the model is provided in Dirks and Dahowski (1996).

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 type of days (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. 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 Section 2.2.

2.2 DEVELOPMENT OF BUILDING PARAMETERS

The development of input parameters for FEDS in this study is based on several data sources. The primary sources include the 1986 CBECS survey, commercial and residential studies as part of the Regional End Use Monitoring Program (REMP),[a] 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).

(a) Previously known as the End Use Load and Consumer Assessment Program (ELCAP), a large, ongoing monitoring project funded by the Bonneville Power Administration. REMP data include 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).

Information contained in the 1992 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.[a] The following sections describe, by general category of required model input, the 1992 CBECS data used, the kinds of imputations made using the data, and the types of energy calculations made using the original and imputed data. The detailed specifications of the CBECS data imputation module are contained in Appendix A of Belzer et al. (1993). 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 high-intensity discharge [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. Information on the absence or presence of reflectors used in lighting fixtures was collected for the first time in 1992. The survey also provides the respondents' estimates of the percentage of installed lights used when the building is occupied and when it is not.

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

(a) 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.

building type, occupant density, size, and vintage allow imputation of the service hot water system, including whether the system is distributed or central, whether 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 how much the refrigerator rejected heat contributes 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; presence or absence of insulation; 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 of a window shading coefficient. The U-values are used to calculate 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. In the previous PNNL study, this information, along with the building type, was used to impute an aspect ratio (the ratio of the length to the width) and the HVAC zoning strategy. In the 1992 CBECS, the length and width of the building were included as part of the questionnaire. Thus, for the majority of buildings, the actual aspect ratio could be used in the model. In cases where this information was not available, an aspect ratio was imputed from averages by building type.

The 1992 CBECS also reinstated (from the 1986 survey) a question dealing with the amount of window area. Where such data were missing, window areas are imputed as for the 1993 study.[a]

The geometry information is used to calculate 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 indicates whether 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 (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 and the cooling equipment and system types. The survey also indicates whether 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

(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.

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 equipment, and the related distribution systems (e.g., air ducts, fan-coil units, or radiators). The efficiency and static pressure of the ventilation system, as well as the heating and cooling supply temperatures, are imputed from this information. The ventilation control mode (constant ventilation or cycling on and off with the heating and cooling systems) is assumed to depend upon the building type. Taken together, 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 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 data for portions of some months. 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 425 variables for the 6751 buildings for the 1992 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 are 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 of Belzer et al. (1993). Appendix A of the current report discusses major modifications of this translation that were prompted by the changes in the 1992 CBECS. Special C (programming language) routines were used 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, and 3) employment.

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)[a] for each of the 6751 buildings in the 1992 survey. The majority of these estimates were based directly on billing data that were provided by utility suppliers for these buildings. Where billing data were 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 1992 CBECS (EIA 1995).

As in the Belzer et al. (1993) study, 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, again 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 on a monthly basis for 1992. This required consideration of the following issues during the development of this database: 1) alignment of bills to

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(a) District heating includes steam and hot water.

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 straightforward 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. As for the 1993 PNNL study, such procedures were not considered because of resource and schedule constraints. As monthly plots of the aggregate EUIs suggest, 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 procedures described in Chapters 5 and 6, the data set was limited to buildings that had at least eleven separate bills covering twelve months during 1992.

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 was 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 was 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.

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.

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

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	761	761	418	512	291
Education	720	720	282	505	200
Food Sales	103	103	71	60	36
Food Service	232	232	122	184	109
Hospital	133	133	63	113	61
Lodging	305	305	121	220	87
Large Office	653	653	310	422	207
Small Office	864	864	473	522	312
Retail/Service	1,230	1,128	686	827	451
Warehouse	1,025	965	442	495	252
Other	725	610	239	300	155
Total	6,751	6,574	3,227	4,160	2,161

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

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 for secondary heating.

The FEDS model generates values for only a single heating fuel (that includes primary and secondary) because 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. Belzer et al. (1993) analyzed monthly gas and electricity consumption for buildings with this combination. Using April and October as base months, the preceding study 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.

In the current study, we attempted to estimate the amount of electricity consumption for secondary heating as part of the SAE model. Chapter 5 details the results of this modified approach.

The treatment of multiple fuels for water heating and cooking was unchanged from the previous study. 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 1992, 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 PNNL 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 1992. Within each census division, we identified the weather 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 6751 buildings in the 1992 CBECS.

4.0 END-USE INTENSITY ESTIMATION APPROACH: BACKGROUND

The engineering methods in FEDS incorporate thermodynamic principles to estimate end-use consumption, but are not constrained to reflect the observed total energy consumption. 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. In the Belzer et al. (1993) study, 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 for the 1989 CBECS. This alternative SAE approach uses only annual data. The details of the current approach relative to electricity and natural gas are discussed in Chapter 5 and to non-heating uses of natural gas in Chapter 6.

4.1 NOMENCLATURE AND DISAGGREGATION

Unchanged from the 1993 study is the nomenclature used 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 EIA's National Energy Modeling System (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 non-refrigerated)
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

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

Eight end uses (u) are distinguished in the FEDS model:

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)

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 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

$$F_{ik} = \sum_{u} F_{iku} * D_{iku} \qquad (4.1)$$

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.

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

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

The billing data from the CBECS provide 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:

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

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 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 can be specified between the unobserved EUIs and the engineering EUIs:

(a) All EUIs are expressed in terms of the building's gross square footage. Although the engineering model takes into account that not all of the building floorspace may be heated or cooled, the heating and cooling EUIs are still computed on the basis of the total floorspace in the building. This convention assures that the sum of the end-use EUIs is equivalent to the overall EUI for the building.

$$EUI_{iku} = a_{ku} * EUIR_{iku} + w_{iku} \quad (4.4)$$

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 whole-building EUI (derived from the billing data) as the dependent variable:

$$EUI_{iku} = \sum_{u} a_{ku} * D_{iku} + e \quad (4.5)$$

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

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, 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 and the "typical" building.

4.2.2 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 exists for systematic biases in the engineering EUI estimates, stemming from using what were judged to be "typical" engineering or operational assumptions in areas where the CBECS does not provide specific information. The one-period model provides an estimate of the overall average difference between the engineering EUI and the true EUI.

The assumption of constant bias in the engineering estimates, however, may be overly restrictive. Clearly, there may be a number of dimensions along which this bias may vary. Building age, climate zone, size, and occupant density 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 judgment guide the final model.

At this point, we illustrate this extended model by focusing upon the building-specific vintage. Considering vintage, the overall whole building intensities published for the 1992 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 1989, after which they fall by about 10 percent. The

TABLE 4.2. Whole Building EUIs by Vintage

Year Constructed	Electricity kWh/ft^2	Natural Gas CF/ft^2
1899 or before	6.5	48.3
1900 to 1919	5.8	35.4
1920 to 1945	7.6	52.5
1946 to 1959	9.6	47.2
1960 to 1969	12.4	46.6
1970 to 1979	13.4	55.7
1980 to 1989	14.3	40.8
1990 to 1992	12.9	28.7

Source: EIA 1995a, Table 3.15; EIA 1995b, Table 3.31.

natural gas intensities increase in the post-war period and then remain fairly constant through 1979. Gas intensities then decline sharply in buildings built in the 1980s and 1990s.

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 use less heating energy 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 4.2. 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 and existing buildings.

To operationalize vintage effects, we need to collapse the number of vintage "dummy" variables from the number shown in Table 4.2. Three general vintages have been used in the regression analysis: 1) pre-war buildings (up to 1945), 2) post-war buildings 1946 through 1979, and 3) buildings built after 1979.

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

$$EUI_{iku} = a_{ku1} * EUIR_{iku} + a_{ku2} * EUIR_{iku} * V_2 + a_{ku3} * EUIR_{iku} * V_3 + w_{iku} \tag{4.6}$$

where V_2 = 1 if i was built between 1946 and 1979, 0 otherwise

V_3 = 1 if 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.

The discussion above illustrates the overall framework for including building-specific variables in the SAE specification. In addition to vintage, two other variables figured prominently in the final SAE specification: building size and employment density. In addition to these variables, a set of variables was investigated to capture "high-intensity" uses that were the focus of several questions introduced for the first time in the 1992 CBECS. The specific variables and empirical results are described in the next chapter.

4.3 EXPERIENCE WITH ONE-PERIOD SAE MODEL

In the 1993 study, 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 1.0. As a result, the SAE-based intensities disagreed considerably with those generated by the engineering model. Some example results of this approach are discussed in Chapter 4 of Belzer et al. (1993). That report also discussed some of the possible reasons for these results.

As a response to the results of the SAE model applied to the monthly billing data, the 1993 study sought 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 was then followed up with SAE models that were estimated with annual data. As background to the approach in the current study, this procedure is reviewed in the following section.

4.4 1993 METHODOLOGY: SAE APPROACH USING MONTHLY BILL DECOMPOSITION

As indicated above, the final methodology for the 1993 study was to estimate EUIs for electricity and gas by decomposing monthly bills prior to a SAE modeling effort. Given the conventional uses for electricity as compared to gas, the decomposition procedures differed slightly. The following sections provide an overview of the procedures finally used in the Belzer et al. (1993) study.

4.4.1 Electricity Decomposition Procedure

For electricity, monthly consumption data were 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 sought to distinguish total HVAC consumption from 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 temperatures) as explanatory variables for the weather sensitive consumption, we used the simulated FEDS HVAC consumption.

The decomposition procedure was conducted for each building in the sample that contained monthly electricity billing data (including buildings with imputed data, see Section 3.0). The monthly HVAC and non-HVAC consumption estimates were then aggregated to annual values.

4.4.2 Natural Gas Decomposition

For natural gas, monthly consumption data were 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 the sum of non-heating end uses can be identified from observed gas consumption during the summer. In 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 generated a cross section of annual HVAC and non-HVAC consumption for each building type. The "actual" HVAC consumption (intensity) was then regressed against the FEDS values for total HVAC intensity and other building-specific demographic variables. This model was similar to that discussed in Section 4.2.2, with the exception that only one end use (actually, the sum of heating, cooling and ventilation) is being explained. The same SAE procedure was 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.

The general procedure was 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 non-HVAC 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.

4.5 1995 METHODOLOGY: NONLINEAR SAE APPROACH USING ANNUAL BILLING DATA

Based upon the results of an outside technical review EIA conducted in early 1995, we altered the fundamental SAE approach for the analysis of the 1992 CBECS. The biggest change involves the end-use estimation for electricity, in which the monthly decomposition analysis was replaced by a nonlinear SAE model involving only annual data. The treatment of the natural gas consumption is similar to the 1989 study, although the specification is expanded to consider occupant density and other information which is new to the 1992 CBECS.

The fundamental criticism of the 1993 methodology for electricity is that the presence of simultaneous heating and cooling can bias the estimates of the heating and cooling consumption downward. Essentially, a flat monthly profile of whole-building electricity in the winter months can be consistent with either a situation in which there is no appreciable electric space heating or a situation in which a rising heating consumption is being offset with a falling cooling consumption. Although the 1989 study lumped the FEDS heating, cooling, and ventilation variables together in its SAE specification, a proposed estimation of SAE parameters for each HVAC end use was not deemed appropriate to solve the underlying problem. Application of the FEDS HVAC end uses in a monthly SAE specification (for each building) is presumed to embody an "errors-in-variables" problem that would still bias the coefficients downward.

In this author's opinion, it remains an open question as to whether a monthly decomposition method can be effectively used to decompose electricity end-use consumption. A thorough examination of this topic would involve monthly heating and cooling degrees at different temperature bases. Monthly temperature data were unavailable for analysis within the time constraints of the present study.

As a result, this study follows the outside review's recommendation that the electricity decomposition approach be dropped in favor of SAE models that are estimated with annual billing data. The annual specification, however, goes well beyond the simple linear specifications that were first used with the 1989 data. A nonlinear framework, embodying some of the characteristics of EIA's end-use analysis of the Residential Energy Consumption Survey (EIA 1995c) was implemented. This framework allows greater flexibility in the way that variables such as building size and employment density interact with the engineering estimates of end-use consumption.

Another feature of the SAE specification is that heating use for natural gas is estimated simultaneously with the electricity end uses. The approach was followed in order to provide a more credible picture of electric heating consumption.

The outside review concluded that the decomposition approach for natural gas--using summer consumption to estimate non-heating gas use--was reasonable and, thus, this general approach has been retained in the present study.

The next two chapters provide details of the SAE models and estimation results. Chapter 5 discusses the EUI estimation procedure and selected empirical results for electricity and natural gas heating. Chapter 6 presents the methodology and results for non-heating uses of natural gas.

5.0 ESTIMATES OF ELECTRICITY AND NATURAL GAS HEATING

This chapter discusses the methodology used to estimate electricity end uses and space heating use of natural gas. The electricity and gas heating end uses were estimated simultaneously in order to better identify electric space heating. The non-heating end uses for gas are treated in Chapter 6.

The estimation of electricity end-use consumption from the 1992 CBECS is based upon an SAE model. As discussed in Chapter 4, the SAE approach uses regression analysis to adjust the engineering estimates to better match the actual consumption. Consumption estimates by end use are generated by FEDS for eight end uses: 1) heating 2) cooling, 3) ventilation, 4) lighting, 5) refrigeration, 6) cooking, 7) hot water, and 8) miscellaneous equipment.

The cross-sectional analysis of electricity and gas heating is based upon a set of model specifications of increasing complexity. The number of observations and the results of the FEDS engineering simulations influence how many separate effects can be statistically determined from the CBECS data.

5.1 SPECIFIC COMPONENTS OF SAE MODEL

To a large degree, heating and cooling requirements are influenced by the estimates of internal loads, dominated in most building types by lighting and miscellaneous (equipment) loads. In the discussion below, we begin by examining the factors related to the loads other than heating, cooling, and ventilation. These specific end uses are discussed separately at the end of the section.

5.1.1 Worker Density

Although FEDS generates variation across buildings in lighting and miscellaneous equipment electricity consumption from differences in reported operating hours by building, these end uses are further influenced by the number of building occupants. The number of occupants will affect task lighting and amount of equipment that is being used (from PCs to elevators). At present, the relationship of electricity consumption to occupancy can only be estimated statistically from a variety of buildings with different occupancy levels.

Unfortunately, we do not have a good measure of occupancy for every building type. The CBECS asks for the number of workers, but not building occupancy. This is not a problem for offices and warehouses where the number of employees is essentially the same as the number of occupants. However, given that the SAE models are estimated separately for each building type, this problem is mitigated to some degree. Generally, one can assume that utilization of equipment and to a lesser degree, lighting, will still be strongly linked to the number of employees, even though they may be a minority of actual building occupants.[a] Thus, for instance, the number of workers in a restaurant will still be a reasonable surrogate for the use of cooking, miscellaneous equipment, and lighting.

Given the relatively fixed nature of many lighting and equipment loads, we expect that the relationship of these end uses to employment density will be less than proportional. Thus, as we increase the density of employees, energy use will increase to a smaller degree. At high levels of occupancy, we might expect that additional employees would result in a lower average ratio of equipment to employees. For example, additional office workers would be expected to share offices, use PCs during off hours, and use common equipment such as copiers and faxes more intensively.

To estimate this relationship, we assume that employment density will adjust lighting, miscellaneous loads, refrigeration, and cooking by the following function:

$$\begin{aligned} \text{SAE Non-HVAC EUIs} &= \text{AdjEmp} * \text{FEDS Non-HVAC EUIs} \\ \text{AdjEmp} &= a1 * \text{EmpDen}^{a2} \end{aligned} \tag{5.1}$$

where EmpDen = number of employees per thousand square feet.

5.1.2 "Old" Buildings

In addition to occupancy, we have a strong presumption that older buildings (especially, those built prior to World War II) do not have the same baseload electricity intensity as those built more recently. Some building

(a) In the discussion below, workers and employees are used interchangeably.

characteristics behind these lower intensities may be 1) fewer elevators, 2) no cooking facilities, 3) more daylighting use, and 4) more open space. Beyond these factors, probably the biggest influence is that newer buildings, commanding higher rents (implicit or market), simply attract the types of activities whose per employee use of electricity is higher. Anecdotally, an old office building may be satisfactory for a rural lawyer's office, with a typewriter and a PC; banks--with a larger density of office equipment and computers--are likely to be in a newer structure.

The adjustments from employment density and older buildings are combined into a single adjustment factor, AdjNHAC:

$$AdjNHAC = a1 * EmpDen^{a2} + a3 * Pre\text{-}War \tag{5.2}$$

where Pre-War = 1 if building built prior to 1946, 0 otherwise.

5.1.3 Lighting

FEDS default values for miscellaneous loads and lighting are primarily based upon average profiles from REMP (formerly ELCAP) metered data and other information. For lighting, variation across buildings is generated in FEDS by the lighting technology (fluorescent, incandescent, HID) and utilization information.

The FEDS model generates an estimate for lighting based upon the following information collected in the CBECS:

1. percent of floorspace lit, by lighting type (fluorescent, incandescent, and HID)
2. percent of floorspace lit during operating and non-operating hours
3. presence of specular reflectors.

This information is combined with assumptions regarding installed capacities (Watts/ft^2) to generate estimates of annual lighting consumption.

The resulting estimates show considerable variance of lighting levels between sample buildings even of the same type (i.e., office, retail, grocery). Our experience with the 1989 CBECS led us to speculate that these rigid engineering assumptions, combined with the CBECS responses regarding percentages of space lit, were producing a variation of lighting EUIs that does not reflect actual operating conditions. As a case in point, we have no information as to the *relative* utilization of incandescent versus fluorescent lighting. Thus, if incandescent lighting is actually operated at lower illumination levels than fluorescent, the engineering approach will estimate lighting consumption on the high side. A second problem may be the extent to which respondents believed that 100 percent of the floorspace was lit during operating hours. The results from metering studies suggest that this is rarely the case.

To get some indication of the quality of the FEDS lighting estimates, we first *assume* that the *average* level of lighting generated per operating hour within FEDS is correct for a given building type. We then try to determine the degree to which the variation around the mean needs to be attenuated in order to best fit the empirical data. Formally, this process begins by computing average lighting per *operating hour*. Thus, for each building i, we have

$$\text{OpLight}_i = \text{FEDLight}_i/\text{annhrs}_i \tag{5.3}$$

where FedLight = Lighting Consumption per Year (FEDS)
annhrs = Weekly operating hours * 52

We then define a scalar, AveLight, which is the mean of OpLight across the buildings that are included in the estimation sample:

$$\text{AveLight} = \text{Mean}(\text{Oplight}_i) \tag{5.4}$$

A new variable for each building i is constructed as the ratio of OpLight to Avelight:

$$\text{RelLight}_i = \text{OpLight}_i / \text{AveLight} \tag{5.5}$$

RelLight includes the variation across buildings in 1) lighting technologies and 2) fraction of space reported to be lit in non-operating hours.

By its construction, RelLight does not, however, reflect differences in weekly operating hours, which are judged to be more accurate than the other factors contributing to the FEDS lighting estimates.

In addition to the adjustment for lighting intensity in Equation (5.5), we also apply the adjustment for employee density as discussed earlier in Equation (5.2). Thus, the final lighting measure in the SAE model results from the following term in the cross-sectional regression equation:

$$SAELight = (RelLight^{a4} * AveLight * annhrs) * AdjNHAC \qquad (5.6)$$

If the estimated coefficient, a4, is one, the product of the terms above yields an estimate of the lighting EUI for each building as it comes from FEDS. A coefficient of 0 yields an estimate that is simply the mean lighting level per operating hour for the buildings in the sample. The building-to-building variation will be the result of operating hours only. Thus, the estimates of a4 are intended to provide some measure of the quality of the engineering estimates (and CBECS inputs) to explain cross-sectional variation in total electricity consumption.

An additional term in the SAE specification is intended to measure the extent to which lighting intensities have declined in new buildings. This term simply adjusts the estimated lighting intensity in Equation (5.6) in a proportional manner for buildings built after 1979:

$$a5 * Post79 * SAELight \qquad (5.7)$$

where Post79 = 1.0 if the building was constructed after 1979; 0 otherwise.

5.1.4 Water Heating

Electric water heating is estimated as a proportional adjustment to the FEDS estimate of water heating, with a further adjustment based upon employment density. The FEDS water estimates have a relationship to occupant density built into the engineering calculations. However, these estimates do not appear to display the same sensitivity to employee density as implied by initial estimates of the parameter a2 in Equation (5.1). As a compromise, we apply 1/2 of the employee density adjustment from Equation (5.1) to the FEDS water heating estimates. Thus, our specification for electric water heating (when electric water heating is present) is

$$\text{SAEwtheat} = \text{a6} * \text{FEDSWtheat} * 0.5 * (1.0 + \text{AdjEmp}) \qquad (5.8)$$

5.1.5 Cooling

The variation of cooling across buildings results from a complex function of a number of factors. Cooling consumption is a function of outside temperature (climate zone), internal loads, the conductive properties of the building envelope, solar gains, and efficiency of cooling equipment. All of these factors are incorporated within FEDS.

In the basic specification of the SAE model, actual cooling is posited to be proportional to the estimate provided by FEDS. This specification will at least provide a means to correct any systematic biases in the envelope characteristics, solar gain, and equipment efficiencies. Any adjustment related to errors in the internal loads assumed by FEDS is more difficult. We will discuss this issue below. To summarize, the cooling adjustment thus becomes

$$\text{SAECool} = \text{a7} * \text{FEDSCool} \qquad (5.9)$$

5.1.6 High-Intensity Uses

The CBECS asks a number of questions aimed toward identifying particularly large special uses of energy in the building. These include 1) commercial food preparation, 2) computer room with separate A/C, 3) special ventilation equipment, 4) space requiring large amounts of hot water, and 5) space requiring large amounts of energy. The answers to these questions cannot provide any measure of the specific amount of energy with which the use is associated. Thus, the best we can do in the cross-sectional model is to estimate the average impact of the most important of these factors.

One problem with the use of such variables is that often they are surrogates for other sources of electricity consumption in the building. Perhaps the most notable case involves the presence of a computer room with separate air conditioning system. For both small and large offices, this variable is always highly statistically significant, regardless of the nature of the specification estimated. However, in a strictly additive form the incremental consumption implied by the estimated coefficients far exceeds the available engineering estimates of mainframe computers. Clearly, this variable is picking up other office equipment (and perhaps higher lighting levels) that are likely greater in buildings that have such computer rooms. In the case of the central computer room, the coefficient is set *a priori*, based upon the engineering estimates (along with the estimated cooling and ventilation loads). For other high-intensity variables, we examined the values of the coefficients and made adjustments where we felt it was warranted.

As part of the empirical SAE estimation, we limited the number of high-intensity variables to two. Preliminary regressions were conducted to help identify those variables with the greatest explanatory power. In the general specification to be presented in Section 5.3, we simply label these variables as HighUse1 and HighUse2. The specific variables employed by building type are discussed in Section 5.4.

5.1.7 Heating

The variation of heating consumption across buildings stems from the same factors as cooling, although the relative contributions differ. Because the temperature differentials (inside vs outside) are much greater for heating than for cooling, heating consumption depends more upon the conductive properties of the building envelope than does cooling. The effect of solar gains and internal gains are not as important for heating as for cooling. Solar gains are not as important because a higher fraction of winter days are cloudy; internal gains are not as critical as much of the heating consumption is during the night or as a result of morning pick-up loads. Even these generalizations are oversimplified when one examines particular building types with their typical envelope characteristics (e.g., window area) and typical operating schedules (which influence the effect of internal loads on heating).

The quantification of electric space heating consumption in commercial buildings is a particularly vexing issue. The national commercial sector electric space estimates made with the 1989 CBECS (Belzer et al. 1993) were considerably lower than those then in use by EIA and other commercial models. The methodology in the 1989 study used the available monthly billing data exclusively. The seasonal patterns of bills were used to adjust the FEDS estimates on a building-by-building basis (a quasi-PRISM approach using FEDS estimates in the place of degree-days). As discussed at the end of the previous chapter, this approach has been criticized in that it may not adequately account for the offsetting seasonal patterns of cooling and heating (cooling consumption declining as heating increases), which will tend to underestimate both heating and cooling. Hopefully, more thorough examination of this will be the subject of future research.

