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Methodology for Modeling Building Energy Performance across the Commercial Sector

Technical Report
NREL/TP-550-41956
March 2008

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