A formal review of the methodology for the 1989 CBECS suggested estimating heating and cooling from the annual cross-section data. Belzer et al. (1993) attempted such an approach (for the 1989 CBECS), but the results were deemed to be insufficiently robust to accurately estimate end-use (in particular, electric space heating and cooling) consumption. The methodology applied to the 1992 CBECS with regard to estimation of space heating is designed to improve upon the previous study.

In general, electric space heating is difficult to measure because it is difficult to disentangle from other characteristics in the cross section of buildings. With the exception of the inland Northwest, electrically heated buildings generally are located in warmer areas of the U.S. This fact is recognized within the FEDS model, with significantly higher average heating EUIs for buildings heated by gas as compared to those reporting primary electric heat. The use of annual data means the effect of additional electric load from heating is masked to some degree by the concomitant higher cooling consumption.

Moreover, electrically heated buildings are generally newer; FEDS assumes some improvements in average envelope characteristics which further lower electric space heating consumption (and further separate the *average* heating EUI for gas-heated buildings from that of electric).

As a practical issue, only about one fourth to one third of buildings in the CBECS report electric space heating. With the possible exception of the office and retail building types, the small number of observations makes it difficult to identify biases in the FEDS heating consumption estimates and simultaneously address all of the other end uses in a single equation to explain total electricity consumption.

The innovation adopted in this study of the 1992 CBECS is to use the available gas consumption data to "inform" the electricity model with regard to the heating load served by electricity. As described in Chapter 4, the gas consumption is decomposed into heating and non-heating components based upon a simple examination of monthly billing data. We then attempt to correct for biases in the FEDS heating estimates for gas in a two-equation system along with the electricity equation. In its simplest form, this two equation system is

$$E = f(\, a_1 \times g\,(\text{FEDSeheat}, Y),\ \text{Other FEDS end uses},\ X) \qquad (5.10)$$

$$G = g(\, \text{FEDSgheat}, Y);$$

where E = Total Electric Consumption

G = Total Gas Consumption estimated for heating

FEDSeheat = FEDS electric space heat estimate

FEDSgheat = FEDS gas space heat estimate

Y = Building characteristics to adjust heating estimates

X = Building characteristics to adjust non-heating end uses.

The above system is based upon the fact that FEDS generates a space heating *load* that is fuel independent. If the building primarily heats with gas, the consumption estimate is derived by dividing the space heating load by an estimated efficiency of the gas heating equipment. If the building heats with electricity, the load is converted to electricity consumption by the estimated efficiency of the electric heating equipment. For electricity, the efficiency will differ depending upon whether the building reports the use of heat pumps rather than other (resistance only) systems.

The function g is estimated with all of the observations that report either electric or gas space heating. This function is designed to correct for systematic biases that FEDS might display with respect to estimating heating loads across key building characteristics. Currently, the function is fairly simple; we first look for the presence of vintage effects not captured in the FEDS assumptions. These would generally result from deviations from the envelope characteristics (u-values) assumed by FEDS. In addition, we use building size as an additional explanatory variable to correct for biases in the zoning assumed in FEDS. The specification of g is homogeneous of degree one for the FEDS estimate of heat; that is, we generate a function used to multiplicatively adjust the FEDS estimate of gas heating consumption estimate:

$$\begin{aligned} \text{Gheat} &= g(\text{FEDSgHeat}, Y) + e \\ &= [(a11 + a12\ \text{Pre-War} + a13\ \text{Post79})\ \text{Size}^{a14}]\ \text{FEDSgheat} + e \\ &= \text{AdjHeat} * \text{FEDSgHeat} + e \\ &= \text{SAEgHeat} + e \end{aligned} \tag{5.11}$$

where Gheat = Space heating consumption of gas, as estimated from monthly bills

Pre-War = 1 if building built prior to 1946, 0 otherwise

Post79 = 1 if building built after 1979, 0 otherwise

Size = Building size, square feet

e = error term.

Based upon Equation (5.11) the adjustment for electric space heating is

$$\text{SAEeHeat} = a15 \times \text{AdjHeat} \times \text{FEDSeHeat} \tag{5.12}$$

The coefficient a15 reflects any other efficiencies of electric space heating systems (and, perhaps, differences in internal loads) that are found in buildings heated by electricity as compared to those heated by gas. Thus, a coefficient of 1.0 takes the FEDS (adjusted) electric space consumption at its full value. Values smaller than 1.0 indicate further efficiencies of electric systems that are not captured in FEDS even after the heating load correction by the vintage and building size in AdjHeat [in Equation (5.11)].

The monthly billings indicate that secondary electric heating is important in some buildings. We estimate the consumption related to this heating as a simple fraction of the FEDS heating *load*. Thus, we have

$$\text{SAEseHeat} = \text{a16} \times \text{FEDSHeatLD} \tag{5.13}$$

5.1.8 Ventilation

Ventilation loads are generated within FEDS primarily on the basis of estimated fan use to supply cooled or heated air to meet space conditioning requirements. For hospitals and large offices, FEDS assumes that the ventilation system is running constantly during operating hours.

Even though ventilation loads are linked to heating and cooling loads (especially, the latter), we have decided not to link any adjustment in ventilation loads to those used for heating and cooling. What metered data exist suggest that ventilation is seasonally variable in retail and offices, but that this variation may not be as great as the FEDS model indicates. The implication is that the number of buildings using constant ventilation in some or all of their conditioned space is greater than what is assumed by FEDS. Accordingly, we assume that the FEDS' annual average ventilation is a reasonable approximation to actual ventilation consumption, although its seasonal variation may be too pronounced.

Ventilation shares the same specification as water heating. We take a middle position between using the FEDS estimate without adjustment or assuming that ventilation requirements would respond to employee density the same as lights and miscellaneous equipment. Thus, we employ the SAE specification for ventilation as

$$\text{SAEVent} = 0.5\ (1.0 + \text{AdjNHAC}) \times \text{FEDSVent} \tag{5.14}$$

5.1.9 End-Use Interactions

The discussion to this point has considered lighting and miscellaneous equipment loads independent from space heating and cooling. From a physical point of view, these end uses are, of course, linked; any adjustment of internal loads should also cause a secondary adjustment of heating and cooling estimates.

As discussed above, the principal driving variables for internal loads in the SAE model are worker density and vintage. Over wide ranges of adjustment, it is also plausible to expect that high worker density will have an effect on intensity through equipment utilization, in addition to the physical linkage through heat gains. That is, more workers in a building may lead to more cooling and heating, simply to achieve higher comfort levels for the greater number of occupants.

The utilization effect for cooling will be in the same direction as the heat gain effect. More workers will likely lead to more cooling demand; to maintain this higher level of comfort ("cooling services") will require additional energy to remove the heat generated from the additional equipment and lighting required by the greater number of workers.

For heating, the utilization effect will work in the opposite direction from any impacts through changes in internal loads. Higher occupant densities may require additional heating (e.g., less zoning--areas where heat is not required), even though the increase in occupancy will also produce additional internal gains. Which effect will dominate in a cross-sectional framework is an empirical matter.

To estimate the impact of these interaction and utilization effects, we add two terms to the SAE specification, one for cooling and one for heating. Essentially, both terms are used to estimate the relationship of the cooling and heating adjustments to the adjustment (AdjNHAC) used to modify the non-space conditioning loads. Each adjustment is specified in a multiplicative manner:[a]

(a) The numbering of the coefficients may appear disjointed in Equations 5.15 and 5.16, but we wished to group the coefficients associated with cooling separately from those for heating.

$$AdjCoolGn = AdjNHAC^{a8} \quad (5.15)$$

$$AdjHeatGn = AdjNHAC^{a17} \quad (5.16)$$

If a8 (a17) is equal to one, then the cooling (heating) load adjustment is proportionately the same as that for the internal loads. Values less or greater than 1 will adjust the cooling or heating disproportionately relative to the internal gains.

5.2 BIAS CORRECTION FOR GAS SPACE HEATING

As discussed at the end of the last section, both the electricity and natural gas specifications were modeled as homogeneous functions (of degree 1) of the FEDS engineering estimates. Estimation of such functions does have the potential that the mean predicted value of total building EUIs will not be similar to the mean of the actual EUIs. In an ordinary least squares regression that includes a constant term, this issue is not a problem--the very nature of the procedure is such that the predicted mean and the actual mean are identical.

In preliminary testing of the specification involving both electricity and natural gas heating, the means of the predicted electricity EUIs were somewhat closer to the actual means than were the means for gas heating. For some building types, the mean predicted gas heating was up to 25 percent below the mean actual value.

An examination of residuals from the gas heating equation revealed that at low levels of the predicted FEDS heating load, a number of buildings had significant heating loads. In an engineering context, this problem may stem from an inaccurate assessment of internal loads for specific buildings. FEDS will generate no heating consumption if it views, in essence, that the required heat is being supplied by lights and miscellaneous equipment.

In a statistical context, the problem might be viewed as a case of a truncated distribution. The least squares framework we have adopted, even in its nonlinear variant, still assumes that errors are distributed symmetrically around the mean predicted value. In this application, we can never observe negative consumption levels. At small values of the predicted EUI [even after applying the transformation in Equation (5.11) involving vintage and size], we necessarily observe positive residuals.

Some adjustment of this tendency to underpredict the mean is more critical for natural gas than it is for electricity. The SAE results for electricity are generally used to allocate total electricity consumption. On the other hand, for gas, it is more critical to predict the appropriate *magnitude* of space heating consumption. The predicted values of space heating consumption are combined with predicted values of non-heating uses to allocate total gas consumption.

The need to generate an unbiased estimate of gas heating consumption suggests some type of adjustment is required. Treating this issue as a case of a truncated distribution goes beyond the scope of the current study. The choice is how to make a basic adjustment to correct for this bias. One alternative is to include a constant term in the natural gas equation in the combined electricity-gas model. First, this approach has the problem of what such a constant term implies for electric space heating--the initial motivation for the joint estimation. Second, we wished to throw as much of the adjustment as possible onto the vintage and size variables for heating; in essence, we still view the homogeneous function as the most theoretically appropriate.

Accordingly, we have chosen to apply a correction adjustment to the gas heating equation on an *ex post* basis. Motivated by the issue of a truncated distribution, we use a function that predicts the residuals of the SAE equation as a declining function of the SAE value. The function employed is

$$R = b1 * (\text{SAEgHeat} + 1.0)^{b2} \qquad (5.17)$$

where R = residual from SAE model, Gheat - SAEgHeat.

We have added 1.0 (kBtu/ft^2) to the predicted level of gas intensity to ensure that the estimation procedure will not fail. A negative coefficient b2 is evidence that the relative magnitude of the residuals declines at higher predicted levels of heating intensity.

To estimate gas heating intensity out of sample (SAEgHeat'), we apply the bias adjustment in the following manner:

$$SAEgHeat' = SAEgHeat + b1\ (SAEgheat+1.0)^{b2} \qquad (5.18)$$

5.3 THE COMPLETE SAE MODEL: ELECTRICITY AND GAS SPACE HEATING

Based upon the discussion above, the SAE model for electricity is organized around two levels of complexity. The first level ignores space heating and is a nonlinear function of 10 parameters. It defines a basic model that can be estimated for a sample that does not report electric space heating.

The basic model depends strongly upon the following adjustment factors:

$$AdjEMP = a1 * EmpDen^{a2}$$

$$AdjNHAC = a1 * EmpDen^{a2} + a3 * Pre\text{-}War$$

Thus,

	SAE End Use
$E = AdjNHAC * FEDSRefrig$	Refrigeration
$+ AdjNHAC * FEDSCook$	Cooking
$+ AdjNHAC * FEDSMisc$	Misc.
$+ AdjNHAC * (RelLight^{a4} \times AveLight \times annhrs) * (1 + a5\ Post79)$	Lighting
$+ a6 * 0.5 * (1.0 + AdjEmp)\ FEDSwtheat$	Water Heating
$+ a7 * FedsCool * AdjNHAC^{a8}$	Cooling
$+ 0.5 * (1.0 + AdjNHAC) * FEDSVent$	Ventilation
$+ a9 * HighUse1$	High Use 1
$+ a10 * HighUse2$	High Use 2

The model expanded to include electric space heat (SAEHeat) includes the following terms:

$$AdjHeat = [\ (a11 + a12\ Pre\text{-}War + a13\ Post79) * Size^{a14}\ ]$$

$$SAEeHeat = AdjHeat * (a15\ FEDSeheat + a16\ FEDSheatld) * AdjNHAC^{a17}$$

The adjustment for natural gas also uses AdjHeat. Thus, we have

$$G_{heat} = AdjHeat * FEDSgheat * AdjNHAC^{a17} \quad (5.19)$$

where G_{heat} = Estimated actual consumption for gas heating

FEDSgheat = FEDS consumption for gas heating.

Because the model is multiplicative with each of the FEDS end-use estimates, our goal is make it as valuable in validating the FEDS estimates as it is in adjusting the FEDS estimates. Setting coefficients a1, a4, a6, a7, a11, and a16 equal to one and all other coefficients equal to zero will result in the SAE estimates that are identical to the FEDS estimates. Coefficients a9 a10, and a16 are used to identify end uses not captured in FEDS.

5.4 EMPIRICAL IMPLEMENTATION

The full SAE model with its 17 parameters requires a considerable number of observations to achieve acceptably robust results. Because the number of observations with available billing data varies by building type, the full model was estimated for only several building types. In the remaining building types, we concentrated upon those parameters we believed would still provide a coherent explanation of the cross-sectional variation.

5.4.1 Sample Selection

As in the Belzer et al. (1993) study, we judged the presence of very high-intensity buildings to be detrimental to the overall SAE procedure. In the 1993 study, we excluded high-intensity buildings that were three times greater than the *maximum* FEDS-predicted intensity. This criterion was applied on the basis of building type.

The current study uses a somewhat more statistically appropriate procedure. Each building's total intensity (for both electricity and gas) is assessed relative to its FEDS prediction to determine if it should be included in the final estimation sample.

For electricity, we calculated the root mean squared error (RMSE) of the logarithmic errors (ln (Actual/FEDS) for each building type. Any high-intensity building whose logarithmic (roughly, relative percentage error) was greater than 3 times the RMSE for that building type was deleted. This procedure is based upon the assumption that the log of the errors was approximately normally distributed. If so, the "3-sigma" rule would remove roughly one-half percent of the buildings with the greatest relative errors.

A similar procedure was followed for natural gas heating, with the exception that we used the residual errors themselves (Actual - FEDS), rather than the logs of the errors. Since we are dealing with a single end use, we encounter buildings for which either the actual or FEDS-predicted heating use is near 0 (thus, generating extremely high or low logarithmic errors). We did not wish to eliminate observations for which the FEDS-predicted value was near 0, but for which the observed gas consumption might be reasonable in an absolute sense.

Table 5.1 shows the final numbers of observations with electricity and gas consumption data that were used in SAE models. The criterion for deleting high-intensity cases was conservative; only 65 buildings out of over 3200 with suitable electricity data were deleted from the estimation.[a] For natural gas, a total of 34 buildings exceeded the limits chosen. The last two columns of the table show the final numbers of observations used in the two-equation SAE model. The estimation and prediction procedure was simplified by deleting any observation whose electricity consumption was too high--even if the gas consumption was within acceptable bounds. This procedure led to the omission of a few additional observations with natural gas heating.

(a) Before the deletion of the high-intensity observations, one additional screen was applied on the basis of the electricity bills. Buildings in which a bill with no consumption was observed in *both* the first part of the calendar year (January-May) and the last part of the year (September-December) were omitted. This screen removes some buildings which were effectively not occupied for the whole year. This screen primarily affected warehouses (5 cases dropped) and miscellaneous buildings (8 cases dropped). This procedure explains why the number of observations for electricity differ between Tables 3.1 and 5.1.

TABLE 5.1. Number of Observations Used in SAE Models

Building Type	Electric (Initial Obs.)	Electric (Obs. dropped)	Gas (Initial Obs.)	Gas (Obs. dropped)	Electric (Final Obs.)	Gas (Final Obs.)
Assembly	415	14	242	7	401	228
Education	282	4	154	3	278	151
Food Sales	71	0	28	0	71	28
Food Service	122	2	82	2	120	80
Hospital	63	0	37	0	63	37
Lodging	121	2	41	2	119	39
Large Office	310	6	135	4	304	129
Small Office	473	12	262	6	461	252
Retail/Service	685	13	366	6	672	358
Warehouse	437	7	217	2	430	212
Misc. Building	231	4	122	1	227	120

5.4.2 Estimation Strategy

The basic strategy was to ensure that adjusted estimates reflected the general magnitudes of heating, cooling, lighting, and miscellaneous equipment consumption. Thus, we strived to allow the parameters related AdjNHAC (a1 - a3), the gas heating parameters (a11 and a14), and the adjustment parameters for cooling (a7) and electric heating (a15) to be freely estimated with the available sample data. Other parameters were added in a general sequential sequence.

Although the expected signs were generally observed in the building types with most observations, in other building types, incorrect signs were not uncommon. In these cases, we simply set the coefficients to reasonable magnitude suggested by the engineering simulation or we set the coefficient to 0. Thus, for example, we encountered negative coefficients for the FEDS water heating variable in some building types. In such cases, we set the coefficient to 1.0, yielding the FEDS estimate.

The most difficult pair of coefficients to estimate involved the end-use interactions--coefficients a8 and a17. These coefficients are strongly related to the simple proportional adjustment coefficients, a7 and a15, respectively. In general, if implausible elasticities were obtained for a8 or a17, they were set to a small positive value (usually 0.01).

5.4.3 Use of Monthly Electricity Billing Data

For heating and cooling, we also used the results of a decomposition of the monthly billing data to set lower bounds for the adjustment parameters. The decomposition procedure involved an enhancement of the specification used in Belzer et al. (1993). The procedure involves a two stages. In the first stage, we estimate ventilation associated with heating and cooling. For *each* building with suitable billing data, we estimate the following equation using the monthly predictions from the FEDS model:

$$\text{FEDSVent} = a0 + a1\ \text{FEDSHeat} + a2\ \text{FEDSCool} \tag{5.20}$$

We then define ventilation-adjusted heating and ventilation-adjusted cooling as

$$\text{FEDSHeata} = \text{FEDSHeat} + a1\ \text{FEDSHeat} \tag{5.21}$$

$$\text{FEDSCoola} = \text{FEDSHeat} + a2\ \text{FEDSCool}$$

In the second stage, actual monthly consumption is regressed upon a constant term, the ventilation-adjusted cooling, and the ventilation-adjusted heating:

$$E = b0 + b1\ \text{FEDSHeata} + b2\ \text{FEDSCoola}$$

Given that FEDS sometimes produces small estimates of heating or cooling, the adjustment parameters are very high in a few cases. Thus, a simple average of the b1 and b2 coefficients can distort the average *end-use consumption* adjustment for an individual building type. Thus, we compute the building type average adjustments for heating and cooling, respectively, as

Ave. Heating Adjustment = Sum (b1 FEDSHeat)/Sum (FEDSHeat)

Ave. Cooling Adjustment = Sum (b2 FEDSCool)/Sum (FEDSCool)

5.5 EMPIRICAL RESULTS

The estimated coefficients for the final SAE specification are shown in Table 5.2. As shown in the row labeled "a2", the most consistent effect involved employment density. The elasticities with respect to employment density generally ranged between 0.3 and 0.9. As might be reasonable to expect, the elasticities were highest for restaurants and lodging. The restaurant building type covers establishments that range from full service restaurants serving only dinner to fast food establishments. Employment densities in lodging will vary greatly from budget motels to first-class hotels.

With the exception of lodging, warehouses, and miscellaneous buildings, the coefficients on the pre-war categorical variable were all negative and statistically significant.[a] Educational buildings, hospitals, large offices, and retail buildings showed the greatest relative differences between the pre-war and post-war vintages.

5.5.1 Lighting

The SAE model suggests that a pure engineering approach to the estimation of lighting may overestimate the differences in lighting intensity among buildings within the same building type. The freely estimated attenuation coefficients were retained for seven out of the eleven building types. The estimated coefficients for most other building types were closer to 0 and were sometimes negative. We generally set these coefficients to 0.20 based on the assembly, office, and retail building results.

The estimated coefficient on the Post79 categorical variable for lighting ranged between -0.27 and -0.53 in large offices, small offices, and retail. The results in other building types in preliminary testing were mixed, with no uniform pattern emerging. The coefficients were set *a priori* to -0.1 in these other building types.

(a) The coefficients on lodging and warehouses were fixed on the basis of simpler specifications to overcome problems of convergence in the estimation procedure.

TABLE 5.2. Coefficients from Nonlinear SAE Regressions

	Assem	Educat	FoodSale	FoodServ	Hospital	Lodging
No. obs: elec	401	278	71	120	63	119
No. obs: gas	228	151	28	80	37	39
a1 (baseload scale)	0.534	0.824	0.771	0.300	0.765	0.970
	8.178	15.058	8.973	0.003	5.038	4.922
a2 (empden expon.)	0.288	0.263	0.309	0.897	0.415	0.600
	(6.5)	(4.1)	(2.4)	(17.8)	(2.0)	(0.0)
a3 (Pre-war dummy)	-0.177	-0.432	-0.258	-0.514	-0.560	-0.100
	(-3.4)	(-4.9)	(-1.4)	(-15.3)	(-2.4)	(-0.0)
a4 (rellight ^a4)	0.153	0.200	0.697	0.200	0.524	0.100
	(1.5)	(0.0)	(0.6)	(0.0)	(0.9)	(0.0)
a5 (post-79 lightng)	-0.100	-0.100	-0.100	-0.100	-0.100	-0.100
	(-0.0)	(-0.0)	(-0.0)	(-0.0)	(-0.0)	(-0.0)
a6 (water heating)	1.000	1.940	4.000	2.000	1.000	2.000
	(0.0)	(3.0)	(0.0)	(0.0)	(0.0)	(0.0)
a7 (cooling adjust)	0.600	0.600	0.700	1.500	2.000	2.000
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
a8 (cool/base elas.)	0.200	0.100	0.100	0.066	0.100	0.100
	(0.0)	(0.0)	(0.0)	(0.4)	(0.0)	(0.0)
a9 (High use 1)	2.459	27.381	28.798	39.556	0.010	0.010
	(1.0)	(3.6)	(1.3)	(1.6)	(0.0)	(0.0)
a10 (High use 2)	0.010	0.010	0.010	26.803	0.010	0.010
	(0.0)	(0.0)	(0.0)	(1.9)	(0.0)	(0.0)
a11 (scl. fact - heat)	0.665	0.527	0.008	0.009	1.664	0.017
	(2.5)	(20.0)	(4.5)	(2.9)	(8.5)	(3.1)
a12 (pre-war heating)	-0.098	0.229	0.013	0.010	0.100	0.010
	(-1.1)	(4.2)	(2.1)	(0.0)	(0.0)	(0.0)
a13 (post79 heating)	-0.336	-0.014	0.029	0.010	0.003	0.010
	(-2.2)	(-0.2)	(1.4)	(0.0)	(0.0)	(0.0)
a14 (size^a14)	0.017	0.100	0.500	0.617	0.010	0.498
	(0.3)	(0.0)	(0.0)	(17.6)	(0.0)	(14.2)
a15 (elec htg factor)	0.952	0.727	0.700	0.800	1.000	1.000
	(6.5)	(5.1)	(0.0)	(0.0)	(0.0)	(0.0)
a16 (sec. elec heat)	0.050	0.050	0.050	0.100	0.010	0.300
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
a17 (heat/util elas)	0.212	0.010	0.010	0.741	0.010	1.524
	(1.5)	(0.0)	(0.0)	(6.8)	(0.0)	(9.9)
(effective heat adj)	0.541	0.987	0.503	0.842	1.890	2.435
(effective cool adj)	0.498	0.577	0.683	1.426	1.983	1.931

TABLE 5.2. (contd)

	LrgOff	SmlOff	Retail	Warehou	Misc
No. obs: elec	304	461	672	430	227
No. obs: gas	129	252	358	212	120
a1 (baseload scale)	0.742	0.437	1.049	1.266	0.783
	(11.3)	(4.7)	(9.5)	(11.4)	(0.008)
a2 (empden expon.)	0.382	0.484	0.462	0.200	0.278
	(6.0)	(5.7)	(5.9)	(0.0)	(4.7)
a3 (Pre-war dummy)	-0.470	-0.279	-0.508	-0.200	-0.233
	(-3.2)	(-3.7)	(-4.7)	(-0.0)	(-3.1)
a4 (rellight ^a4)	0.200	0.135	0.334	0.222	0.182
	(0.0)	(0.6)	(2.5)	(1.5)	(0.6)
a5 (post-79 lightng)	-0.529	-0.273	-0.293	-0.100	-0.100
	(-4.5)	(-1.2)	(-2.4)	(-0.0)	(-0.0)
a6 (water heating)	4.000	14.170	13.609	28.669	10.000
	(0.0)	(2.5)	(3.4)	(2.0)	(0.0)
a7 (cooling adjust)	1.200	0.850	0.425	1.386	0.500
	(0.0)	(2.0)	(1.4)	(3.3)	(0.0)
a8 (cool/base elas.)	0.100	0.267	1.378	0.100	0.100
	(0.0)	(0.6)	(1.2)	(0.0)	(0.0)
a9 (High use 1)	2.500	1.800	6.259	17.862	1.145
	(0.0)	(0.0)	(0.6)	(3.3)	(0.1)
a10 (High use 2)	0.725	0.008	38.980	6.559	0.010
	(0.1)	(0.0)	(6.2)	(1.9)	(0.0)
a11 (scl. fact - heat)	4.637	0.142	0.103	0.277	0.224
	(0.9)	(2.7)	(3.2)	(2.3)	(2.5)
a12 (pre-war heating)	3.131	0.028	-0.022	-0.095	0.010
	(0.9)	(1.6)	(-1.8)	(-1.7)	(0.0)
a13 (post79 heating)	1.682	-0.027	0.009	0.093	0.010
	(0.7)	(-1.2)	(0.7)	(1.3)	(0.0)
a14 (size^a14)	-0.075	0.274	0.228	0.153	0.270
	(-0.8)	(6.3)	(6.4)	(3.5)	(6.0)
a15 (elec htg factor)	0.924	0.800	0.789	0.500	0.433
	(2.8)	(0.0)	(3.7)	(0.0)	(2.3)
a16 (sec. elec heat)	0.207	0.203	0.100	0.554	0.100
	(0.5)	(0.7)	(0.0)	(2.4)	(0.0)
a17 (heat/util elas)	0.010	0.276	0.236	1.225	2.354
	(0.0)	(3.1)	(2.5)	(4.1)	(4.1)
(effectiveheat adj)	2.167	0.953	0.585	0.635	0.796
(effectivecool adj)	1.191	0.739	0.505	1.408	0.479

5.5.2 Water Heating

The performance of the adjustment for electric water heating was mixed across building types. In general, the data appear to indicate that the consumption stemming from the engineering model is too low. Small offices and retail showed the largest deviations, with coefficients suggesting an order of magnitude increase from the engineering assumptions. Both may indicate that significantly more hot water is used for clean-up than simply for domestic use. (The retail building type includes laundromats; however, most of these establishments very likely use gas for water heating).

For several building types (assembly, hospital), the adjustment for water heating was inexplicably negative. For these building types, we used the FEDS estimate without adjustment (setting a6 = 1.0).

5.5.3 Cooling

For cooling, the adjustments varied by building type, with most building types making a downward adjustment from the FEDS value. The actual adjustment to the FEDS cooling values is a function of both the scaling coefficient (a7) and the utilization-internal gain elasticity (a8). This second elasticity was estimated for only three building types: food service, small office, and retail. As a means of looking at the effect of both parameters, we compute an effective average adjustment after the coefficients have been estimated. This adjustment, calculated as the average of the SAE cooling intensities divided by the mean FEDS cooling intensity, is shown on the last line of the table.

Cooling was adjusted upwards from the FEDS estimates in five building types: food service, hospital, lodging, large offices, and warehouses. The upward adjustment involved more than a doubling of the FEDS estimates in food service buildings.

For education, small office, and retail buildings, the cooling adjustments were statistically significant and suggested that the FEDS estimates of cooling were too high by about a factor of 2. Based upon the statistical significance and examination of the intensities in the Cooling Degree-Day (CDD) quintiles, these coefficients were left unaltered.

For assembly, food sales, hospital, and miscellaneous buildings, the freely estimated adjustment factors from the annual cross-sectional SAE regression were significantly lower than the average adjustment factors implied by the monthly bill decomposition. In these building types, the SAE coefficients were fixed at values that reflected the monthly billing analysis.

5.5.4 Heating

For most building types, the estimated size elasticity coefficient (a14) was positive. This result stemmed from a tendency in FEDS to reduce heating demands with respect to building size somewhat more than the consumption data indicated. No clear pattern emerges from the vintage adjustment coefficients (a12 and a13). In particular, we were looking to correct any biases within FEDS with regard to buildings built after 1979. Only in assembly buildings was there strong statistical evidence that the model was overpredicting the gas heating consumption for post-1979 buildings. For food sales and large offices, the estimated coefficients indicate that FEDS is underpredicting space heating in newer buildings.

The same tendency is true in hospitals where FEDS severely underpredicts heating consumption. Hospitals are difficult to simulate with a simple engineering model because they combine high internal loads, but often have patient "wings" that presumably still have relatively high heating loads. We were unable to estimate a reasonable size elasticity coefficient for hospitals. Separate coefficients (a11 and a13) simply multiply the FEDS heating estimates to yield magnitudes that best fit the gas consumption data.

The end-use interaction coefficient for heating (a17) was estimated in a little more than half of the building types. In all cases, the coefficient was positive, indicating that the utilization effect (as discussed in Section 5.1) outweighs the internal gain effect. The coefficient is strongest in miscellaneous buildings--not a surprising result considering the range of building types (vacant, parking garages, and public order and safety) that is included in the group. The coefficient was very high and statistically significant for food service, lodging, small offices, and retail.

The motivation for estimating gas heating consumption simultaneously with electricity was to better identify space heating loads served by electricity. The empirical results indicate that even after higher (site) energy efficiency is assumed by FEDS for electric space heating, further efficiencies may be widespread in electrically heated buildings. None of the estimated electric space heating coefficients exceeded 1, although in assembly and large offices the coefficients approached that value. With a large number of observations and a small interaction term, the coefficient for retail buildings was slightly less than 0.8.

As for cooling, we used the results of the monthly decomposition of electricity bills to set lower bounds for some building types for which the cross-sectional results were substantially inconsistent with the billing data analysis. These lower bounds were set for food sales, food service, hospitals, lodging, small offices, and warehouses.

Finally, for secondary electric space heating, warehouse was the sole building type to yield a positive coefficient with modest statistical significance. In all other building sectors, we set the secondary heating coefficient to 0.05 or 0.1, based upon a casual examination of the monthly billing analysis for buildings reporting primary gas heating and secondary electric heating.

5.5.5 High-Intensity Uses

Table 5.3 shows the special energy use variables and their estimated coefficients for the eleven building types in the study.

Food preparation was highly significant in retail buildings, marginally so in assembly buildings. Surprisingly, the variable did not show up in the food sales building type. High hot water entered with the correct sign in

TABLE 5.3. Estimated Coefficients for High-Intensity Uses

Building Type	High Use 1	Coef.	T-stat	High Use 2	Coef.	T-stat
Assembly	Food Prep	2.5	1.0	Not Estimated		
Education	Manufacturing	27.4	3.6	Not Estimated		
Food Sales	Food Prep	28.8	1.3	Not Estimated		
Food Service	High Vent	39.6	1.6	High Heat/Cool	26.8	1.9
Hospitals	Not Estimated			Not Estimated		
Lodging	Not Estimated			Not Estimated		
Large Office	Computer Room	2.5	Fixed	High Hot Water	0.7	0.1
Small Office	Computer Room	1.8	Fixed	P.C. density	0.008	<0.01
Retail	High Hot Water	6.3	0.6	Food Prep	40.0	6.2
Warehouse	Refrig. Warehouse	19.7	>10.0	Manufac.	8.9	>10.0
Misc. Bldgs.	Laboratory	40.2	4.4	Not Estimated		

large office and retail buildings, but the statistical significance is low. A categorical variable representing high ventilation was estimated with a large magnitude for food service buildings.

When freely estimated, the coefficients on computer rooms (with separate A/C systems) in large and small offices far exceeded the available metered information on the electricity consumption by large computers. As we discussed earlier, the computer room is serving as a proxy for other types of equipment in the building and possibly even portions of the HVAC loads. Using metered information from the REMP in the Pacific Northwest, we fixed these coefficients to represent the average energy use of large computers and an incremental amount (20%) representing the associated cooling load.

In several cases, the more detailed EIA building types served as categorical variables. Refrigerated warehouses and laboratories, as expected, are more energy-intensive than the remainder of the buildings in building types warehouse and miscellaneous. In the miscellaneous building category, we also entered public order and safety as categorical variables in the expectation that these buildings are more energy-intensive, holding other factors constant in the SAE specification, than vacant buildings and parking garages. The estimated coefficient, however, was not positive. As we noted earlier, the employment and end-use interaction terms in the SAE specification are able to pick up much of the variation in energy consumption even across these dissimilar building types. Manufacturing use showed up with a statistically significant coefficient in two building types. Although this result was expected in warehouses, its inclusion in the educational building category was somewhat surprising. It may result from manufacturing activities in technical schools.

5.5.6 Bias Corrections for Natural Gas Heating

Table 5.4 presents the results of the bias adjustment coefficients for natual gas heating. All of the buildings indicate a declining percentage adjustment for higher predicted levels of gas heating, as indicated by the negative coefficients for a2. For example, in assembly buildings, an SAE estimate of 10 kBtu/ft^2 would be adjusted upward by about 8 kBtu/ft^2. For an SAE estimate of 50 kBtu/ft^2, the adjustment would only be about 4 kBtu.

Table 5.4. Coefficients Gas Heating Bias Adjustment

	Assem	Educat	FoodSale	FoodServ	Hospital	Lodging
a1 (a1*RES^a2)	21.913	27.122	33.580	46.445	118.114	33.443
	(2.2)	(1.8)	(2.2)	(1.8)	(3.9)	(1.6)
a2 (a2*RES^a2)	-0.418	-0.352	-0.418	-0.255	-5.386	-0.160
	(-2.1)	(-1.7)	(-1.3)	(-1.3)	(-0.9)	(-0.7)

	LrgOff	SmlOff	Retail	Warehou	Misc
a1 (a1*RES^a2)	18.875	29.939	24.492	13.308	35.640
	(3.8)	(3.3)	(2.1)	(3.5)	(3.1)
a2 (a2*RES^a2)	-0.466	-0.346	-0.399	-0.167	-0.211
	(-2.6)	(-2.6)	(-2.1)	(-1.2)	(-1.3)

6.0 <u>ESTIMATES OF NON-HEATING USES OF NATURAL GAS</u>

This chapter discusses the SAE specification and empirical results for non-heating uses of natural gas. The predicted non-heating use of gas is added to the predicted heating use (as explained in the previous chapter) to estimate total gas consumption by CBECS building.

6.1 SPECIFICATION OF SAE MODEL

As for the electricity model, the SAE model for non-heating uses of natural gas is a nonlinear function of employment density to help explain the cross-sectional variation in water heating and cooking uses of natural gas. The specification also uses several of the "high-intensity" variables used in the electricity specification, namely "High hot water use" and "Commercial food preparation."

As stated above, the focus of the non-heating natural gas model is to satisfactorily identify water heating and cooking use of natural gas in relation to other uses: 1) manufacturing, 2) cogeneration, and 3) miscellaneous use.

Our experience with the 1989 CBECS led us to conclude that a strict conditional demand approach to individually estimate water heating and cooking is not feasible with the CBECS. The problem stems from the heterogeneity of end uses within the building types. The clearest example involves retail and service establishments. Buildings reporting gas use <u>only</u> for hot water have higher consumption than buildings using gas for hot water <u>and</u> cooking. Retail and service buildings using only hot water include laundromats with very high consumption. When cooking and water heating variables are separately put into the conditional demand framework, the coefficient on cooking in such a data set is negative. We found this problem of negative (or implausibly low) coefficients for cooking (or sometimes, water heating) in other building types besides retail and service.

Our response to this problem from the 1989 CBECS is extended to this study. We separately estimate coefficients for 1) water heating without cooking, 2) cooking without water heating, and 3) water heating and cooking together. We look at the separate coefficients on the first two variables and use outside information or judgment to allocate the combined consumption picked up by the third variable into separate water heating and cooking EUIs. All three of these terms are modified by the utilization variables derived from employment density.

The remaining end uses are estimated from a straightforward conditional demand approach. Five categorical variables (zero-one) are included in the specification without modification by employment density:

1. Activity using large amounts of hot water
2. Commercial food preparation (10% or greater of floor area)
3. Manufacturing use of natural gas
4. Cogeneration use of natural gas
5. Miscellaneous use (no end use reported, or only heating use of gas reported).

We made an effort to estimate two other effects that are important with respect to predicting non-heating use of gas. The first involved the share of water heating load that is served by natural gas when the building also reports electricity as being used for water heating. Without information to the contrary, our approach to multiple fuels in the non-heating end uses has been to divide the estimated consumption equally among reported fuels. For water heating, we hoped that the data might provide some evidence on the appropriateness of this assumption.

To estimate a water heating fuel share, we include a variable that can be modified during the estimation procedure to alter the relative fuel shares. For those buildings reporting both electricity and natural gas, we include the term $(1/2)^{a10}$. If the coefficient on a10 is near one, then our assumption of equal fuels shares is reasonable. The coefficient can take on other values (positive or negative) to move the natural gas share up or down from the initial value of 1/2.

Finally, we tested several other occupancy variables to improve the overall explanatory power of the SAE equation. The first was months in use.

Partly because of the small number of buildings reporting fewer than 12 months of use, in no building type did this variable even have a t-statistic near one with the expected sign. The second variable tested the influence of the CBECS information on the percentage of floorspace vacant. This variable was included with an elasticity coefficient ($PctVac^{a11}$), which was entered multiplicatively in the employment density function. The performance of this second variable is discussed in Section 6.3 below.

6.2 THE COMPLETE SAE MODEL: NON-HEATING NATURAL GAS END USES

The basic model depends strongly upon the following adjustment factor:

$$AdjDEN = WrkDen^{a1} * PctVAC^{a11}$$

Thus, following the format of the previous chapter, the complete model can be formally specified as

Model	SAE End Use
G = a2 * AdjDEN * FEDSwtheat *whonly * GasWH	Water heating
+ a3 * HighHW	Water heating
+ a4 * AdjDEN * FEDSCook * ckonly	Cooking
+ a5 * FoodPrep	Cooking/Water ht
+ a6 * AdjDEN * (FEDSwtheat + FEDSCook) * whck	Waterht/Cook
+ a7 * Manufacturing	Manufacturing
+ a8 * Cogeneration	Cogeneration
+ a9 * Miscellaneous	Miscellaneous
+ $(1/2)^{a10}$ * ElecWH * whonly * FEDSwtheat	Water Heat

where G = estimated non-heating use of gas (summer consumption level)

whonly = gas used for water heating, but not cooking

ckonly = gas used for cooking, but not water heating

whck = gas used for water heating and cooking

GasWH = only gas used for water heating

ElecWH = electricity and gas used for water heating

FEDSwtheat = FEDS estimate of gas water heating EUI

FEDScook = FEDS estimate of gas cooking EUI

HighHW = 1.0 if activity with large amount of hot water, 0 otherwise

FoodPrep = if commercial food preparation, floorspace > 9%, 0 otherwise

Miscellaneous = 1.0 if no reported use of gas other than heating or cooling, 0 otherwise

Manufacturing = 1.0 if manufacturing use of gas reported, 0 otherwise

Cogeneration = 1.0 if cogeneration use of gas reported, 0 otherwise

6.3 EMPIRICAL RESULTS

The model specified in Section 6.2 was estimated in two variants. The first was a standard conditional demand (CD) specification where all of the explanatory variables, including water heating and cooking, were 0-1 type variables. The second variant was a hybrid SAE model, where the independent variables for water heating and cooking were EUI estimates from FEDS. We will describe first the results for the CD version of the model.

6.3.1 Conditional Demand Variant

The estimated coefficients of the CD model are shown in Table 6.1. As shown in the top row, the elasticities with respect to employment density represented by a1 are generally a little higher than they are for the electricity model. This result seems reasonable since the principal non-heating use of gas, water heating, is likely to be more strongly related to employee density than is overall electricity use. (This result, however, was not observed in office buildings.) This coefficient was difficult to estimate for warehouses; it was fixed on the basis of preliminary regression analyses with fewer terms.

There were sufficient numbers of buildings that reported water heating without cooking to permit the a2 coefficient to be estimated in a fairly robust manner. Unfortunately, the presence of the employment density does not permit the coefficients to be readily interpreted as conditional EUIs.

TABLE 6.1. Coefficients from Nonlinear SAE Regressions: Gas Non-heating, Conditional Demand Specification

	Assem	Educat	FoodSale	FoodServ	Hospital	Lodging
a1 (EmpDen ^ a1)	0.458	0.857	1.339	0.863	0.273	0.699
	(4.0)	(4.8)	(5.1)	(9.7)	(1.1)	(5.3)
a2 (Water ht only)	11.256	5.151	2.182	38.529	55.840	96.267
	(7.0)	(3.4)	(1.3)	(3.0)	(2.1)	(5.4)
a3 (High ht. water)	0.010	0.777	0.010	0.010	0.010	0.010
	(0.0)	(0.1)	(0.0)	(0.0)	(0.0)	(0.0)
a4 (Cooking only)	6.962	2.000	35.809	82.464	15.689	11.002
	(1.6)	(0.0)	(2.9)	(5.2)	(0.6)	(0.2)
a5 (Food prep.)	0.010	0.010	0.010	0.010	55.656	0.010
	(0.0)	(0.0)	(0.0)	(0.0)	(2.2)	(0.0)
a6 (W Heat/Cooking)	12.688	7.357	18.726	68.650	109.018	53.883
	(4.8)	(4.6)	(4.3)	(7.4)	(4.3)	(4.5)
a7 (Manufacturing)	0.010	30.387	1.000	0.010	0.010	0.100
	(0.0)	(3.2)	(0.0)	(0.0)	(0.0)	(0.0)
a8 (Cogeneration)	4.089	0.540	0.100	0.010	0.010	69.110
	(0.8)	(0.2)	(0.0)	(0.0)	(0.0)	(3.0)
a9 (Miscellaneous)	5.041	12.608	5.439	1.189	4.833	4.895
	(2.7)	(3.6)	(0.7)	(0.0)	(0.1)	(0.1)
a10 (Elec/Gas Shr)	1.171	1.731	1.000	1.000	1.000	1.000
	(0.6)	(0.2)	(0.0)	(0.0)	(0.0)	(0.0)
a11 (Pct Vacant^a11)	0.100	0.050	0.100	0.010	0.010	0.010
	(0.0)	(0.3)	(0.0)	(0.0)	(0.0)	(0.0)
(water heat share,a6)	0.500	0.850	0.300	0.250	0.700	0.800

TABLE 6.1. (contd)

	LrgOff	SmlOff	Retail	Warehou	Misc
a1 (EmpDen ^ a1)	0.042 (0.1)	0.140 (0.7)	0.571 (4.2)	0.500 (0.0)	0.362 (2.3)
a2 (Water ht only)	7.724 (2.7)	7.108 (4.4)	8.534 (5.7)	3.715 (4.0)	19.551 (3.7)
a3 (High ht. water)	0.010 (0.0)	0.010 (0.0)	15.351 (2.0)	0.010 (0.0)	0.010 (0.0)
a4 (Cooking only)	1.168 (0.4)	7.717 (0.6)	1.699 (0.3)	0.010 (0.0)	2.891 (0.1)
a5 (Food prep.)	8.686 (1.6)	0.010 (0.0)	8.447 (1.9)	33.399 (4.3)	0.010 (0.0)
a6 (W Heat/Cooking)	11.287 (2.6)	43.358 (3.8)	8.615 (2.5)	2.659 (0.4)	64.321 (4.9)
a7 (Manufacturing)	31.715 (2.9)	11.409 (1.3)	38.075 (5.7)	20.327 (5.2)	0.010 (0.0)
a8 (Cogeneration)	5.935 (1.5)	0.100 (0.0)	0.010 (0.0)	5.459 (1.9)	6.606 (0.5)
a9 (Miscellaneous)	6.489 (2.9)	5.643 (3.7)	5.002 (3.6)	1.717 (1.9)	9.997 (1.6)
a10 (Elec/Gas Shr)	3.657 (0.3)	-0.468 (-0.6)	1.000 (0.0)	3.770 (0.2)	-1.062 (-1.7)
a11 (Pct Vacant^a11)	1.218 (0.8)	0.695 (0.7)	0.010 (0.0)	-0.336 (-8.2)	4.460 (0.9)
(water heat share,a6)	0.850	0.500	0.700	0.900	0.700

Nevertheless, the magnitudes of the coefficients are still indicators of relative EUIs for water heating among building types. Clearly, the water heating requirements in restaurants, hospitals, and lodging are significantly higher than the remaining building types. Warehouses show a low coefficient as do, somewhat unexpectedly, educational buildings. For educational buildings, the relatively high value for a1 may be capturing the water-heating effect.

The coefficient on the variable representing a special activity requiring large amounts of hot water (a3) was statistically significant in only one building type, retail and service. As we alluded to above, this result may reflect buildings with laundromats. For buildings in which the freely estimated values were negative (or where the inclusion of this variable caused a2 to be negative), we set the coefficient effectively to zero (0.01).

While positive in most building types, the coefficient (a4) on cooking without water heating is statistically significant in only food sales and food service. This result stems from the fact that outside these building types, only a few buildings reported cooking use of gas without heating. The coefficient (a5) on food preparation indicated additional gas use for cooking in hospitals, large offices, retail, and warehouses. In the latter building type, the commercial food preparation is probably for processed foods.

The combined water heat and cooking coefficient (a6) was statistically significant in all building types except warehouses. In about half of the building types, the coefficient for either water heating only (a2) or cooking only (a4) exceeded the value of the combined end uses. In spite of this contradiction of the simple conditional demand assumption, we do rely on the relative magnitudes of the a2 and a4 coefficients (as well as other conditional averages computed from the sample) to assign the water heating and cooking shares of the consumption associated with both of these variables. As shown in the last row of the table, the assignments generally make water heating the dominant use of this combined estimated consumption.

Manufacturing use of natural gas was statistically significant in five building types. Both building types that showed significant electricity consumption for manufacturing activity--education and warehouses--were also found to use natural gas for this purpose.

A high amount of cogeneration use of gas was estimated for lodging buildings (a8). Smaller amounts were detected for large offices, warehouses, assembly, and miscellaneous buildings.

The nature of the miscellaneous use category is difficult to ascertain. In these buildings, we find significant summer consumption of natural gas, but with none of the CBECS end uses (water heat, cooking, manufacturing or cogeneration) being reported. We speculate that some portion of this consumption is likely water heating not specified by the respondent for one reason or another. However, we have chosen not to make an arbitrary assignment of this consumption to any one or set of end uses.

The attempt to empirically estimate the electric-gas water heating shares in multiple fuel buildings via the specification in Section 6.2 was not successful. Only in assembly and miscellaneous buildings is the t-value for a10 even close to 1.0. Clearly, there is no identifiable pattern to the results across the building types.

The results for the percent-of-floorspace-vacant variable are nearly as poor. Only in large offices and miscellaneous buildings (which include vacant buildings) does this variable show a hint of statistical significance. The results appear to support the notion that the employment density is already explaining much of this variation across buildings (i.e., employees per square foot of the total building is a consistent measure, even in buildings that report some portion of the space as vacant).

6.3.2 SAE Variant

Table 6.2 shows the results of the same equation when the FEDS model predictions are used for water heating and cooking. The coefficients a2, a4, and a6 clearly show that FEDS is generally underpredicting the magnitude of these end uses. Most of the other coefficients are reasonably close to those in the CD variant.

TABLE 6.2. Coefficients from Nonlinear SAE Regressions: Gas Non-heating, Statistically Adjusted Engineering Model Specification

	Assem	Educat	FoodSale	FoodServ	Hospital	Lodging
a1 (EmpDen ^ a1)	0.470 (4.0)	0.802 (5.1)	1.626 (5.2)	0.989 (12.6)	0.323 (1.2)	0.840 (4.9)
a2 (Water ht only)	2.395 (6.9)	0.693 (3.6)	0.196 (1.1)	1.097 (3.4)	0.854 (1.5)	3.162 (4.4)
a3 (High ht. water)	0.010 (0.0)	0.660 (0.0)	0.010 (0.0)	0.010 (0.0)	0.010 (0.0)	0.010 (0.0)
a4 (Cooking only)	4.898 (0.9)	2.000 (0.0)	10.064 (2.5)	5.654 (5.9)	20.108 (0.6)	8.292 (0.1)
a5 (Food prep.)	0.010 (0.0)	0.010 (0.0)	0.010 (0.0)	0.010 (0.0)	54.721 (2.0)	0.010 (0.0)
a6 (W Heat/Cooking)	2.128 (4.7)	0.911 (5.1)	1.369 (3.7)	1.556 (8.4)	3.702 (4.1)	1.714 (3.1)
a7 (Manufacturing)	0.010 (0.0)	26.960 (2.9)	1.000 (0.0)	0.100 (0.0)	0.010 (0.0)	0.100 (0.0)
a8 (Cogeneration)	4.002 (0.7)	-0.206 (-0.1)	0.010 (0.0)	0.010 (0.0)	0.100 (0.0)	89.183 (3.7)
a9 (Miscellaneous)	5.031 (2.7)	12.598 (3.7)	5.429 (0.7)	1.179 (0.0)	4.823 (0.1)	4.885 (0.1)
a10 (Elec/Gas Shr)	0.048 (0.0)	1.219 (0.2)	1.000 (0.0)	1.000 (0.0)	1.000 (0.0)	1.000 (0.0)
a11 (Pct Vacant^a11)	0.201 (0.7)	0.045 (0.2)	0.010 (0.0)	0.010 (0.0)	0.010 (0.0)	0.010 (0.0)
(water heat share,a6)	0.500	0.850	0.300	0.250	0.700	0.850

TABLE 6.2. (contd)

	LrgOff	SmlOff	Retail	Warehou	Misc
a1 (EmpDen ^ a1)	0.139 (0.5)	0.154 (0.8)	0.478 (3.5)	0.500 (0.0)	0.237 (0.8)
a2 (Water ht only)	3.681 (2.7)	3.974 (4.3)	5.686 (6.3)	12.134 (4.3)	4.784 (1.7)
a3 (High ht. water)	0.010 (0.0)	0.010 (0.0)	16.384 (2.2)	0.010 (0.0)	0.010 (0.0)
a4 (Cooking only)	1.812 (0.3)	17.232 (0.6)	4.060 (0.5)	0.010 (0.0)	134.002 (0.6)
a5 (Food prep.)	8.383 (1.6)	0.010 (0.0)	7.463 (1.7)	32.832 (4.7)	0.010 (0.0)
a6 (W Heat/Cooking)	5.006 (3.0)	21.683 (3.9)	4.397 (2.8)	11.538 (0.7)	11.820 (2.5)
a7 (Manufacturing)	31.705 (3.0)	11.304 (1.3)	37.883 (5.7)	20.959 (5.6)	0.100 (0.0)
a8 (Cogeneration)	5.115 (1.3)	0.100 (0.0)	0.100 (0.0)	5.548 (2.1)	12.463 (0.8)
a9 (Miscellaneous)	6.479 (2.9)	5.633 (3.6)	4.992 (3.6)	1.707 (2.0)	9.987 (1.5)
a10 (Elec/Gas Shr)	2.473 (0.2)	-1.247 (-1.7)	1.000 (0.0)	2.525 (0.2)	-4.027 (-3.8)
a11 (Pct Vacant^a11)	0.580 (0.5)	0.733 (0.7)	0.010 (0.0)	-0.342 (-9.2)	0.033 (0.1)
(water heat share,a6)	0.800	0.500	0.700	0.900	0.900

In several building types, the statistical fit of CD variant was significantly better than the SAE. For miscellaneous (other) buildings we use the CD model and its estimated coefficients to predict water heating and cooking use for the full CBECS sample.

6.4 NATURAL GAS COOLING

As in the 1993 study, consumption of natural gas for cooling was handling outside of the SAE framework. About 100 buildings with twelve months of billing data reported gas as cooling fuel. Of these buildings, 25 suggested some measurable cooling with gas, based upon the monthly profiles of gas usage. The remainder of these buildings revealed either no increase in natural gas during the summer months or total gas usage was negligible during these months.

For the 25 buildings that appeared to use gas for cooling, we estimated the actual cooling consumption based upon the increase in consumption from the shoulder months in the spring and fall. This procedure differs from that used for the 1989 CBECS in which we used the FEDS simulated cooling consumption for such buildings. As before, the remainder of the buildings in the "gas billing sample" were not assigned any gas consumption for cooling.

In the 1993 study, we set gas cooling consumption to zero for buildings outside of the billing sample. In the current study, we use a fraction of the FEDS cooling estimate. The fraction is set to 20% to correspond to the implied probability--based upon inspection of those 1992 CBECS buildings with monthly bills--that a building reporting gas cooling in fact uses a non-negligible amount of gas for this end use.

7.0 SUMMARY OF END-USE INTENSITY ESTIMATES

This chapter provides a summary of the EUI estimates from the methodology discussed in the previous two chapters. We first focus on the 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 1992 CBECS sample. The top of the table shows the calculated floorspace from the database used in the estimation methodology, 67.88 billion square feet.

7.1.1 EUI Definitions

Table 7.1 shows a number of end-use intensities for each fuel to facilitate various comparisons. The top panel of Table 7.1 shows intensities for electricity by nine end uses: heating, cooling, ventilation, lighting, refrigeration, cooking, hot water, miscellaneous, and manufacturing/cogeneration.[a] The first three lines provide intensities on a unweighted basis. That is, a simple average of the EUIs is computed for each end use. The simple average EUIs are shown since the SAE models were estimated on an unweighted basis.

Within the category of unweighted estimates, we display the (average) FEDS value, the average SAE value, and the average value after calibration (CALIB) to the published EIA fuel consumption. The CALIB estimates are derived by proportionately scaling all of the SAE end-use consumption estimates to match the reported fuel consumption from EIA for each individual building.

(a) Cogeneration is irrelevant for electricity, but may apply to the panels for natural gas, oil, or district heat (steam).

TABLE 7.1. End-Use Energy Consumption Estimates for 1992 CBECS: All Buildings

Building Type: AllBldgs Subgroup: All N =6751 , 67.876.6 Bill. SF

Fuel: Elec	Unweighted (Simple Average) EUIs (kBtu/sf)									
End Use:	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	2.57	8.31	2.96	19.35	3.38	1.46	0.72	7.44	0.00	46.18
SAE	2.51	7.30	2.87	15.24	2.69	1.00	2.97	6.40	0.13	41.10
CALIB	2.39	8.24	3.22	18.91	3.03	0.96	3.15	8.05	0.10	48.04
Fuel: Elec	Weighted (by Floorspace) EUIs (kBtu/sf)									
FEDS	1.72	7.28	2.48	18.74	2.60	1.12	0.58	7.09	0.00	41.61
SAE	1.90	6.12	2.31	14.57	2.01	0.62	2.42	5.78	0.16	35.88
CALIB	1.64	6.34	2.42	16.29	2.01	0.54	2.49	6.58	0.11	38.43
Fuel: Elec	Weighted Conditional EUIs (kBtu/sf)									
FEDS	4.54	8.99	2.94	19.11	2.66	6.11	1.54	7.23	0.00	
SAE	5.03	7.56	2.74	14.86	2.05	3.36	6.45	5.89	8.41	
CALIB	4.34	7.83	2.88	16.62	2.05	2.96	6.63	6.71	5.81	

Fuel: Gas	Unweighted (Simple Average) EUIs (kBtu/sf)									
End Use:	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	13.46	0.25	0.00	0.00	0.00	0.39	2.38	0.00	0.00	16.48
SAE	20.59	0.16	0.00	0.00	0.00	3.53	7.98	1.14	0.92	34.32
CALIB	24.63	0.25	0.00	0.00	0.00	4.29	9.66	1.21	0.95	41.00
Fuel: Gas	Weighted (by Floorspace) EUIs (kBtu/sf)									
FEDS	10.27	0.28	0.00	0.00	0.00	0.35	2.27	0.00	0.00	13.18
SAE	19.46	0.20	0.00	0.00	0.00	2.18	6.43	1.21	1.53	31.01
CALIB	19.65	0.34	0.00	0.00	0.00	2.50	7.14	0.77	1.62	32.02
Fuel: Gas	Weighted Conditional EUIs (kBtu/sf)									
FEDS	18.10	10.22	0.00	0.00	0.00	1.56	5.15	0.00	0.00	
SAE	34.30	10.89	1.00	1.00	1.00	9.69	14.56	12.53	30.06	
CALIB	34.64	17.85	0.73	0.73	0.73	11.14	16.17	8.03	31.75	

Fuel: Oil	Unweighted (Simple Average) EUIs (kBtu/sf)									
End Use:	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	2.50	0.01	0.00	0.00	0.00	0.00	0.49	0.00	0.00	3.00
SAE	3.32	0.00	0.00	0.00	0.00	0.01	1.59	0.00	0.93	5.84
CALIB	3.51	0.00	0.00	0.00	0.00	0.01	0.91	0.02	0.21	4.66
Fuel: Oil	Weighted (by Floorspace) EUIs (kBtu/sf)									
FEDS	1.94	0.02	0.00	0.00	0.00	0.00	0.46	0.00	0.00	2.42
SAE	3.32	0.00	0.00	0.00	0.00	0.01	1.29	0.00	1.11	5.74
CALIB	2.89	0.00	0.00	0.00	0.00	0.02	0.90	0.01	0.18	4.01
Fuel: Oil	Weighted Conditional EUIs (kBtu/sf)									
FEDS	17.92	12.11	0.00	0.00	0.00	0.43	12.61	0.00	0.00	
SAE	30.73	2.42	0.00	0.00	0.00	10.65	35.32	0.10	10.71	
CALIB	26.76	2.03	0.00	0.00	0.00	17.09	24.75	5.22	1.78	

Fuel: Stm	Unweighted (Simple Average) EUIs (kBtu/sf)									
End Use:	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.11	0.11	0.00	0.00	0.00	0.01	0.51	0.00	0.00	1.74
SAE	2.73	0.02	0.00	0.00	0.00	0.08	1.18	0.00	0.01	4.02
CALIB	7.17	0.05	0.00	0.00	0.00	0.12	2.70	0.01	0.02	10.07
Fuel: Stm	Weighted (by Floorspace) EUIs (kBtu/sf)									
FEDS	0.82	0.07	0.00	0.00	0.00	0.01	0.36	0.00	0.00	1.26
SAE	2.40	0.01	0.00	0.00	0.00	0.09	0.83	0.00	0.01	3.36
CALIB	4.33	0.03	0.00	0.00	0.00	0.13	1.87	0.01	0.04	6.40
Fuel: Stm	Weighted Conditional EUIs (kBtu/sf)									
FEDS	10.56	21.79	0.00	0.00	0.00	0.86	7.47	0.00	0.00	
SAE	31.13	4.36	0.00	0.00	0.00	7.92	18.12	0.10	4.83	
CALIB	56.01	8.81	0.00	0.00	0.00	11.10	38.42	17.66	14.96	

In the second set of three estimates, the building size and sample weight are used in the calculation of the average EUI. These weighted EUIs are generally used in most applications; EIA's published fuel consumption values per square foot use these same floorspace weights. As might be expected, the weighted EUIs for heating and cooling are smaller than the unweighted values, since the intensities for smaller buildings are generally higher than those for larger buildings.

Conditional EUIs are shown as the third set of estimates in the section dealing with electricity. These intensities are the average values for all buildings that contain the specific end use. One can compute a rough estimate of the fuel share by dividing the average intensity by the conditional intensity. Thus, using the SAE estimates for heating, we divide 1.90 by 4.99 to obtain 0.38, the fraction of floorspace using electricity for heating.

For refrigeration, we did not use the specific CBECS information on end use. As discussed in Appendix A of Belzer et al. (1993), this end use (together with miscellaneous) is modeled basically as an average intensity that applies to all buildings within a given building type. Lighting and ventilation are assumed to be present in nearly all buildings and depend upon a number of CBECS variables to determine their intensity. Thus, for these uses, the weighted average and weighted conditional EUIs are very similar.

These three sets of estimates--unweighted, floorspace-weighted, and conditional floorspace-weighted--are repeated for natural gas, fuel oil, and steam (more accurately, district heat). The fuel oil and district heat estimates are based on the SAE coefficients estimated for the natural gas models.

7.1.2 Key Results

For electricity, the weighted average EUI values across all building are fairly comparable across all three EUI sources--FEDS, SAE, and CALIB. The largest difference from the FEDS values is for hot water. As discussed in the previous chapter, the estimation of a separate adjustment factor for electric water heating yields considerably higher consumption estimates for most building types. For heating and cooling, all three estimates are roughly comparable. The all-buildings average EUI for lighting is adjusted downward from the FEDS simulated values.

For natural gas, it is clear that FEDS is underpredicting total consumption by a considerable degree. As was discussed in the previous chapter, the underprediction for heating varies by building type. The EUIs for cooking and water heating are also increased substantially from the FEDS values.

When examining these intensities by fuel, one should keep in mind that the EUIs cannot be expected to represent the amount of fuel to deliver the same 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 than for electricity. For buildings with high demands for these end uses (e.g., restaurants, laundromats, hospitals), gas is the less expensive fuel. Nevertheless, as we discuss in the next chapter, additional work may be required to better rationalize the differences in EUIs found in this study.

7.1.3 End Use Shares

The values of the average intensities can be used to determine the fractions of end-use consumption by fuel. Consistent with EIA's use of these estimates for the NEMS, we use the weighted average CALIB figures. For electricity, lighting is the largest end use, composing about 43% (16.29/38.43) of total consumption. At 16%, the next single largest use is cooling, followed closely by miscellaneous uses (office equipment, task lighting, task lighting, etc.) which make up about 17% of total consumption.

As would be expected, heating is the principal use for natural gas and oil. However, over one third of natural gas use is estimated to be for nonheating 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 less than that for heating.

Figure 7.2 show the composition of energy as expressed in primary energy. On this basis, electricity is converted to Btu by a factor of 10,700 Btu/kWh to account for the generation and transmission losses associated with electricity.[a] On a primary energy basis, lighting becomes the largest single end use with 28% of total energy consumption. Miscellaneous use follows with a 25% share. HVAC consumption is about a third of primary energy use, with heating making up a little more than half of this consumption.

7.1.4 Comparison with Previous Estimates

A natural question is how the new EUI estimates and resulting end-use distribution compare with the values estimated for the 1989 CBECS (Belzer et al. 1993). At a broad level, Table 7.2 compares the current composition of end uses by fuel with that published by Belzer et al. in 1993.

In looking at the table, emphasis should be placed upon the percentage distribution of end uses rather than the absolute consumption figures. The estimates for 1989 are shown in column three of Table 7.2.

The table clearly shows some significant differences in the end use composition of electricity previously modeled and the estimates from the current study. Based both on the changes in the FEDS model and SAE approach in the present study, cooling conditioning consumption is substantially higher in the current study than in the 1993 study. Electric heating is slightly higher from the new work, while ventilation is about half of the previous estimate. The revised ventilation consumption stems largely from major changes made in the FEDS model between Release 1 and Release 3. Lighting

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(a) This factor is derived from the ratio of electrical system energy losses to electricity sales for the commercial sector for 1992 as published in the State Energy Data Report 1993, DOE/EIA-0214(93), July 1995.

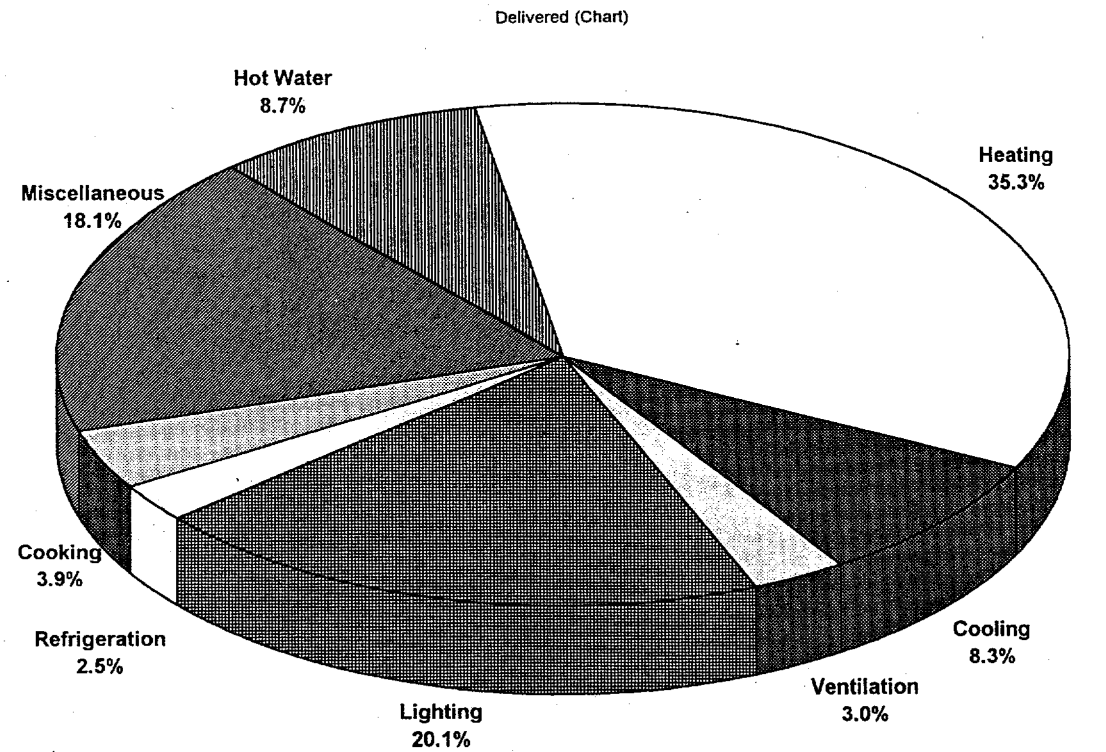

FIGURE 7.1. Estimated Distribution of End-Use Energy Consumption in U.S. Commercial Buildings, Delivered Energy Basis

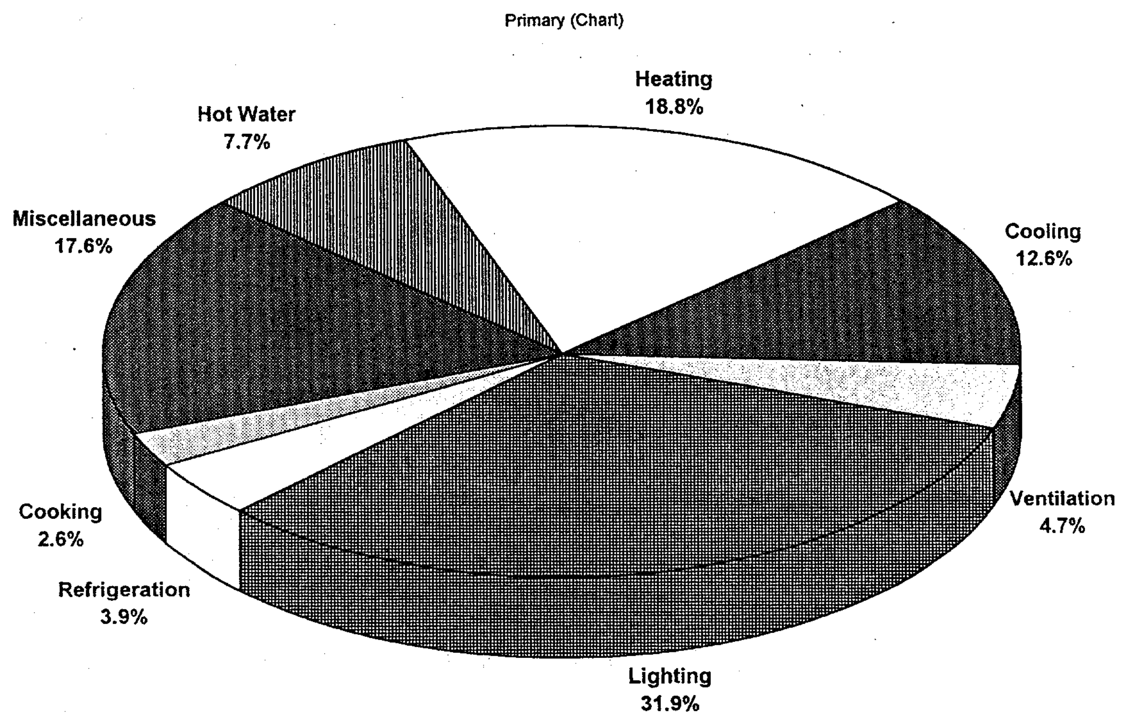

FIGURE 7.2. Estimated Distribution of End-Use Energy Consumption in U.S. Commercial Buildings, Primary Energy Basis

TABLE 7.2. Comparison of EUIs: Current Study versus Previous PNL Estimates for 1989

	Current Study (for 1992)		Prior Study (for 1989)	
	QBtu	(%)	QBtu	(%)
Electricity				
Space Heating	0.11	4.3%	0.10	3.5%
Cooling	0.43	16.5%	0.28	10.2%
Ventilation	0.16	6.3%	0.28	10.0%
Lighting	1.11	42.5%	1.02	36.9%
Other	0.80	30.4%	1.09	40.4%
Total	2.61	100.0%	2.77	100.0%
Natural Gas				
Space Heating	1.32	61.4%	1.30	62.9%
Cooling	0.02	1.1%	0.00	0.2%
Water Heating	0.49	22.3%	0.31	15.0%
Cooking	0.18	7.8%	0.22	10.8%
Other	0.16	7.4%	0.24	11.1%
Total	2.17	100.0%	2.07	100.0%
Oil (distillate)				
Space Heating	0.20	72.3%	0.31	85.8%
Other	0.07	27.7%	0.05	14.2%
Total	0.27	100.0%	0.36	17.2%

consumption is also about the same. The current study finds significantly less 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 between the two studies, with the exception of space cooling and water heating. As discussed in Chapter 6, gas consumption for absorption cooling remains insignificant in the sample of buildings covered by the 1992 CBECS. However, the current estimate is about five times that of the 1989 estimate, reflecting both an increased number of sample buildings that seem to actually use gas for cooling as well as a change in the current estimation method (see Section 6.4). The higher water heating estimate stems from changes in SAE procedures used to decompose non-HVAC uses for natural gas.

The fraction of distillate oil used for heating is significantly lower in the current estimate, although it remains the dominant use of oil in commercial buildings. Water heating accounts for most of the remaining consumption.

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. 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 cooling intensity varies significantly across building types. Space cooling intensities are very high in three building types: food service, hospitals, and lodging. These three building types account for just over 8% of the total floorspace in the commercial sector, but contribute to over 30% 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 the building types are not exactly comparable throughout,[b] the values clearly indicate that the dramatic differences in intensities in the EIA report reflect more the differences in non-heating consumption than in heating. This explanation is particularly true for the food service buildings and hospitals.

(a) Converted to kBtu from thousand ft^3.
(b) The EIA figure for hospitals is actually for health care; it includes out-patient facilities that are classified as offices in this study. For offices, we show the average EIA value for all offices, not distinguishing between large and small. Finally, there is no single published value corresponding to the miscellaneous building category.

TABLE 7.3. End-Use Energy Consumption Estimates for 1992 CBECS: By Building Type

Building Type: Assembly N =761 , 8,302.7 mill. sq. ft.

Fuel: Elec	Unweighted (Simple Average) EUIs (kBtu/sf)								
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	3.54	6.73	2.01	11.54	0.99	0.13	0.65	2.49	0.00	28.08
SAE	2.04	3.38	1.47	10.63	0.48	0.09	0.46	1.13	0.00	19.67
CALIB	1.58	4.05	1.68	15.38	0.63	0.13	0.58	1.53	0.00	25.58
Fuel: Elec	**Weighted (by Floorspace) Average EUIs (kBtu/sf)**									
FEDS	2.61	5.60	1.54	10.65	1.03	0.44	0.83	3.11	0.00	25.81
SAE	1.44	2.73	1.10	10.73	0.40	0.12	0.55	1.08	0.00	18.14
CALIB	1.12	3.11	1.10	15.74	0.51	0.30	1.14	1.61	0.00	24.64
Fuel: Elec	**Weighted Conditional EUIs (kBtu/sf)**									
FEDS	5.98	6.59	1.97	10.65	1.03	1.39	1.82	3.11	0.00	
SAE	3.29	3.22	1.40	10.73	0.40	0.38	1.19	1.08	0.00	
CALIB	2.56	3.66	1.40	15.74	0.51	0.97	2.50	1.61	0.00	
Fuel: Gas	**Unweighted (Simple Average) EUIs (kBtu/sf)**									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	22.46	0.15	0.00	0.00	0.00	0.15	1.99	0.00	0.00	24.75
SAE	17.63	0.08	0.00	0.00	0.00	0.78	3.18	0.46	0.11	22.23
CALIB	22.72	0.10	0.00	0.00	0.00	1.43	6.33	0.45	0.16	31.19
Fuel: Gas	**Weighted (by Floorspace) Average EUIs (kBtu/sf)**									
FEDS	16.98	0.16	0.00	0.00	0.00	0.27	1.96	0.00	0.00	19.37
SAE	15.10	0.11	0.00	0.00	0.00	0.86	2.52	0.50	0.14	19.23
CALIB	14.16	0.16	0.00	0.00	0.00	1.22	3.74	0.26	0.25	19.79
Fuel: Gas	**Weighted Conditional EUIs (kBtu/sf)**									
FEDS	28.52	11.56	0.00	0.00	0.00	1.15	4.36	0.00	0.00	
SAE	25.37	8.77	0.00	0.00	0.00	3.69	5.59	4.99	4.00	
CALIB	23.78	12.45	0.00	0.00	0.00	5.22	8.32	2.64	6.96	
Fuel: Oil	**Unweighted (Simple Average) EUIs (kBtu/sf)**									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	4.57	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	5.02
SAE	3.70	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.11	4.61
CALIB	3.92	0.00	0.00	0.00	0.00	0.00	0.94	0.08	0.07	5.00
Fuel: Oil	**Weighted (by Floorspace) Average EUIs (kBtu/sf)**									
FEDS	3.24	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	3.62
SAE	3.40	0.00	0.00	0.00	0.00	0.00	0.78	0.00	0.14	4.32
CALIB	2.51	0.00	0.00	0.00	0.00	0.00	0.68	0.03	0.01	3.23
Fuel: Oil	**Weighted Conditional EUIs (kBtu/sf)**									
FEDS	25.70	0.00	0.00	0.00	0.00	0.00	15.50	0.00	0.00	
SAE	26.93	0.00	0.00	0.00	0.00	0.00	31.67	0.10	4.00	
CALIB	19.93	0.00	0.00	0.00	0.00	0.00	27.57	7.16	0.25	
Fuel: Stm	**Unweighted (Simple Average) EUIs (kBtu/sf)**									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.39	0.03	0.00	0.00	0.00	0.00	0.43	0.00	0.00	1.85
SAE	1.56	0.01	0.00	0.00	0.00	0.02	0.84	0.00	0.00	2.42
CALIB	4.04	0.02	0.00	0.00	0.00	0.02	1.63	0.00	0.00	5.70
Fuel: Stm	**Weighted (by Floorspace) Average EUIs (kBtu/sf)**									
FEDS	0.90	0.01	0.00	0.00	0.00	0.00	0.20	0.00	0.00	1.11
SAE	0.98	0.00	0.00	0.00	0.00	0.01	0.34	0.00	0.00	1.34
CALIB	2.00	0.01	0.00	0.00	0.00	0.01	0.74	0.00	0.00	2.75
Fuel: Stm	**Weighted Conditional EUIs (kBtu/sf)**									
FEDS	19.27	14.97	0.00	0.00	0.00	0.51	7.62	0.00	0.00	
SAE	21.06	2.99	0.00	0.00	0.00	6.06	13.08	0.00	0.00	
CALIB	42.74	10.02	0.00	0.00	0.00	6.29	28.38	0.00	0.00	

TABLE 7.3. (contd)

Building Type: Education N = 720 , 8469.6 mill. sq. ft.

Fuel: Elec	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	3.50	9.72	2.29	17.36	0.99	0.16	1.08	2.47	0.00	37.59
SAE	3.53	5.67	2.12	13.25	0.74	0.12	1.86	1.83	0.42	29.53
CALIB	3.52	6.35	2.36	16.99	0.96	0.14	2.09	2.37	0.29	35.06
Fuel: Elec Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	1.57	8.24	1.39	19.06	1.00	0.21	0.93	2.56	0.00	34.96
SAE	1.86	4.72	1.23	13.11	0.67	0.14	1.51	1.73	0.37	25.34
CALIB	1.56	4.67	1.29	15.49	0.78	0.16	1.47	2.05	0.23	27.69
Fuel: Elec Weighted Conditional EUIs (kBtu/sf)										
FEDS	6.17	10.10	1.64	19.06	1.00	0.68	3.93	2.56	0.00	
SAE	7.28	5.79	1.45	13.11	0.67	0.47	6.41	1.73	27.38	
CALIB	6.13	5.72	1.51	15.49	0.78	0.52	6.20	2.05	17.31	

Fuel: Gas	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	14.33	0.42	0.00	0.00	0.00	0.26	3.76	0.00	0.00	18.77
SAE	27.65	0.46	0.00	0.00	0.00	0.37	2.91	0.26	0.27	31.93
CALIB	29.02	0.70	0.00	0.00	0.00	0.74	5.28	0.48	0.38	36.60
Fuel: Gas Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	12.90	0.97	0.00	0.00	0.00	0.42	4.84	0.00	0.00	19.13
SAE	28.95	0.97	0.00	0.00	0.00	0.48	3.14	0.23	0.19	33.97
CALIB	27.31	1.53	0.00	0.00	0.00	0.62	4.10	0.45	0.35	34.35
Fuel: Gas Weighted Conditional EUIs (kBtu/sf)										
FEDS	18.34	16.97	0.00	0.00	0.00	0.86	7.43	0.00	0.00	
SAE	41.16	17.72	0.00	0.00	0.00	0.98	4.82	10.62	2.14	
CALIB	38.83	27.88	0.00	0.00	0.00	1.25	6.29	20.33	3.92	

Fuel: Oil	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	2.58	0.05	0.00	0.00	0.00	0.00	0.78	0.00	0.00	3.41
SAE	5.87	0.01	0.00	0.00	0.00	0.00	0.51	0.00	0.00	6.40
CALIB	7.41	0.00	0.00	0.00	0.00	0.00	0.58	0.01	0.06	8.05
Fuel: Oil Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	2.65	0.13	0.00	0.00	0.00	0.00	0.86	0.00	0.00	3.63
SAE	6.83	0.03	0.00	0.00	0.00	0.00	0.56	0.00	0.01	7.42
CALIB	6.63	0.02	0.00	0.00	0.00	0.00	0.58	0.01	0.03	7.26
Fuel: Oil Weighted Conditional EUIs (kBtu/sf)										
FEDS	14.49	15.34	0.00	0.00	0.00	0.00	9.12	0.00	0.00	
SAE	37.37	3.07	0.00	0.00	0.00	0.00	5.91	0.10	0.10	
CALIB	36.26	2.55	0.00	0.00	0.00	0.00	6.16	5.79	0.49	

Fuel: Stm	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	2.34	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	3.08
SAE	4.88	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	5.40
CALIB	8.61	0.00	0.00	0.00	0.00	0.00	1.01	0.08	0.00	9.70
Fuel: Stm Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	1.21	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	1.71
SAE	2.94	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	3.27
CALIB	5.05	0.00	0.00	0.00	0.00	0.00	0.74	0.04	0.00	5.84
Fuel: Stm Weighted Conditional EUIs (kBtu/sf)										
FEDS	15.91	2.40	0.00	0.00	0.00	0.00	10.99	0.00	0.00	
SAE	38.86	0.48	0.00	0.00	0.00	0.00	7.08	0.10	0.00	
CALIB	66.67	1.02	0.00	0.00	0.00	0.00	16.11	17.66	0.00	

TABLE 7.3. (contd)

Building Type: Food Sales N = 103 , 756.8 mill. sq. ft.

Fuel: Elec	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	4.55	21.91	5.38	37.36	113.64	0.56	2.71	7.54	0.00	193.64
SAE	2.63	14.92	4.81	28.76	90.91	0.89	10.15	7.74	0.00	160.81
CALIB	2.64	15.33	4.78	31.21	95.19	0.95	11.32	8.05	0.00	169.48
Fuel: Elec — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	2.92	20.59	5.51	37.50	113.91	0.68	2.37	7.60	0.00	191.07
SAE	2.51	13.74	4.78	27.45	85.74	1.01	8.69	7.66	0.00	151.58
CALIB	2.52	12.83	4.50	27.88	84.08	1.09	8.34	7.49	0.00	148.74
Fuel: Elec — Weighted Conditional EUIs (kBtu/sf)										
FEDS	7.75	21.49	5.69	37.50	113.91	2.23	4.64	7.60	0.00	
SAE	6.67	14.34	4.94	27.45	85.74	3.33	17.00	7.66	0.00	
CALIB	6.70	13.39	4.65	27.88	84.08	3.59	16.32	7.49	0.00	

Fuel: Gas	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	18.54	0.00	0.00	0.00	0.00	0.48	3.20	0.00	0.00	22.22
SAE	25.73	0.00	0.00	0.00	0.00	5.12	1.92	0.26	2.58	35.60
CALIB	20.14	0.00	0.00	0.00	0.00	5.97	3.11	0.26	2.59	32.06
Fuel: Gas — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	14.80	0.00	0.00	0.00	0.00	0.66	3.78	0.00	0.00	19.24
SAE	27.94	0.00	0.00	0.00	0.00	5.26	2.05	0.24	4.72	40.21
CALIB	19.25	0.00	0.00	0.00	0.00	4.98	2.61	0.19	4.73	31.76
Fuel: Gas — Weighted Conditional EUIs (kBtu/sf)										
FEDS	25.00	0.00	0.00	0.00	0.00	2.22	7.65	0.00	0.00	
SAE	47.21	0.00	0.00	0.00	0.00	17.60	4.15	5.43	55.76	
CALIB	32.53	0.00	0.00	0.00	0.00	16.66	5.28	4.35	55.93	

Fuel: Oil	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	2.39	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	2.71
SAE	2.08	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	2.22
CALIB	1.86	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.01	1.92
Fuel: Oil — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	0.99	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	1.06
SAE	0.98	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	1.00
CALIB	0.99	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	1.00
Fuel: Oil — Weighted Conditional EUIs (kBtu/sf)										
FEDS	42.64	0.00	0.00	0.00	0.00	0.00	33.46	0.00	0.00	
SAE	41.84	0.00	0.00	0.00	0.00	0.00	14.06	0.00	0.01	
CALIB	42.25	0.00	0.00	0.00	0.00	0.00	5.22	0.00	0.55	

Fuel: Stm	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SAE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CALIB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel: Stm — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SAE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CALIB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fuel: Stm — Weighted Conditional EUIs (kBtu/sf)										
FEDS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
SAE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
CALIB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

TABLE 7.3. (contd)

Building Type: Food Service N = 232 , 1491.4 mill. sq. ft.

Fuel: Elec — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	4.29	26.01	6.39	40.96	27.82	37.51	2.96	3.47	0.00	149.41
SAE	4.32	38.34	8.36	25.04	15.73	23.73	4.67	3.95	0.00	124.13
CALIB	4.09	42.93	8.96	30.32	19.25	21.36	4.04	4.65	0.00	135.60

Fuel: Elec — Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	2.39	24.78	5.39	40.09	28.03	40.54	2.80	3.53	0.00	147.55
SAE	3.09	35.38	6.48	17.12	10.46	16.03	3.82	3.52	0.00	95.90
CALIB	2.37	34.55	6.23	18.47	11.30	13.30	2.59	3.46	0.00	92.28

Fuel: Elec — Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	8.75	27.08	6.04	40.09	28.03	96.66	10.82	3.53	0.00
SAE	11.34	38.67	7.25	17.12	10.46	38.21	14.76	3.52	0.00
CALIB	8.68	37.76	6.98	18.47	11.30	31.70	10.00	3.46	0.00

Fuel: Gas — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	24.30	0.91	0.00	0.00	0.00	8.51	16.10	0.00	0.00	49.81
SAE	34.57	0.71	0.00	0.00	0.00	79.89	24.71	0.02	0.00	139.89
CALIB	32.38	0.83	0.00	0.00	0.00	88.09	28.95	0.02	0.00	150.27

Fuel: Gas — Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	16.41	0.76	0.00	0.00	0.00	8.84	15.41	0.00	0.00	41.41
SAE	29.25	0.72	0.00	0.00	0.00	56.77	17.71	0.01	0.00	104.47
CALIB	25.70	0.84	0.00	0.00	0.00	59.59	18.87	0.01	0.00	105.01

Fuel: Gas — Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	28.61	22.13	0.00	0.00	0.00	12.63	25.38	0.00	0.00
SAE	51.02	28.39	0.00	0.00	0.00	81.16	29.18	1.18	0.01
CALIB	44.83	32.99	0.00	0.00	0.00	85.19	31.07	1.47	0.00

Fuel: Oil — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	3.03	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.00	4.18
SAE	4.18	0.00	0.00	0.00	0.00	0.00	0.96	0.00	0.00	5.14
CALIB	2.47	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	2.91

Fuel: Oil — Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	2.87	0.00	0.00	0.00	0.00	0.00	1.46	0.00	0.00	4.33
SAE	4.40	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00	5.43
CALIB	2.65	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	3.13

Fuel: Oil — Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	30.15	0.00	0.00	0.00	0.00	0.00	45.97	0.00	0.00
SAE	46.33	0.00	0.00	0.00	0.00	0.00	32.28	0.00	0.01
CALIB	27.91	0.00	0.00	0.00	0.00	0.00	14.93	0.00	0.01

Fuel: Stm — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	0.29	0.00	0.00	0.00	0.00	0.10	0.71	0.00	0.00	1.10
SAE	1.64	0.00	0.00	0.00	0.00	0.40	0.31	0.00	0.00	2.35
CALIB	2.86	0.00	0.00	0.00	0.00	0.43	0.46	0.00	0.00	3.75

Fuel: Stm — Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.08	0.00	0.00	0.00	0.00	0.24	1.39	0.00	0.00	2.71
SAE	2.77	0.00	0.00	0.00	0.00	0.66	0.37	0.00	0.00	3.80
CALIB	4.21	0.00	0.00	0.00	0.00	0.90	0.57	0.00	0.00	5.67

Fuel: Stm — Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	18.94	0.00	0.00	0.00	0.00	5.69	24.62	0.00	0.00
SAE	48.72	0.00	0.00	0.00	0.00	15.68	6.62	0.00	0.00
CALIB	74.11	0.00	0.00	0.00	0.00	21.35	10.00	0.00	0.00

TABLE 7.3. (contd)

Building Type: Hospital N = 133 , 1286.6 mill. sq. ft.

Fuel:		Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Fuel:	Elec	Unweighted (Simple Average) EUIs (kBtu/sf)									
FEDS		1.79	8.77	7.72	36.62	4.65	1.97	3.31	22.44	0.00	87.26
SAE		3.42	17.23	7.52	32.79	4.25	1.79	3.56	20.51	0.00	91.07
CALIB		2.06	16.08	6.80	34.33	4.47	1.93	1.42	21.58	0.00	88.67
Fuel:	Elec	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS		1.42	10.14	7.95	40.44	4.65	1.98	1.76	22.44	0.00	90.78
SAE		2.76	19.79	7.75	34.36	4.22	1.68	1.72	20.34	0.00	92.63
CALIB		1.69	18.77	6.88	34.18	4.40	1.88	0.67	21.22	0.00	89.68
Fuel:	Elec	Weighted Conditional EUIs (kBtu/sf)									
FEDS		3.62	11.32	7.98	40.44	4.65	4.46	33.55	22.44	0.00	
SAE		7.05	22.10	7.78	34.36	4.22	3.78	32.89	20.34	0.00	
CALIB		4.30	20.95	6.90	34.18	4.40	4.23	12.87	21.22	0.00	
Fuel:	Gas	Unweighted (Simple Average) EUIs (kBtu/sf)									
		Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS		12.05	1.16	0.00	0.00	0.00	0.37	15.28	0.00	0.00	28.86
SAE		26.44	1.24	0.00	0.00	0.00	10.49	39.50	10.56	0.01	88.23
CALIB		33.85	2.77	0.00	0.00	0.00	17.12	44.81	18.24	0.07	116.86
Fuel:	Gas	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS		12.92	0.78	0.00	0.00	0.00	0.43	16.72	0.00	0.00	30.84
SAE		30.85	1.08	0.00	0.00	0.00	11.28	47.01	11.51	0.01	101.74
CALIB		35.33	2.54	0.00	0.00	0.00	15.40	50.47	16.10	0.04	119.88
Fuel:	Gas	Weighted Conditional EUIs (kBtu/sf)									
FEDS		17.85	11.61	0.00	0.00	0.00	0.59	25.80	0.00	0.00	
SAE		42.63	39.15	0.00	0.00	0.00	15.59	72.53	14.73	0.10	
CALIB		48.82	92.01	0.00	0.00	0.00	21.27	77.88	20.60	0.38	
Fuel:	Oil	Unweighted (Simple Average) EUIs (kBtu/sf)									
		Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS		1.33	0.03	0.00	0.00	0.00	0.01	1.73	0.00	0.00	3.10
SAE		5.56	0.01	0.00	0.00	0.00	0.31	2.78	0.00	0.07	8.72
CALIB		2.44	0.01	0.00	0.00	0.00	0.39	6.08	0.04	0.64	9.60
Fuel:	Oil	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS		1.40	0.03	0.00	0.00	0.00	0.02	2.60	0.00	0.00	4.05
SAE		5.98	0.01	0.00	0.00	0.00	0.74	4.90	0.00	0.07	11.70
CALIB		3.00	0.00	0.00	0.00	0.00	1.20	10.77	0.08	0.45	15.51
Fuel:	Oil	Weighted Conditional EUIs (kBtu/sf)									
FEDS		3.25	4.08	0.00	0.00	0.00	0.43	22.24	0.00	0.00	
SAE		13.94	0.82	0.00	0.00	0.00	14.33	41.89	0.10	0.10	
CALIB		7.00	0.70	0.00	0.00	0.00	23.24	92.06	5.57	0.62	
Fuel:	Stm	Unweighted (Simple Average) EUIs (kBtu/sf)									
		Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS		4.04	0.71	0.00	0.00	0.00	0.06	6.18	0.00	0.00	10.99
SAE		7.83	0.14	0.00	0.00	0.00	2.32	12.21	0.00	0.00	22.49
CALIB		19.85	0.37	0.00	0.00	0.00	4.11	29.73	0.00	0.00	54.06
Fuel:	Stm	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS		2.53	0.43	0.00	0.00	0.00	0.05	4.22	0.00	0.00	7.24
SAE		5.02	0.09	0.00	0.00	0.00	2.41	10.04	0.00	0.00	17.55
CALIB		13.12	0.21	0.00	0.00	0.00	3.90	24.01	0.00	0.00	41.23
Fuel:	Stm	Weighted Conditional EUIs (kBtu/sf)									
FEDS		8.63	31.47	0.00	0.00	0.00	0.35	18.84	0.00	0.00	
SAE		17.14	6.29	0.00	0.00	0.00	15.95	44.83	0.00	0.00	
CALIB		44.73	15.44	0.00	0.00	0.00	25.85	107.23	0.00	0.00	

Building Type: Lodging N = 305 , 2890.7 mill. sq. ft.

Fuel: Elec	Unweighted (Simple Average) EUIs (kBtu/sf)									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	2.89	9.24	1.79	15.84	1.14	1.47	3.39	4.68	0.00	40.44
SAE	6.32	18.05	1.67	12.77	0.89	1.15	6.79	3.65	0.00	51.29
CALIB	6.31	22.95	2.52	24.84	1.76	1.61	4.87	7.23	0.00	72.09
Fuel: Elec	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	2.71	7.71	1.69	14.37	1.14	1.85	2.24	4.68	0.00	36.39
SAE	6.10	14.81	1.44	11.48	0.81	1.42	4.11	3.33	0.00	43.51
CALIB	5.98	20.76	3.39	21.94	1.57	1.74	3.57	6.45	0.00	65.41
Fuel: Elec	Weighted Conditional EUIs (kBtu/sf)									
FEDS	5.16	9.65	1.85	14.37	1.14	8.94	16.31	4.68	0.00	
SAE	11.64	18.53	1.58	11.48	0.81	6.87	29.85	3.33	0.00	
CALIB	11.39	25.98	3.70	21.94	1.57	8.41	25.94	6.45	0.00	

Fuel: Gas	Unweighted (Simple Average) EUIs (kBtu/sf)									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	5.95	0.08	0.00	0.00	0.00	0.33	12.75	0.00	0.00	19.11
SAE	22.36	0.00	0.00	0.00	0.00	1.41	36.42	0.05	6.73	66.98
CALIB	25.21	0.01	0.00	0.00	0.00	2.11	41.11	0.68	4.74	73.85
Fuel: Gas	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	4.72	0.11	0.00	0.00	0.00	0.51	10.31	0.00	0.00	15.66
SAE	22.81	0.01	0.00	0.00	0.00	1.67	20.66	0.01	11.94	57.10
CALIB	23.11	0.01	0.00	0.00	0.00	2.65	33.09	0.21	7.55	66.63
Fuel: Gas	Weighted Conditional EUIs (kBtu/sf)									
FEDS	10.52	2.39	0.00	0.00	0.00	1.15	15.37	0.00	0.00	
SAE	50.80	0.48	0.00	0.00	0.00	3.74	30.82	0.42	89.18	
CALIB	51.48	0.48	0.00	0.00	0.00	5.93	49.37	15.02	56.40	

Fuel: Oil	Unweighted (Simple Average) EUIs (kBtu/sf)									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.14	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	1.81
SAE	2.99	0.00	0.00	0.00	0.00	0.00	1.40	0.00	11.70	16.09
CALIB	2.64	0.00	0.00	0.00	0.00	0.00	1.28	0.00	0.26	4.18
Fuel: Oil	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	1.41	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	2.03
SAE	3.98	0.00	0.00	0.00	0.00	0.00	1.26	0.00	18.28	23.52
CALIB	3.32	0.00	0.00	0.00	0.00	0.00	1.28	0.00	0.79	5.40
Fuel: Oil	Weighted Conditional EUIs (kBtu/sf)									
FEDS	14.98	0.50	0.00	0.00	0.00	0.00	15.72	0.00	0.00	
SAE	42.18	0.10	0.00	0.00	0.00	0.00	32.03	0.00	89.18	
CALIB	35.26	0.00	0.00	0.00	0.00	0.00	32.40	0.00	3.88	

Fuel: Stm	Unweighted (Simple Average) EUIs (kBtu/sf)									
	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	3.79	0.13	0.00	0.00	0.00	0.02	2.06	0.00	0.00	6.00
SAE	13.11	0.03	0.00	0.00	0.00	0.02	3.74	0.00	0.00	16.90
CALIB	23.41	0.05	0.00	0.00	0.00	0.04	4.75	0.00	0.00	28.25
Fuel: Stm	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	3.03	0.06	0.00	0.00	0.00	0.05	1.41	0.00	0.00	4.55
SAE	11.76	0.01	0.00	0.00	0.00	0.03	1.83	0.00	0.00	13.63
CALIB	20.32	0.02	0.00	0.00	0.00	0.05	2.26	0.00	0.00	22.66
Fuel: Stm	Weighted Conditional EUIs (kBtu/sf)									
FEDS	15.10	12.60	0.00	0.00	0.00	1.14	8.67	0.00	0.00	
SAE	58.59	2.52	0.00	0.00	0.00	0.65	11.27	0.00	0.00	
CALIB	101.25	5.03	0.00	0.00	0.00	1.07	13.90	0.00	0.00	

TABLE 7.3. (contd)

Building Type: Lrg Office N = 653 , 6766.0 mill. sq. ft.

Fuel: Elec	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	1.38	9.15	9.89	28.68	0.38	0.14	0.43	17.62	0.00	67.67
SAE	3.26	11.13	9.77	19.83	0.36	0.13	1.71	18.38	0.00	64.59
CALIB	3.23	11.83	10.75	22.05	0.42	0.16	1.88	21.04	0.00	71.36
Fuel: Elec — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	1.01	9.56	9.26	28.48	0.38	0.13	0.34	17.40	0.00	66.56
SAE	2.46	11.41	8.86	19.74	0.33	0.13	1.35	16.51	0.00	60.79
CALIB	2.53	10.91	9.08	20.40	0.36	0.15	1.44	17.99	0.00	62.86
Fuel: Elec — Weighted Conditional EUIs (kBtu/sf)										
FEDS	2.32	9.72	9.26	28.48	0.38	0.40	0.79	17.40	0.00	
SAE	5.69	11.60	8.86	19.74	0.33	0.39	3.12	16.51	0.00	
CALIB	5.84	11.08	9.08	20.40	0.36	0.47	3.34	17.99	0.00	

Fuel: Gas	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	2.42	0.26	0.00	0.00	0.00	0.12	0.53	0.00	0.00	3.33
SAE	9.92	0.25	0.00	0.00	0.00	1.17	2.99	0.46	0.48	15.28
CALIB	10.88	0.33	0.00	0.00	0.00	2.13	3.70	0.58	0.49	18.10
Fuel: Gas — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	3.58	0.14	0.00	0.00	0.00	0.12	0.66	0.00	0.00	4.50
SAE	12.82	0.22	0.00	0.00	0.00	0.98	3.76	0.50	0.23	18.50
CALIB	11.00	0.38	0.00	0.00	0.00	1.65	4.16	0.48	0.17	17.84
Fuel: Gas — Weighted Conditional EUIs (kBtu/sf)										
FEDS	7.04	10.27	0.00	0.00	0.00	0.44	1.69	0.00	0.00	
SAE	25.24	18.19	0.00	0.00	0.00	3.68	9.55	6.38	6.84	
CALIB	21.65	32.10	0.00	0.00	0.00	6.21	10.57	6.11	5.08	

Fuel: Oil	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	0.24	0.01	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.33
SAE	1.39	0.00	0.00	0.00	0.00	0.00	0.30	0.00	2.57	4.27
CALIB	1.01	0.01	0.00	0.00	0.00	0.00	0.43	0.00	0.45	1.91
Fuel: Oil — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	0.48	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.68
SAE	2.39	0.00	0.00	0.00	0.00	0.00	0.78	0.00	1.91	5.09
CALIB	1.65	0.00	0.00	0.00	0.00	0.00	0.69	0.00	0.42	2.76
Fuel: Oil — Weighted Conditional EUIs (kBtu/sf)										
FEDS	3.91	7.63	0.00	0.00	0.00	0.44	3.53	0.00	0.00	
SAE	19.60	1.53	0.00	0.00	0.00	0.81	13.96	0.10	5.11	
CALIB	13.51	4.08	0.00	0.00	0.00	0.65	12.34	0.21	1.12	

Fuel: Stm	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	1.21	0.77	0.00	0.00	0.00	0.01	0.48	0.00	0.00	2.47
SAE	4.04	0.15	0.00	0.00	0.00	0.14	1.90	0.00	0.05	6.28
CALIB	7.41	0.32	0.00	0.00	0.00	0.18	3.32	0.00	0.05	11.29
Fuel: Stm — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	1.91	0.49	0.00	0.00	0.00	0.01	0.58	0.00	0.00	3.00
SAE	5.21	0.10	0.00	0.00	0.00	0.24	2.36	0.00	0.02	7.93
CALIB	7.45	0.20	0.00	0.00	0.00	0.24	2.69	0.00	0.02	10.58
Fuel: Stm — Weighted Conditional EUIs (kBtu/sf)										
FEDS	8.84	23.00	0.00	0.00	0.00	0.25	3.40	0.00	0.00	
SAE	24.05	4.60	0.00	0.00	0.00	5.58	13.90	0.00	31.70	
CALIB	34.38	9.11	0.00	0.00	0.00	5.42	15.80	0.00	30.62	

TABLE 7.3. (contd)

Building Type: Sml Office N = 864 , 6028.9 mill. sq. ft.

Fuel: Elec Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	2.39	13.83	3.12	25.65	0.38	0.00	0.39	16.66	0.00	62.41
SAE	2.58	10.23	2.55	15.14	0.22	0.00	4.45	10.23	0.00	45.40
CALIB	2.69	12.19	3.22	18.63	0.29	0.00	5.16	13.06	0.00	55.24

Fuel: Elec Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.81	12.87	2.80	24.25	0.38	0.01	0.38	16.67	0.00	59.16
SAE	2.31	9.22	2.20	13.36	0.20	0.00	4.16	9.20	0.00	40.65
CALIB	2.12	11.18	2.79	16.78	0.25	0.01	5.10	11.63	0.00	49.87

Fuel: Elec Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	4.08	13.60	3.02	24.25	0.38	0.44	0.75	16.67	0.00
SAE	5.19	9.74	2.37	13.36	0.20	0.19	8.30	9.20	0.00
CALIB	4.78	11.81	3.01	16.78	0.25	0.52	10.18	11.63	0.00

Fuel: Gas Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	10.50	0.44	0.00	0.00	0.00	0.01	0.67	0.00	0.00	11.63
SAE	20.83	0.07	0.00	0.00	0.00	0.43	3.97	0.94	1.56	27.81
CALIB	39.86	0.07	0.00	0.00	0.00	0.44	7.59	1.01	1.62	50.59

Fuel: Gas Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	9.10	0.45	0.00	0.00	0.00	0.01	0.68	0.00	0.00	10.24
SAE	21.34	0.03	0.00	0.00	0.00	0.49	3.59	0.88	5.92	32.27
CALIB	37.10	0.02	0.00	0.00	0.00	0.61	5.58	0.80	5.97	50.09

Fuel: Gas Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	16.15	7.93	0.00	0.00	0.00	0.41	1.66	0.00	0.00
SAE	37.89	3.43	1.00	1.00	1.00	17.71	8.75	8.61	320.60
CALIB	65.86	2.62	0.99	0.99	0.99	21.72	13.60	7.81	323.43

Fuel: Oil Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.54	0.01	0.00	0.00	0.00	0.00	0.61	0.00	0.00	2.16
SAE	2.92	0.00	0.00	0.00	0.00	0.00	2.55	0.00	0.00	5.48
CALIB	3.11	0.00	0.00	0.00	0.00	0.00	1.31	0.00	0.06	4.48

Fuel: Oil Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.78	0.04	0.00	0.00	0.00	0.00	0.71	0.00	0.00	2.53
SAE	3.48	0.01	0.00	0.00	0.00	0.00	2.78	0.00	0.00	6.27
CALIB	3.56	0.01	0.00	0.00	0.00	0.00	1.28	0.00	0.03	4.88

Fuel: Oil Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	19.51	10.37	0.00	0.00	0.00	0.00	17.89	0.00	0.00
SAE	38.15	2.07	0.00	0.00	0.00	0.00	70.24	0.00	0.10
CALIB	38.98	1.34	0.00	0.00	0.00	0.00	32.47	0.00	1.13

Fuel: Stm Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	0.92	0.05	0.00	0.00	0.00	0.00	0.26	0.00	0.00	1.23
SAE	2.43	0.01	0.00	0.00	0.00	0.00	1.20	0.00	0.00	3.64
CALIB	19.14	0.02	0.00	0.00	0.00	0.00	4.11	0.00	0.00	23.28

Fuel: Stm Weighted (by Floorspace) Average EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	0.50	0.02	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.71
SAE	1.46	0.00	0.00	0.00	0.00	0.00	0.86	0.00	0.00	2.33
CALIB	3.32	0.00	0.00	0.00	0.00	0.00	3.15	0.00	0.00	6.47

Fuel: Stm Weighted Conditional EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN
FEDS	11.44	27.27	0.00	0.00	0.00	0.00	8.65	0.00	0.00
SAE	33.24	5.45	0.00	0.00	0.00	0.00	39.05	0.00	0.00
CALIB	75.38	5.02	0.00	0.00	0.00	0.00	142.83	0.00	0.00

TABLE 7.3. (contd)

Building Type: Retail N =1230 , 12401.5 mill. sq. ft.

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Fuel: Elec	Unweighted (Simple Average) EUIs (kBtu/sf)									
FEDS	3.27	7.79	2.47	20.40	0.76	0.06	0.32	3.98	0.00	39.04
SAE	2.10	4.07	2.62	20.32	1.39	0.27	4.59	5.00	0.00	40.36
CALIB	2.03	4.59	2.87	23.67	1.45	0.28	5.26	5.62	0.00	45.77
Fuel: Elec	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	2.20	7.96	2.19	20.85	0.77	0.09	0.30	4.07	0.00	38.43
SAE	1.88	4.13	2.27	21.49	1.77	0.64	4.21	5.46	0.00	41.84
CALIB	1.57	3.42	2.10	18.68	1.21	0.30	4.08	4.49	0.00	35.84
Fuel: Elec	Weighted Conditional EUIs (kBtu/sf)									
FEDS	5.33	9.26	2.37	20.86	0.77	0.44	0.68	4.07	0.00	
SAE	4.55	4.80	2.45	21.51	1.77	3.30	9.49	5.46	0.00	
CALIB	3.79	3.98	2.27	18.69	1.21	1.57	9.19	4.49	0.00	

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Fuel: Gas	Unweighted (Simple Average) EUIs (kBtu/sf)									
FEDS	24.62	0.18	0.00	0.00	0.00	0.06	0.54	0.00	0.00	25.40
SAE	23.55	0.05	0.00	0.00	0.00	0.58	8.67	0.74	0.34	33.94
CALIB	27.41	0.10	0.00	0.00	0.00	0.83	12.04	1.10	0.43	41.92
Fuel: Gas	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	16.41	0.16	0.00	0.00	0.00	0.10	0.68	0.00	0.00	17.36
SAE	20.00	0.01	0.00	0.00	0.00	1.28	8.90	0.61	0.55	31.35
CALIB	19.33	0.04	0.00	0.00	0.00	1.18	9.14	0.55	0.45	30.69
Fuel: Gas	Weighted Conditional EUIs (kBtu/sf)									
FEDS	24.52	6.80	0.00	0.00	0.00	0.44	1.50	0.00	0.00	
SAE	29.89	1.54	1.00	1.00	1.00	5.69	19.68	5.00	13.72	
CALIB	28.89	5.00	0.99	0.99	0.99	5.22	20.21	4.53	11.30	

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Fuel: Oil	Unweighted (Simple Average) EUIs (kBtu/sf)									
FEDS	5.19	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	5.80
SAE	4.40	0.00	0.00	0.00	0.00	0.00	4.09	0.00	0.16	8.65
CALIB	5.38	0.00	0.00	0.00	0.00	0.00	1.50	0.02	0.38	7.27
Fuel: Oil	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	3.37	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	3.83
SAE	3.26	0.00	0.00	0.00	0.00	0.00	2.72	0.00	0.11	6.10
CALIB	2.93	0.00	0.00	0.00	0.00	0.00	1.21	0.00	0.27	4.42
Fuel: Oil	Weighted Conditional EUIs (kBtu/sf)									
FEDS	37.10	0.00	0.00	0.00	0.00	0.00	19.87	0.00	0.00	
SAE	35.89	0.00	0.00	0.00	0.00	0.00	118.48	0.10	1.34	
CALIB	32.22	0.00	0.00	0.00	0.00	0.00	52.64	19.02	3.37	

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Fuel: Stm	Unweighted (Simple Average) EUIs (kBtu/sf)									
FEDS	0.57	0.04	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.74
SAE	0.71	0.01	0.00	0.00	0.00	0.00	0.94	0.00	0.00	1.66
CALIB	1.05	0.01	0.00	0.00	0.00	0.00	0.54	0.00	0.00	1.61
Fuel: Stm	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	0.31	0.03	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.36
SAE	0.40	0.01	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.58
CALIB	0.78	0.01	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.99
Fuel: Stm	Weighted Conditional EUIs (kBtu/sf)									
FEDS	26.03	36.02	0.00	0.00	0.00	0.00	8.11	0.00	0.00	
SAE	33.65	7.20	0.00	0.00	0.00	0.00	61.61	0.00	0.00	
CALIB	65.86	12.86	0.00	0.00	0.00	0.00	70.01	0.00	0.00	

Building Type: Warehouse N =1025 , 11484.3 mill. sq. ft.

Fuel: Elec	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	1.04	1.35	0.41	8.90	0.42	0.00	0.05	5.40	0.00	17.56
SAE	1.33	1.89	0.43	9.27	1.12	0.00	1.38	5.66	0.53	21.62
CALIB	0.97	1.71	0.44	9.48	1.26	0.00	1.34	8.64	0.47	24.32
Fuel: Elec — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	0.99	1.36	0.33	8.68	0.43	0.00	0.05	5.62	0.00	17.46
SAE	1.26	1.89	0.33	8.92	1.08	0.00	1.37	5.31	0.67	20.83
CALIB	0.72	1.53	0.29	9.50	1.19	0.00	1.23	7.12	0.48	22.06
Fuel: Elec — Weighted Conditional EUIs (kBtu/sf)										
FEDS	2.64	2.01	0.45	8.92	0.45	0.01	0.12	5.77	0.00	
SAE	3.36	2.79	0.46	9.16	1.11	0.01	3.49	5.46	6.56	
CALIB	1.92	2.26	0.40	9.76	1.23	0.02	3.12	7.31	4.69	

Fuel: Gas	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	6.26	0.02	0.00	0.00	0.00	0.00	0.06	0.00	0.00	6.34
SAE	15.05	0.05	0.00	0.00	0.00	0.10	7.61	0.17	1.37	24.35
CALIB	16.68	0.11	0.00	0.00	0.00	0.20	1.57	0.26	1.59	20.41
Fuel: Gas — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	5.23	0.01	0.00	0.00	0.00	0.00	0.06	0.00	0.00	5.31
SAE	12.92	0.01	0.00	0.00	0.00	0.14	4.73	0.19	1.50	19.49
CALIB	13.62	0.03	0.00	0.00	0.00	0.22	1.31	0.20	1.67	17.05
Fuel: Gas — Weighted Conditional EUIs (kBtu/sf)										
FEDS	10.17	1.12	0.00	0.00	0.00	0.01	0.21	0.00	0.00	
SAE	25.11	1.57	0.00	0.00	0.00	14.97	15.38	1.67	43.36	
CALIB	26.48	3.66	0.00	0.00	0.00	23.04	4.25	1.79	48.37	

Fuel: Oil	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	1.23	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	1.33
SAE	2.04	0.00	0.00	0.00	0.00	0.00	1.10	0.00	0.20	3.34
CALIB	2.20	0.00	0.00	0.00	0.00	0.00	0.27	0.03	0.23	2.73
Fuel: Oil — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	0.57	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.63
SAE	1.26	0.00	0.00	0.00	0.00	0.00	0.66	0.00	0.19	2.11
CALIB	1.54	0.00	0.00	0.00	0.00	0.00	0.35	0.02	0.17	2.08
Fuel: Oil — Weighted Conditional EUIs (kBtu/sf)										
FEDS	9.50	0.00	0.00	0.00	0.00	0.00	4.40	0.00	0.00	
SAE	21.16	0.00	0.00	0.00	0.00	0.00	42.90	0.10	6.75	
CALIB	25.82	0.00	0.00	0.00	0.00	0.00	22.55	4.12	6.19	

Fuel: Stm	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
Unweighted (Simple Average) EUIs (kBtu/sf)										
FEDS	0.05	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.08
SAE	0.18	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.02	0.33
CALIB	0.96	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.07	4.03
Fuel: Stm — Weighted (by Floorspace) Average EUIs (kBtu/sf)										
FEDS	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.05
SAE	0.31	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.06	0.46
CALIB	2.33	0.00	0.00	0.00	0.00	0.00	2.12	0.00	0.22	4.66
Fuel: Stm — Weighted Conditional EUIs (kBtu/sf)										
FEDS	1.49	0.00	0.00	0.00	0.00	0.00	1.59	0.00	0.00	
SAE	13.42	0.00	0.00	0.00	0.00	0.00	8.94	0.00	20.96	
CALIB	99.34	0.00	0.00	0.00	0.00	0.00	237.07	0.00	72.39	

TABLE 7.3. (contd)

Building Type: Oth Bldg N = 725 , 7998.0 mill. sq. ft.

Fuel: Elec — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	2.04	3.84	0.85	15.45	0.38	0.01	0.13	5.80	0.00	28.48
SAE	1.25	1.84	0.73	10.60	0.20	0.00	2.27	3.69	0.00	20.59
CALIB	1.41	2.28	1.01	16.54	0.38	0.01	2.80	5.07	0.00	29.50
Fuel: Elec	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	1.22	4.13	0.69	17.92	0.39	0.01	0.12	5.90	0.00	30.37
SAE	0.64	1.93	0.56	10.29	0.18	0.00	2.31	3.24	0.00	19.14
CALIB	0.79	2.30	0.69	13.52	0.28	0.00	2.56	3.76	0.00	23.90
Fuel: Elec	Weighted Conditional EUIs (kBtu/sf)									
FEDS	4.63	7.14	1.04	20.51	0.45	0.18	0.38	6.75	0.00	
SAE	2.43	3.33	0.84	11.78	0.21	0.12	7.48	3.71	0.00	
CALIB	2.99	3.98	1.03	15.48	0.32	0.10	8.29	4.30	0.00	

Fuel: Gas — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	7.12	0.15	0.00	0.00	0.00	0.01	0.27	0.00	0.00	7.55
SAE	21.75	0.05	0.00	0.00	0.00	0.20	4.40	4.88	0.18	31.46
CALIB	19.30	0.07	0.00	0.00	0.00	0.52	7.86	2.71	0.54	30.99
Fuel: Gas	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	4.79	0.15	0.00	0.00	0.00	0.02	0.27	0.00	0.00	5.23
SAE	21.02	0.03	0.00	0.00	0.00	0.20	3.60	5.29	0.24	30.38
CALIB	15.71	0.04	0.00	0.00	0.00	0.32	4.71	0.98	2.18	23.94
Fuel: Gas	Weighted Conditional EUIs (kBtu/sf)									
FEDS	12.59	2.13	0.00	0.00	0.00	0.24	0.91	0.00	0.00	
SAE	55.32	1.01	1.00	1.00	1.00	2.03	12.09	87.72	3.22	
CALIB	41.34	1.37	0.01	0.01	0.01	3.27	15.84	16.23	29.57	

Fuel: Oil — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	1.32	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	1.62
SAE	2.16	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.70	3.09
CALIB	1.75	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.16	2.12
Fuel: Oil	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	1.11	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.00	1.27
SAE	2.59	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.60	3.34
CALIB	1.81	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.12	2.04
Fuel: Oil	Weighted Conditional EUIs (kBtu/sf)									
FEDS	15.65	0.54	0.00	0.00	0.00	0.00	16.98	0.00	0.00	
SAE	36.50	0.11	0.00	0.00	0.00	0.00	15.26	0.00	6.61	
CALIB	25.48	0.07	0.00	0.00	0.00	0.00	12.14	0.00	1.31	

Fuel: Stm — Unweighted (Simple Average) EUIs (kBtu/sf)

	Heat	Cool	Vent	Light	Refrg	Cook	HotWt	Misc	M/CGN	Total
FEDS	0.89	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00	1.24
SAE	3.50	0.00	0.00	0.00	0.00	0.02	0.78	0.00	0.00	4.31
CALIB	6.96	0.00	0.00	0.00	0.00	0.03	1.80	0.00	0.00	8.79
Fuel: Stm	Weighted (by Floorspace) Average EUIs (kBtu/sf)									
FEDS	0.48	0.00	0.00	0.00	0.00	0.01	0.21	0.00	0.00	0.69
SAE	4.11	0.00	0.00	0.00	0.00	0.06	1.00	0.00	0.00	5.17
CALIB	5.69	0.00	0.00	0.00	0.00	0.10	1.56	0.00	0.00	7.35
Fuel: Stm	Weighted Conditional EUIs (kBtu/sf)									
FEDS	3.74	0.75	0.00	0.00	0.00	0.42	3.83	0.00	0.00	
SAE	32.13	0.15	0.00	0.00	0.00	4.24	18.31	0.00	0.01	
CALIB	44.53	0.37	0.00	0.00	0.00	6.64	28.45	0.00	0.01	

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	8.30	12.2%	3.75	3.18	26.4	6.0%
Education	8.47	12.5%	5.71	4.66	39.5	9.0%
Food Sales	0.76	1.1%	13.32	12.76	9.7	20.2%
Food Serv.	1.49	2.2%	35.99	34.42	51.3	11.7%
Hospital	1.29	1.9%	20.94	18.76	24.2	5.5%
Lodging	2.89	4.3%	25.99	20.77	60.0	13.7%
Lrg. Office	6.77	10.0%	11.03	10.85	73.5	16.8%
Sml. Office	6.03	8.9%	11.75	11.12	67.0	15.3%
Retail/Serv	12.40	18.3%	3.90	3.35	41.5	9.5%
Warehouse	11.48	16.9%	2.69	1.82	20.9	4.8%
Misc. Bldgs	8.00	11.8%	4.93	2.92	23.4	5.3%
All Buildings	67.88	100.0%	7.93	6.44	437.3	100.0%

TABLE 7.5. Natural Gas Intensities by Building Type

Bldg. Type	Ft^2 (bil.)	%	1992 Conditional Gas Heat EUI (KBtu/Sq.Ft)	1989 Conditional Gas Heat EUI (KBtu/Sq.Ft)[a]
Assembly	8.30	12.2%	23.8	30.4
Education	8.47	12.5%	38.5	42.4
Food Sales	0.76	1.1%	30.1	47.2
Food Serv.	1.49	2.2%	37.1	137.1
Hospital	1.29	1.9%	47.9	122.4
Lodging	2.89	4.3%	50.9	86.4
Lrg. Office	6.77	10.0%	21.6	49.4
Sml. Office	6.03	8.9%	65.9	49.4
Retail/Serv	12.40	18.3%	28.8	40.7
Warehouse	11.48	16.9%	26.2	30.9
Misc. Bldgs	8.00	11.8%	41.5	NA
All Buildings	67.88	100.0%	34.3	48.3

(a) Figures derived from EIA (1995b), Table 3.30.

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 selected electricity end uses. The second is to further modify the input assumptions in FEDS to improve the 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 and the preceding study represents one of the most ambitious attempts to use a building engineering model, along with monthly billing data, as a means of estimating end-use consumption for a national sample of commercial buildings. The nonlinear SAE models developed in the current study help explain about twice the cross-sectional variance of annual EUIs as compared with 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 current 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 because of 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 categories of end uses.

On the HVAC side, additional work is still required to validate and refine the estimates of electric space heating. While the nonlinear annual cross-section approach increases the estimates of electric space heating over the 1993 study using the 1989 CBECS, the intensity estimates are still substantially lower than those for natural gas. Not all of this difference can be attributed simply to differences in weather and vintages of the buildings. A resolution may involve obtaining more detailed knowledge of the type of HVAC systems installed and whether these system effects are biased in favor of higher efficiencies with electric space heating.

Further analysis is also needed to examine the estimates of electric water heating. The 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.

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 method for splitting the non-heating uses can be further improved.

One way to contribute to more accurate EUIs is to develop a means of rationalizing the monthly patterns of gas consumption with the reported end uses. Both the 1989 and the 1992 CBECS contain a considerable number of buildings that report no heating use of gas, but whose gas bills display a seasonal pattern that strongly suggests gas is used for heating. On the other hand, a large number of buildings report only heating consumption, but show significant consumption throughout the summer.

Two other end uses appear to manifest a similar problem. As mentioned in Chapter 6, only about a quarter of the buildings (with billing data) which reported gas use for cooling showed any significant increase in summer gas consumption. The data concerning cogeneration also seem to be inconsistent with respect to actual consumption. For many buildings, a positive response to the cogeneration question from the CBECS appears to 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 noted 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 by pooling the results of the 1992 survey with those from the 1986 and 1989 surveys.

8.1.3 Improved Treatment of High-Intensity Cases

An unresolved problem in analyzing the CBECS--in both the current study and well as the 1993 effort--is how to treat high intensity cases. As in previous surveys, both the 1989 and 1992 CBECS contain a number of buildings that display total EUIs that are 20, to as many as 50, times the mean intensity within a single building type.

This study and many other analyses of the CBECS require 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 criterion for what represents a high-intensity case was generally based upon a statistical rule that omitted cases that fell in the top 1% of an assumed normal distribution.

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 both the current and the previous study, we assumed that any consumption over the FEDS-defined limit fell into the miscellaneous equipment category.

Future work should be devoted to exploring available audit data sets and perhaps to 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 from energy-intensive equipment not normally found in a typical building. 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.

In spite of the improvements that were introduced in FEDS between the 1993 study and this study, the current approach still relies heavily upon a SAE methodology. Predictions of energy consumption for end uses or combinations of end uses are used as independent variables in a regression model to explain total consumption. The estimated coefficients of the nonlinear SAE model can be combined to provide 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 building-specific engineering calibration and requires embedding the building simulation code 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 attempt to offset a variety of systematic errors in the engineering model and input assumptions, primarily involving errors associated with the treatment of envelope characteristics, system type, and plant efficiency.

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 of the existing problems in using only office and retail prototypes to represent the commercial building stock. This tool could also employ the 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

(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.

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 area involves testing various relationships between equipment and employee density. In the nonlinear SAE models for electricity, this correlation was one of the strongest relationships present; moreover, it was observed in all but a few building types. A third area would attempt to improve the influence of building schedule on energy consumption; the SAE results also 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 such a way 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 noted above, 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.

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APPENDIX A

OVERVIEW OF REVISIONS IN FEDS ENGINEERING MODEL TO ESTIMATE END-USE CONSUMPTION FOR THE 1992 CBECS

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OVERVIEW OF REVISIONS IN FEDS ENGINEERING MODEL TO ESTIMATE END-USE CONSUMPTION FOR THE 1992 CBECS

This appendix briefly discusses how the engineering basis for PNNL's estimation of end-use consumption in the 1992 CBECS differs from that employed for the 1989 CBECS. The engineering framework is revised as a result of two developments: 1) a significantly improved building simulation model has become available, and 2) additional building-specific information was collected in the 1992 CBECS. A more complete description of the FEDS model and how it employs the CBECS variables is provided in Appendix B of this report and in Appendixes A and C of (Belzer et al. 1993).

A.1 SUMMARY OF FEDS MODEL CHANGES

The development of end-use intensity estimates for the 1989 CBECS was based on Release 1 of PNNL's Facility Energy Decision Screening Model (FEDS). Software for Release 1 was made publicly available in October 1992. This version of the model was used during the spring of 1993 to provide initial estimates of energy consumption for eight end uses for each of the 5,876 buildings in the 1989 CBECS. The estimates were subsequently adjusted to better match the available monthly billing histories via statistical analysis.

Many changes have been made to the FEDS system during the past three years. These changes were collected into Releases 2 and 3 of the model, which were first issued in February 1994 and May 1995, respectively. The major changes fall in the areas of HVAC modeling, service hot water modeling, and building use and operations. More detailed discussion of the changes for HVAC modeling is contained in Section A.2. The key changes from Release 1 to Release 2 are summarized in Sections A.1.1 through A.1.4 below.

A.1.1 HVAC Modeling

The original FEDS HVAC model was fairly simple. Heating and cooling loads were calculated with the assumption that both infiltration and outdoor ventilation air were introduced to the building simultaneously. The latent heat (the energy required to dehumidify warm, moist air during cooling) was treated as a parasitic cooling load. The ventilation energy was calculated after the heating and cooling load calculations; the energy estimate for ventilation was based on single standard assumptions about the entering air conditions and the fan efficiency.

Release 2 of the FEDS model was completely revamped. The ventilation energy and latent heat calculations have been integrated into the heating and cooling modeling. The effect of both the temperature and the humidity state of the air on the performance of the heating and cooling coils was modeled. When outside air is used for ventilation (i.e., the building is pressurized), it is assumed that infiltration does not occur when the fan is operating.

FEDS now models three different kinds of systems: 1) "linked" heating and/or cooling systems that use fans as the distribution devices (e.g., fan coil units, ducted air handlers, or packaged units); 2) "unlinked" heating (i.e., radiators and electric baseboard units); and 3) evaporative coolers. Distribution system characteristics (from the 1992 CBECS) are now used to help infer fan capacities and efficiencies.

A.1.2 Service Hot Water (SHW) Modeling

SHW system defaults and sizing were significantly altered in Release 2 of FEDS. The service hot water consumption model in the initial version of FEDS was not very responsive to occupant density and schedule. Occupant density was accounted for in the sizing calculation, but it was assumed that the consumption was independent of the number of hours that a building was occupied [see table C.1 on page C.17, Belzer et al. (1993)]. The new version of the service hot water model ties hot water consumption directly to both the number of occupants and the occupancy schedule for the building, rather than to an average load shape.

A.1.3 Building Use and Operations

Beginning with Release 2, FEDS can now model two distinct use areas within a building (for instance, a hotel with a food service area). The separate areas can have different schedules, occupancy, lighting densities, equipment densities, and utilization factors. This feature allows FEDS to model multiple use buildings, as well as buildings with significant vacant portions. Also, FEDS will now model seasonal occupancy on a monthly basis (e.g., shutting a school building down during the summer). This functionality, however, was not used in the simulations of buildings in the 1992 CBECS.

In addition to the new functionality of the engineering model, new building types (with associated inferences) were added. For example, what FEDS treated as health care can now be broken into hospitals and clinics, with appropriate inferences for each of these very different uses. The CBECS-to-FEDS building type mapping can be modified to take advantage of this more detailed breakdown of building types.

A.1.4 Key Changes in Release 3 of FEDS

Release 3 of FEDS was issued in May 1995 and was used to conduct the final simulations for the 1992 CBECS. Of four major enhancements to the model, only the first one listed below had any impact on the simulation results with the CBECS:

- Outside air temperature (OAT) correction curves for cooling and heat pump equipment have been revised to more accurately model temperature affect on COP.

- Residual oil and purchased chilled water have been added as fuel types.

- The following distributed service hot water system parameters are included in baseline consumption and optimization calculations:

  - electronic pilot lights
  - bottom boards
  - heat traps
  - pipes insulated near tank
  - external insulation wraps.

- Linked building set functionality has replaced dual-use separate HVAC to model multiple heating and cooling technologies as well as odd-shaped buildings. (Separate HVAC systems may no longer be modeled together within one building--they must be split into 2 separate buildings and then linked together.)

Much of the difference between Release 2 and Release 3 involved an improved user environment for the model. The changes under this category have no bearing on the simulation work conducted with the CBECS. Briefly, the major changes to the user environment in Release 3 are

- The functionality of the old user interfaces was integrated into one complete Windows-based user-friendly interface.

- Running completely under Windows, Release 3.0 does not have the memory constraints that prior versions encountered under DOS.

- Various other improvements to increase usability are

  - create case - enables creation of cases from within the user interface

  - copy case - allows for copying of case files from within the FEDS UI

  - on-line help available for all minimum set inputs

  - improved range checking on inputs including warnings for values that are acceptable but unlikely or unreasonable

  - user-selectable output options.

A.2 DETAILED DESCRIPTION OF FEDS HVAC REVISIONS

The basis of the FEDS heating and cooling load calculation is a lumped capacitance electric circuit analog of the heat flows in a building [see Figure C.2 and description, page C.12, Belzer et al. (1993).] Solution of this circuit leads to first order differential equations that can be arranged to solve for the either the temperatures or the heat flows at different points in the "circuit." These equations are solved for successive time steps in order to model the response of the building mass to transient heat gains and losses.

In Release 1 of FEDS (used in the analysis of the 1989 CBECS data), it was implicitly assumed that the heating and cooling loads due to the internal gains and transmission losses through the building envelope, as calculated using the lumped capacitance model, were equivalent to the load seen at the heating or cooling coil. Humidity was treated as a parasitic load on the cooling coil, added in after the sensible load was calculated. The heat gains or losses due to air infiltration and outdoor air ventilation were assumed to occur constantly throughout the whole time step. The ventilation consumption was calculated after the heating and cooling loads were determined for an hour and were based on the fraction of the hour heating and/or cooling was required.

The revised version of the heating and cooling model encompasses a more refined approach to the modeling of heating, cooling and ventilation consumption:

1. The actual heating and cooling loads, and especially the ventilation loads, are highly dependent upon the type of distribution system used. Both the ventilation and the heating loads are very different for an electric baseboard system with separate ventilation--(where the operation of the heating coils and the ventilation fan are independent), than for, say, an electric furnace--(where the fan and the heating coil operation are linked together). By accounting for these differences in distribution systems, the model is also able to account for the fact that fan efficiencies vary greatly depending on the fan size and the system type.

2. By linking the fan operation time to the coil operation time (when appropriate for the distribution system type), the contribution of air infiltration to the heating and cooling loads is more accurately modeled. Infiltration does not occur when a building is pressurized, i.e., when the fan is supplying outdoor ventilation air to the space. So, rather than assuming that infiltration occurs throughout a time step, it is now modeled as occurring only during that fraction of the time step when the fan is not in operation.

3. The effect of humidity on cooling coil operation is now incorporated into the calculation. The actual dew point of the air entering the coil is estimated, and the latent cooling load is calculated simultaneously with the sensible cooling load.

4. Finally, evaporative coolers were brought out as a special case. Again, the humidity of the supply and return air are intrinsic to the evaporative cooler calculations. It is also recognized that the energy consumption of evaporative coolers is essentially all fan energy, which is reflected in the way the consumption is reported--as ventilation rather than cooling.

A.3 USE OF NEW INFORMATION AVAILABLE IN THE 1992 CBECS

The following engineering model modifications reflect both the new variables available in the 1992 CBECS and new ways of using the existing variables in order to take advantage of the new FEDS functionality.

A.3.1 Building Characteristics and Geometry

Building shape, length and width (Questions F3-F4 in the 1992 CBECS): FEDS still models buildings as rectangular (square being a special case of rectangular). Data from these questions are used to determine the aspect ratio for a rectangle that would give approximately the same surface to volume ratio for the building. The building shape also influences the default HVAC zone configuration that is used.

Percent glass on exterior (Question F6): The fraction of wall area that is window is taken directly from this question, rather than inferred from the 1986 NBECS data.

A.3.2 HVAC Distribution Systems

Distribution system information (Questions D6, D11): These data are used to select both ventilation system defaults and appropriate HVAC load modeling algorithms. The mapping of distribution systems with central plant information is an substantial improvement over the 1989 and earlier CBECS.

A.3.3 Service Hot Water

Service hot water system descriptions (Question D19A-B): This information can be used to set SHW system and equipment type. Release 2 of FEDS can model either central or distributed water heating systems. Previously, default assumptions based on the fuel type and the building type were used.

A.3.4 Building Occupancy

Seating/bed capacities (Questions B5L-R): These capacities were used to estimate the number of non-employee occupants (i.e., customers or clients) using the building. This information was used modify the HVAC and hot water default estimates from FEDS.

A.4 MISCELLANEOUS ADJUSTMENTS

The following notes should clarify some of the variable definitions that were used in the SAE process:

- For missing employment, set employment density at 0.1 employee/sq. ft.
- High heat and cool dummy variable = 1, only if number of hours > 20. This variable is actually pertains to extra hours used by the heating and cooling equipment (HCHRS5).
- When building reports natural gas used for cooling and <u>not</u> part of billing sample, adjust FEDS cooling by 0.2
- When building reports oil or steam used for cooling, adjust FEDS cooling by factor of 0.2

Some adjustments were made to the FEDS outputs prior to the estimation of use of the SAE equations. These judgmental adjustments were based upon examination of the end-use shares, fragmentary metered data, and the preliminary estimates of natural gas end-use intensities. The FEDS intensities shown in Table 7.3 incorporate these adjustments.

Restaurant

Adjust FEDS electric cooking by factor of 3.0
Adjust FEDS electric miscellaneous by factor of 0.5

Hospital

Adjust FEDS electric cooking by factor of 10.0
Adjust FEDS electric hot water by factor of 2.0

For gas, adjust SAE computed output for cooking by 0.5
The absolute reduction in cooking is then added to miscellaneous

Lodging

Adjust FEDS electric cooking by factor of 10.0

Large Office

Adjust FEDS ventilation by factor of 2.0

A.5 COMPARISON OF FEDS RESULTS FOR 1989 AND 1992 CBECS

Changes in the final end-use intensities between the 1993 study and the current study reflect both changes in the FEDS engineering model and the SAE procedures described in Chapters 5 and 6. Moreover, changes in the way in which the heating and cooling information was collected between the 1989 and 1992 CBECS also contributed to the final estimates of the EUIs.

A full rationalization of these changes is beyond the scope of this study. However, we were able to run the 1989 CBECS with a version of FEDS Release 3 which helps to isolate some of the changes that stem from the engineering model only. Thus, we can roughly compare the simulations with the 1989 data with two versions of FEDS and compare the 1989 and 1992 CBECS with the same version of the model.

Table A.1 present electricity EUIs for eight end uses for four separate cases. Table A.2 shows the EUIs for gas for four end uses. The first case is the set of EUIs produced by FEDS Release 1 with the 1989 CBECS. The second line of each panel shows the results of the revised FEDS model (Release 3) with the same data.

As was noted in Chapter 7, the changes in the FEDS HVAC method (see Section A.1.1 above) had the overall effect of reducing the heating load, increasing the cooling load, and reducing ventilation demands. Across all buildings, lighting increased slightly, as well as electric cooking. The

TABLE A.1. Comparison of FEDS Versions on 1988 and 1992 CBECS: Average Electricity EUI

(kBtu/Square Foot)

All Buildings Stock	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	2.23	5.56	5.47	19.25	4.25	0.22	0.46	2.32	39.76
1989, FEDS-3, Solar Frac = 1.0	1.92	8.16	1.27	20.48	2.74	0.18	0.61	7.73	43.09
1989, FEDS-3, Solar Frac = 0.75	2.06	7.06	1.15	20.48	2.74	0.18	0.61	7.73	42.01
1992, FEDS-3, Solar Frac = 0.75	1.72	7.28	2.48	18.74	2.60	1.12	0.58	7.09	41.61
Assembly	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	3.40	4.09	5.02	10.39	1.61	0.03	0.22	0.60	25.36
1989, FEDS-3, Solar Frac = 1.0	2.44	7.83	1.37	12.71	1.00	0.24	0.51	2.73	28.83
1989, FEDS-3, Solar Frac = 0.75	2.63	6.44	1.22	12.71	1.00	0.24	0.51	2.73	27.48
1992, FEDS-3, Solar Frac = 0.75	2.61	5.60	1.54	10.65	1.03	0.44	0.83	3.11	25.81
Education	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	1.54	3.89	5.16	19.70	1.62	0.03	0.08	0.63	32.65
1989, FEDS-3, Solar Frac = 1.0	1.44	6.92	0.75	19.96	1.01	0.27	0.69	2.73	33.77
1989, FEDS-3, Solar Frac = 0.75	1.51	5.94	0.66	19.96	1.01	0.27	0.69	2.73	32.77
1992, FEDS-3, Solar Frac = 0.75	1.57	8.24	1.39	19.06	1.00	0.21	0.93	2.56	34.96
Food Sales	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	0.80	23.46	9.53	32.19	165.22	4.08	0.64	11.05	246.97
1989, FEDS-3, Solar Frac = 1.0	2.62	22.56	3.12	36.60	113.50	0.75	3.05	7.51	189.71
1989, FEDS-3, Solar Frac = 0.75	2.86	20.00	2.79	36.60	113.50	0.75	3.05	7.51	187.06
1992, FEDS-3, Solar Frac = 0.75	2.92	20.59	5.51	37.50	113.91	0.68	2.37	7.60	191.08
Food Services	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	2.96	23.94	14.36	36.50	19.90	4.61	6.09	20.45	128.81
1989, FEDS-3, Solar Frac = 1.0	3.28	33.83	4.67	42.51	28.21	3.45	3.64	14.34	133.93
1989, FEDS-3, Solar Frac = 0.75	3.57	29.53	4.10	42.51	28.21	3.45	3.64	14.34	129.35
1992, FEDS-3, Solar Frac = 0.75	2.39	24.78	5.39	40.09	28.03	13.54	2.80	3.53	120.55
Hospital	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	1.17	9.32	19.26	45.39	3.49	1.14	1.91	3.35	85.03
1989, FEDS-3, Solar Frac = 1.0	0.48	14.42	3.08	39.60	4.65	0.28	2.35	22.43	87.29
1989, FEDS-3, Solar Frac = 0.75	0.52	12.61	2.90	39.60	4.65	0.28	2.35	22.43	85.34
1992, FEDS-3, Solar Frac = 0.75	1.42	10.14	7.95	40.44	4.65	1.98	1.76	22.44	90.78
Lodging	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	4.25	8.19	9.61	25.66	3.48	0.51	1.83	0.82	54.35
1989, FEDS-3, Solar Frac = 1.0	2.54	10.83	1.27	24.17	1.77	0.23	2.52	7.85	51.18
1989, FEDS-3, Solar Frac = 0.75	2.73	9.57	1.14	24.17	1.77	0.23	2.52	7.85	49.98
1992, FEDS-3, Solar Frac = 0.75	2.71	7.71	1.69	14.37	1.14	1.85	2.24	4.68	36.39
Large Office	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	2.18	5.93	15.29	30.79	3.20	0.05	0.18	3.80	61.42
1989, FEDS-3, Solar Frac = 1.0	1.35	9.22	1.61	31.27	0.38	0.10	0.37	17.75	62.05
1989, FEDS-3, Solar Frac = 0.75	1.46	8.57	1.52	31.27	0.38	0.10	0.37	17.75	61.42
1992, FEDS-3, Solar Frac = 0.75	1.01	9.56	9.26	28.48	0.38	0.13	0.34	17.40	66.56
Small Office	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	5.35	11.93	5.99	23.02	3.18	0.01	0.47	3.68	53.63
1989, FEDS-3, Solar Frac = 1.0	2.91	15.13	2.21	25.83	0.38	0.02	0.42	17.13	64.03
1989, FEDS-3, Solar Frac = 0.75	3.12	13.20	1.96	25.83	0.38	0.02	0.42	17.13	62.06
1992, FEDS-3, Solar Frac = 0.75	1.81	12.87	2.80	24.25	0.38	0.01	0.38	16.67	59.17
Retail	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	2.43	6.06	3.05	18.95	1.21	0.04	0.33	1.88	33.95
1989, FEDS-3, Solar Frac = 1.0	3.14	8.89	1.56	20.76	0.77	0.06	0.33	4.09	39.60

1989, FEDS-3, Solar Frac = 0.75	3.37	7.63	1.41	20.76	0.77	0.06	0.33	4.09	38.42
1992, FEDS-3, Solar Frac = 0.75	2.20	7.96	2.19	20.85	0.77	0.09	0.30	4.07	38.43
Warehouse	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	0.43	0.45	0.06	9.24	0.58	0.01	0.11	1.12	12.00
1989, FEDS-3, Solar Frac = 1.0	0.70	1.12	0.21	10.42	0.45	0.00	0.05	5.80	18.75
1989, FEDS-3, Solar Frac = 0.75	0.76	0.85	0.19	10.42	0.45	0.00	0.05	5.80	18.52
1992, FEDS-3, Solar Frac = 0.75	0.99	1.36	0.33	8.68	0.43	0.00	0.05	5.62	17.46
Other	Heating	Cooling	Vent	Lights	Refrig	Cooking	Hot Water	Misc	Total
1989, FEDS-1	0.93	2.54	0.57	13.63	1.78	0.01	0.12	2.31	21.89
1989, FEDS-3, Solar Frac = 1.0	0.96	3.11	0.47	15.22	0.45	0.02	0.09	5.92	26.24
1989, FEDS-3, Solar Frac = 0.75	1.05	2.47	0.41	15.22	0.45	0.02	0.09	5.92	25.63
1992, FEDS-3, Solar Frac = 0.75	1.22	4.13	0.69	17.92	0.39	0.00	0.12	5.90	30.37

TABLE A.2. Comparison of FEDS Version on 1989 and 1992 CBECS: Average Gas EUI

All Buildings Stock	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	13.46	0.23	0.39	1.45	15.53
1989, FEDS-3, Solar Frac = 1.0	9.44	0.50	0.32	2.29	12.55
1989, FEDS-3, Solar Frac = 0.75	10.17	0.44	0.32	2.29	13.22
1992, FEDS-3, Solar Frac = 0.75	10.27	0.28	0.35	2.27	13.17
Assembly	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	24.90	0.18	0.02	0.58	25.68
1989, FEDS-3, Solar Frac = 1.0	16.95	0.63	0.20	2.18	19.96
1989, FEDS-3, Solar Frac = 0.75	18.27	0.54	0.20	2.18	21.19
1992, FEDS-3, Solar Frac = 0.75	16.98	0.16	0.27	1.96	19.37
Education	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	21.01	0.20	0.05	0.45	21.71
1989, FEDS-3, Solar Frac = 1.0	13.35	0.55	0.39	4.75	19.04
1989, FEDS-3, Solar Frac = 0.75	14.11	0.49	0.39	4.75	19.74
1992, FEDS-3, Solar Frac = 0.75	12.90	0.97	0.42	4.84	19.13
Food Sales	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	10.10	0.17	3.63	1.03	14.93
1989, FEDS-3, Solar Frac = 1.0	10.64	0.07	0.67	2.27	13.65
1989, FEDS-3, Solar Frac = 0.75	11.66	0.06	0.67	2.27	14.66
1992, FEDS-3, Solar Frac = 0.75	14.80	0.00	0.66	3.78	19.24
Food Services	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	19.97	1.38	11.75	20.61	53.71
1989, FEDS-3, Solar Frac = 1.0	17.84	3.23	8.75	13.67	43.49
1989, FEDS-3, Solar Frac = 0.75	19.31	2.67	8.75	13.67	44.40
1992, FEDS-3, Solar Frac = 0.75	16.41	0.76	8.84	15.41	41.42
Hospital	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	6.33	0.94	1.17	10.15	18.59
1989, FEDS-3, Solar Frac = 1.0	1.87	1.97	0.29	12.27	16.40
1989, FEDS-3, Solar Frac = 0.75	2.37	1.74	0.29	12.27	16.67
1992, FEDS-3, Solar Frac = 0.75	12.92	0.78	0.43	16.72	30.85
Lodging	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	11.94	0.34	1.05	7.38	20.71
1989, FEDS-3, Solar Frac = 1.0	6.64	0.51	0.41	10.61	18.17
1989, FEDS-3, Solar Frac = 0.75	7.17	0.41	0.41	10.61	18.60
1992, FEDS-3, Solar Frac = 0.75	4.72	0.11	0.51	10.31	15.65
Large Office	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	4.67	0.22	0.08	0.26	5.23
1989, FEDS-3, Solar Frac = 1.0	2.42	0.52	0.16	0.66	3.76
1989, FEDS-3, Solar Frac = 0.75	2.61	0.50	0.16	0.66	3.93
1992, FEDS-3, Solar Frac = 0.75	3.58	0.14	0.12	0.66	4.50
Small Office	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	17.73	0.50	0.01	0.87	19.11
1989, FEDS-3, Solar Frac = 1.0	7.49	0.79	0.01	0.58	8.87
1989, FEDS-3, Solar Frac = 0.75	8.07	0.69	0.01	0.58	9.35
1992, FEDS-3, Solar Frac = 0.75	9.10	0.45	0.01	0.68	10.24
Retail	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	15.64	0.20	0.09	0.55	16.48
1989, FEDS-3, Solar Frac = 1.0	14.34	0.39	0.13	0.55	15.41
1989, FEDS-3, Solar Frac = 0.75	15.47	0.35	0.13	0.55	16.50
1992, FEDS-3, Solar Frac = 0.75	16.41	0.16	0.10	0.68	17.35

Warehouse	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	6.73	0.01	0.00	0.20	6.94
1989, FEDS-3, Solar Frac = 1.0	5.14	0.06	0.00	0.06	5.26
1989, FEDS-3, Solar Frac = 0.75	5.52	0.04	0.00	0.06	5.62
1992, FEDS-3, Solar Frac = 0.75	5.23	0.01	0.00	0.06	5.30
Other	Heating	Cooling	Cooking	Hot Water	Total
1989, FEDS-1	6.03	0.06	0.02	0.26	6.37
1989, FEDS-3, Solar Frac = 1.0	4.80	0.13	0.02	0.22	5.17
1989, FEDS-3, Solar Frac = 0.75	5.28	0.10	0.02	0.22	5.62
1992, FEDS-3, Solar Frac = 0.75	4.79	0.15	0.02	0.27	5.23

changes in the FEDS hot water models increased the estimated EUIs in the FEDS Release 3 version. Gas water heating increased about 50%, while electric water heating increased about 30%.

The changes in refrigeration and miscellaneous electric EUIs reflect revised assumptions embedded in the FEDS model, as compared to changes in the consumption submodels within FEDS. These revisions were based upon a reexamination of auxiliary data sources that was conducted prior to the publication of Release 3 of the model. For most building types, the miscellaneous load was increased substantially. Refrigeration loads were generally reduced, principally in food sales buildings.

In the development of the EUIs for 1992, a global parameter change was made to adjust the amount of solar radiation that was received by each building modeled. This change was made to decrease the summer cooling peak predicted by the model and bring it more in line with observed aggregate monthly billing data. The final choice was to reduce this effect by 25%. The application of this reduction to the 1989 data is shown in line 3 of the panels in Tables A.1 and A.2 (Solar Frac = 0.75). Only heating, cooling and ventilation are affected by this change. For all buildings, heating (electric) is increased about 7%, cooling is reduced about 13%, and ventilation is reduced about 9%. Gas heating requirements increase similarly to the electric heating, rising about 8%.

The final line of the panels shows the FEDS Release 3 model, with the 25% reduction in the solar impact applied to the 1992 CBECS. Because some other assumptions were also changed, the overall (all buildings) results for all end uses cannot be strictly interpreted as the result of the changes in the two surveys. Brief explanations of the exceptions are provided below.

Heating and cooling, however, are not affected by these additional changes to FEDS. Thus, a comparison between lines three and four in each panel can be taken primarily as a result of differences in the heating and cooling systems and weather between the two surveys. Across all buildings, however, the differences generally wash out; heating declines slightly and cooling is marginally higher.

The differences in ventilation appear to be more affected by changes in the way the heating and cooling systems are described between the two surveys. As described above, the ventilation systems are either "linked" or "unlinked" to the heating and cooling system. In addition, hospitals and large offices were set to a constant ventilation mode in the final 1992 simulations. This treatment helps to explain why the ventilation is more than twice the 1989 estimates. To conclude, the changes in the data and assumptions for ventilation preclude any meaningful comparison of 1989 and 1992 behavior without additional study.

In the 1992 simulations a final adjustment was made to lighting in lodging buildings to account for the fact that the primarily incandescent lighting equipment has a low utilization rate. With the exception of this building type, the lighting estimates are comparable between the two surveys.

Across all buildings, refrigeration and hot water EUIs differed only by a small amount between the two surveys. The refrigeration reduction in lodging comes by way of an adjustment to the FEDS input value and is not CBECS-data-driven. For hot water, the 1992 average EUI is higher in some building types and lower in others, but ends up being about the same across all buildings.

For cooking, input assumptions were increased in the final 1992 simulations for food services, hospitals, and lodging. Miscellaneous consumption was reduced via input assumptions in food services and lodging. For the remaining building types, the differences are very small. Because these end uses in FEDS are primarily the product of average wattage per square foot and operating hours of the building, only the change in the operating hours between 1989 and 1992 will have any effect on the average EUI.

For gas, the results across all building types between the two surveys are very similar. Heating is higher in some building types, lower in other building types, which results in an all-buildings EUI increase of less than one percent.

These tables provide some insight into the changes in the final calibrated EUIs between the 1989 and 1992 studies. The FEDS simulations are largely responsible for higher cooling and lower ventilation estimates in the current study as compared to the 1993 work with the 1989 CBECS. The final lighting estimates also depend heavily on FEDS and, across all buildings, changed little between the two surveys. In spite of the changes in the FEDS model, the engineering simulations for electric and gas water heating changed little between the two studies. However, reliance upon the SAE methodology in this study to adjust the electric water heating estimates from FEDS resulted in much higher final EUIs for this end use.

APPENDIX B

IMPUTATION OF FEDS INPUT PARAMETERS FROM CBECS SURVEY DATA
MODIFICATIONS FOR 1992 CBECS

APPENDIX B

IMPUTATION OF FEDS INPUT PARAMETERS FROM CBECS SURVEY DATA MODIFICATIONS FOR 1992 CBECS

This appendix describes the major modifications that were made to the development of the FEDS input parameters from the 1992 CBECS. Compared with the 1989 CBECS, the 1992 CBECS contained more detailed information in the areas of the heating and cooling technologies as well as lighting. The development of other FEDS inputs from the CBECS remains the same as for the 1993 study and is described in Belzer et al. (1993).

B.1 SELECTION OF HEATING, COOLING, AND VENTILATION TECHNOLOGIES

The 1992 CBECS provided information on the percentage of building floorspace heated or cooled by each major technology type. The FEDS simulations are based upon a single heating or cooling technology for each building type. These primary technologies are selected on the basis of the greatest share of floorspace conditioned.

Note: Variable names in **bold** are names in the 1992 CBECS file.

Basic Approach:

1. Determine the primary heating and cooling technologies.
2. Map the heating technology information from CBECS to FEDS.
3. Map the cooling technology information from CBECS to FEDS.

B.1.1 Selection of Primary Heating and Cooling Technologies

The primary (only) heating and cooling technology for each building is based on the "percent heated by" and "percent cooled by" variables. The heating and cooling technologies with the greatest percentage are the primary technologies; if no percentage is greater than 15%, then the building is considered to be not heated or not cooled.

For heating, the CBECS variables are

HTPHP5, percent heated by heat pump
FURNP5, percent heated by furnace
SLFCNP5, percent heated by self-contained (unit) heaters
STHWP5, percent heated by district steam or hot water
BOILP5, percent heated by boilers
PKGHP5, percent heated by packaged units
OTHTP5, percent heated by other heating equipment.

For cooling, the CBECS variables are

RCACP5, percent cooled by residential central A/C units
HTPCP5, percent cooled by heat pump
ACWNWP5, percent cooled by window/wall air conditioners
CHWTP5, percent cooled by district chilled water
CHILP5, percent cooled by in-building chillers
PKGCP5, percent cooled by packaged units
EVAPP5, percent cooled by evaporative coolers
OTCLQ15, percent cooled by other cooling equipment.

B.1.2 Mapping Heating Types and Equipment

This section discusses how the FEDS "heat type" and equipment types were derived from the CBECS:

htyp: the FEDS heat type
equip: the FEDS equipment type.

The section will discuss the following variables used in the FEDS model:

ventmode: the ventilation control mode
is_ducted: whether or not the distribution system uses ducts
link[HEAT]: whether or not the heating system is linked to the ventilation system.

For cases where link[HEAT] is UNLINKED, ventmode and is_ducted values will be determined based on the cooling types and equipment.

Primary Heating Technology: Heat Pump

If heat pumps are used for heating (**HTPMPH5** is yes), check the primary heating fuel:

- if the primary heating fuel is electric (**HT15** is electric or **ELHT15** is yes), set the FEDS heat type to ELHTPUMP
- if the primary heating fuel is natural gas (**HT15** is gas, or **NGHT15** is yes), set the FEDS heat type to NATGAS
- Any other fuel type is an error condition.

Set the FEDS equipment type to AIR_HEAT_PUMP
Set link[HEAT] to LINKED
Set ventmode to CYCLE

- If the heat pump heat is distributed by vents (**HTPHDC5** is yes), is_ducted is YES
- If the heat pump heat is distributed by fan coil units (**HTPHFC5** is yes), is_ducted is NO

- If the heat pump heat is distributed by other means (**HTPHOT5** is yes), is_ducted is YES

Primary Heating Technology: Furnace

If furnaces are used for heating (**FURNAC5** is yes), check the primary heating fuel:

- if the primary heating fuel is electric (**HT15** is electric or **ELHT15** is yes) set the FEDS heat type to ELRESIST
- if the primary heating fuel is natural gas (**HT15** is gas, or **NGHT15** is yes), set the FEDS heat type to NATGAS
- if the primary heating fuel is fuel oil (**HT15** is fuel oil, or **FKHT15** is yes), set the FEDS heat type to OIL
- if the primary heating fuel is propane (**HT15** is propane, or **PRHT15** is yes), set the FEDS heat type to OTHERHT
- Any other fuel type is an error condition.

Set the FEDS equipment type to CONV_FURN
Set link[HEAT] to LINKED
Set ventmode to CYCLE
Set is_ducted to YES

Primary Heating Technology: Self-Contained Units

If self-contained units are used for heating (**SLFCON5** is yes), check the primary heating fuel:

- if the primary heating fuel is electric (**HT15** is electric or **ELHT15** is yes), set the FEDS heat type to ELRESIST
- if the primary heating fuel is natural gas (**HT15** is gas, or **NGHT15** is yes), set the FEDS heat type to NATGAS
- if the primary heating fuel is fuel oil (**HT15** is fuel oil, or **FKHT15** is yes), set the FEDS heat type to OIL
- if the primary heating fuel is propane (**HT15** is propane, or **PRHT15** is yes), set the FEDS heat type to OTHERHT
- Any other fuel type is an error condition.

Set the FEDS equipment type to CONV_FURN
Set link[HEAT] to LINKED
Set ventmode to CYCLE
Set is_ducted to NO

Primary Heating Technology: Steam or Hot Water Piped In

If district steam or hot water is used for heating (**STHW5** is yes), check the primary heating fuel:

- if the primary heating fuel is district steam (**HT15** is district steam or **STHT15** is yes), set the FEDS heat type to STEAM

- if the primary heating fuel is district hot water (**HT15** is district hot water, or **HWHT15** is yes), set the FEDS heat type to HOTWATER

- Any other fuel type is an error condition.

The FEDS equipment type and ventilation information will depend on how the district steam or hot water is distributed:

- if the district heat is distributed by radiators/baseboards (**STHWBR5** is yes):

  the FEDS equipment type is RADIATOR
  set link[HEAT] to UNLINKED
  set ventmode to NONE
  set is_ducted to NO

- if the district heat is distributed by vents (**STHWDC5** is yes):

  the FEDS equipment type is FORCED_AIR
  set link[HEAT] to LINKED
  set ventmode to CYCLE
  set is_ducted to YES

- if the district heat is distributed by fan coil units (**STHWFC5** is yes):

  the FEDS equipment type is FAN_COIL
  set link[HEAT] to LINKED
  set ventmode to CYCLE
  set is_ducted to NO

- if the district heat is distributed by other (**STHWOT5** is yes):

  the FEDS equipment type is FORCED_AIR
  set link[HEAT] to LINKED
  set ventmode to CYCLE
  set is_ducted to YES

Primary Heating Technology: Boilers

If in-building boilers are used for heating (**BOILER5** is yes), check the primary heating fuel:

- if the primary heating fuel is electric (**HT15** is electric or **ELHT15** is yes), set the FEDS heat type to ELRESIST
- if the primary heating fuel is natural gas (**HT15** is gas, or **NGHT15** is yes), set the FEDS heat type to NATGAS
- if the primary heating fuel is fuel oil (**HT15** is fuel oil, or **FKHT15** is yes), set the FEDS heat type to OIL
- if the primary heating fuel is propane (**HT15** is propane, or **PRHT15** is yes), set the FEDS heat type to OTHERHT
- Any other fuel type is an error condition

The FEDS equipment type is CONV_BOILER

The FEDS ventilation information will depend on how the heat is distributed:

- if the boiler heat is distributed by radiators/baseboards (**BOILBR5** is yes):

```
set link[HEAT] to UNLINKED
set ventmode to NONE
set is_ducted to NO
```

- if the boiler heat is distributed by vents (**BOILDC5** is yes):

```
set link[HEAT] to LINKED
set ventmode to CYCLE
set is_ducted to YES
```

- if the boiler heat is distributed by fan coil units (**BOILFC5** is yes):

```
set link[HEAT] to LINKED
set ventmode to CYCLE
set is_ducted to NO
```

- if the boiler heat is distributed by other (**BOILOT5** is yes):

```
set link[HEAT] to LINKED
set ventmode to CYCLE
set is_ducted to YES
```

Primary Heating Technology: Packaged Units

If packaged units are used for heating (**PKGHT5** is yes), check the primary heating fuel:

- if the primary heating fuel is electric (**HT15** is electric or **ELHT15** is yes), set the FEDS heat type to ELRESIST
- if the primary heating fuel is natural gas (**HT15** is gas, or **NGHT15** is yes), set the FEDS heat type to NATGAS
- if the primary heating fuel is fuel oil (**HT15** is fuel oil, or **FKHT15** is yes), set the FEDS heat type to OIL
- if the primary heating fuel is propane (**HT15** is propane, or **PRHT15** is yes), set the FEDS heat type to OTHERHT
- Any other fuel type is an error condition.

Set the FEDS equipment type to CONV_FURN
Set link[HEAT] to LINKED
Set ventmode to CYCLE
Set is_ducted to YES

Primary Heating Technology: Other Heating Equipment

If other heating equipment is used for heating (**OTHTEQ5** is yes), check the primary heating fuel:

- if the primary heating fuel is electric (**HT15** is electric or **ELHT15** is yes), set the FEDS heat type to ELRESIST
- if the primary heating fuel is natural gas (**HT15** is gas, or **NGHT15** is yes), set the FEDS heat type to NATGAS
- if the primary heating fuel is fuel oil (**HT15** is fuel oil, or **FKHT15** is yes), set the FEDS heat type to OIL
- if the primary heating fuel is propane (**HT15** is propane, or **PRHT15** is yes), set the FEDS heat type to OTHERHT
- Any other fuel type is an error condition.

The FEDS equipment type and ventilation information will depend on how the heat from the other equipment is distributed:

- if the heat is distributed by radiators/baseboards (**OTHTBR5** is yes):

  the FEDS equipment type is RADIATOR
  set link[HEAT] to UNLINKED
  set ventmode to NONE
  set is_ducted to NO

- if the heat is distributed by vents (**OTHTDC5** is yes):

  the FEDS equipment type is FORCED_AIR
  set link[HEAT] to LINKED
  set ventmode to CYCLE
  set is_ducted to YES

- if the heat is distributed by fan coil units (**OTHTFC5** is yes):

  the FEDS equipment type is FAN_COIL
  set link[HEAT] to LINKED
  set ventmode to CYCLE
  set is_ducted to NO

- if the heat is distributed by other (**OTHTOT5** is yes):

  the FEDS equipment type is FORCED_AIR
  set link[HEAT] to LINKED
  set ventmode to CYCLE
  set is_ducted to YES

Error Handling for Heating

If an error condition has been encountered during the heat mapping:

set the FEDS heat type to ELRESIST
set the FEDS equipment type to CONV_FURN
set link[HEAT] to LINKED
set ventmode to CYCLE
set is_ducted to YES

B.1.3 Mapping Cooling Types and Equipment

This section will fill the following variables in the cool_tech structure in the bldg_rec structure:

int ctyp, the FEDS cool type
int equip, the FEDS cooling equipment type.

If link[HEAT] has been set to UNLINKED, then this section will also fill the following variables in the bldg_ventilation structure in bldg_rec:

ventmode, the ventilation control mode; and,
is_ducted, whether or not the distribution system uses ducts.

For all cooling technologies, link[COOL] should be set to LINKED.

Primary Cooling Technology: Residential Type Central AC

If residential type systems are used for cooling (**RCAC5** is yes),

set the FEDS cool type to PKGUNITS
set the FEDS equipment type to PKG_UNIT
set link[COOL] to LINKED
set ventmode to CYCLE
set is_ducted to YES

Primary Cooling Technology: Heat Pump

If heat pumps are used for cooling (**HTPMPC5** is yes),

set the FEDS cool type to ELHTPMP
set the FEDS equipment type to AIR_COOL_PMP
set link[COOL] to LINKED
set ventmode to CYCLE
set is_ducted to YES

Primary Cooling Technology: Window/Wall Air Conditioners

If window air conditioners are used for cooling (**ACWNWL5** is yes),

set the FEDS cool type to PKGUNITS
set the FEDS equipment type to PKG_UNIT
set link[COOL] to LINKED
set ventmode to CYCLE
set is_ducted to NO

Primary Cooling Technology: District Chilled Water

If district chilled water is used for cooling (**CHWT5** is yes),

set the FEDS cool type to CHILWATR
set the FEDS equipment type to CHILWATR_COIL
set link[COOL] to LINKED
set ventmode to CYCLE

If the district cooling is distributed by fan coil units (**CHWTFC5** is yes), set is_ducted to NO

Otherwise, set is_ducted to YES

Primary Cooling Technology: Central Chillers

If in-building chillers are used for cooling (**CHILLR5** is yes), check the cooling fuel:

- if the cooling fuel is electric (**COOL5** is electric or **ELCOOL5** is yes), set the FEDS cool type to SNELCHIL and the FEDS equipment type to CONV_CHILLER

- if the cooling fuel is natural gas (**COOL5** is gas, or **NGCOOL5** is yes), set the FEDS cool type to GSABCHIL and the FEDS equipment type to ABSORP_CHILLER

- if the cooling fuel is district steam (**COOL5** is district steam, or **STCOOL5** is yes), set the FEDS cool type to STABCHIL and the FEDS equipment type to ABSORP_CHILLER

- if the cooling fuel is district hot water (**COOL5** is hot water, or **HWCOOL5** is yes), set the FEDS cool type to WTABCHIL and the FEDS equipment type to ABSORP_CHILLER

- if the cooling fuel is propane (**COOL5** is propane, or **PRCOOL5** is yes), set the FEDS cool type to OTABCHIL and the FEDS equipment type to ABSORP_CHILLER

- Any other fuel type is an error condition.

Set link[COOL] to LINKED
Set ventmode to CYCLE

If the cooling is distributed by fan coil units (**CHILFC5** is yes), set is_ducted to NO

Otherwise, set is_ducted to YES

Primary Cooling Technology: Packaged Units

If packaged units are used for cooling (**PKGCL5** is yes),

set the FEDS cool type to PKGUNITS
set the FEDS equipment type to PKG_UNIT
set link[COOL] to LINKED
set ventmode to CYCLE
set is_ducted to YES

Primary Cooling Technology: Evaporative Coolers

If evaporative coolers are used for cooling (**EVAPCL5** is yes),

```
set the FEDS cool type to EVAPCOOL
set the FEDS equipment type to EVAP_COOLER
set link[COOL] to EVAP_COOLED
set ventmode to CYCLE
```

If the cooling is distributed by fan coil units (**EVAPFC5** is yes), set is_ducted to NO

Otherwise, set is_ducted to YES

Primary Cooling Technology: Other

If other cooling equipment is used for cooling (**OTCLEQ5** is yes),

```
set the FEDS cool type to EVAPCOOL
set the FEDS equipment type to EVAP_COOLER
set link[COOL] to EVAP_COOLED
set ventmode to CYCLE
```

If the cooling is distributed by fan coil units (**OTCLFC5** is yes), set is_ducted to NO

Otherwise, set is_ducted to YES

B.2 LIGHTING: MODIFIED MAPPING PROCEDURES

The basic approach with respect to lighting involves two steps:

1. Map lighting technology information and percentages from CBECS to FEDS.

2. Modify fluorescent lighting type and percentage based on presence or absence of specular reflectors.

There is often more than one lighting technology in a building.

B.2.1 Map Lighting Technology Information and Percentages from CBECS to FEDS:

This section describes how the following variables are filled in the FEDS "light_tech" structure in the FEDS C code:

ltyp, the FEDS lighting technology type
ctyp, the FEDS lighting configuration type
frac_bldg, the fraction of the building lit by this type.

Lighting Technology: Incandescent

If incandescent lighting is present in the building (**BULB5** is yes):

set ltyp for this technology to IN
set ctyp for this technology to 8
take the CBECS variable **BULBP5** and divide by 100, then put the result in frac_bldg for this technology.

Lighting Technology: Standard Fluorescent

If fluorescent lighting is present in the building (**FLUOR5** is yes):

set ltyp for this technology to FL
set ctyp for this technology to 1
take the CBECS variable **FLUORP5** and divide by 100, then put the result in frac_bldg for this technology.

Lighting Technology: Compact Fluorescent

If compact fluorescent lighting is present in the building (**CFLR5** is yes):

set ltyp for this technology to FL
set ctyp for this technology to 175
take the CBECS variable **CFLRP5** and divide by 100, then put the result in frac_bldg for this technology.

Lighting Technology: HID (High Intensity Discharge)

If HID lighting is present in the building (**HID5** is yes):

follow the procedure used for the 1989 data (HID lighting type was based on building type) to determine the ltyp and ctyp.

take the CBECS variable **HIDP5** and divide by 100, then put the result in frac_bldg for this technology.

Lighting Technology: Other

If other lighting is present in the building (**OTLT5** is yes), ignore. Possible other lighting documented for the 1992 CBECS (SASLIB92) include skylights, stagelights and decorative lights (e.g., neon signs). We assumed that these are not of sufficient magnitude to attempt to model in FEDS.

B.2.2 Modify Fluorescent Lighting Type and Percentage Based on Presence or Absence of Specular Reflectors

The 1992 CBECS included a question concerning the presence of specular reflectors in fluorescent fixtures. If specular reflectors are used in a building (**SREF5** is yes):

- Confirm that standard fluorescent lighting is present in the building. If not, an error condition is set up. If fluorescent lighting is present, then

  Set ltyp for this technology to FL
  Set ctyp for this technology to 245
  Take the CBECS variable **SREFP5** and divide by 100, then put the result in frac_bldg for this technology.
  Subtract frac_building for this technology (FL245) from the standard fluorescent technology (FL1). If the result is greater than zero, then place the result into the frac_bldg variable for the FL1 technology. If it equals zero, then remove the FL1 technology record.

B.3 OTHER NEW VARIABLES IN 1992 CBECS USED IN FEDS

Several other key variables were included in the 1992 CBECS that were not available in the 1989 survey.

B.3.1 Building Operating Hours

The 1992 CBECS requested information from respondents on the opening and closing hours for each day of the week (Monday-Sunday). In contrast, the 1989 survey requested only the usual opening and closing hours for weekdays, Saturday, and Sunday.

The experience with the 1989 CBECS indicated a large number of buildings that did not provide opening and closing hours. As a result, schedules were imputed on the basis of the number of operating hours per week, a separate question from the CBECS. With opening and closing hours data for each separate weekday, this imputation procedure would be much more complicated to handle within the FEDS code. As a result, average weekday opening and closing hours, when supplied, were assumed to be represented by the data input for Wednesday. With the exception of some retail stores, the choice of Wednesday should be sufficiently accurate for FEDS modeling purposes. (Note: EIA intends to revert to the 1989 handling of this variable for its forthcoming 1995 CBECS).

B.3.2 Building Aspect Ratio

The 1992 CBECS included questions concerning the building's shape (rectangular, "L" shaped, "H" shaped, etc.) and its length and width. The simplified zoning in FEDS requires that all buildings be modeled as rectangular, but the aspect ratio (length/width) can vary. The 1993 PNNL study used default aspect ratios that varied by building type (Belzer et al. 1993, p. A.4).

For the current study, the specific aspect ratio for the building was used when available. If the aspect ratio was missing, the model reverted to the use of an aspect ratio based upon the building type. The default aspect ratios were also revised to reflect the new information from the 1992 CBECS. Finally, some reported aspect ratios were implausibly high. For the building simulations, an upper limit of 6 for the aspect ratio was chosen.

B.3.3 Window-to-Wall Ratio

The 1989 CBECS did not contain information about the percent of window area in the building's walls. A categorical question was (re)introduced in the 1992 CBECS. The 1992 CBECS categories of the percentage of exterior wall surface that is covered with glass windows or doors are

10 percent or less
11 to 25 percent
26 to 50 percent
51 to 75 percent
76 to 100 percent.

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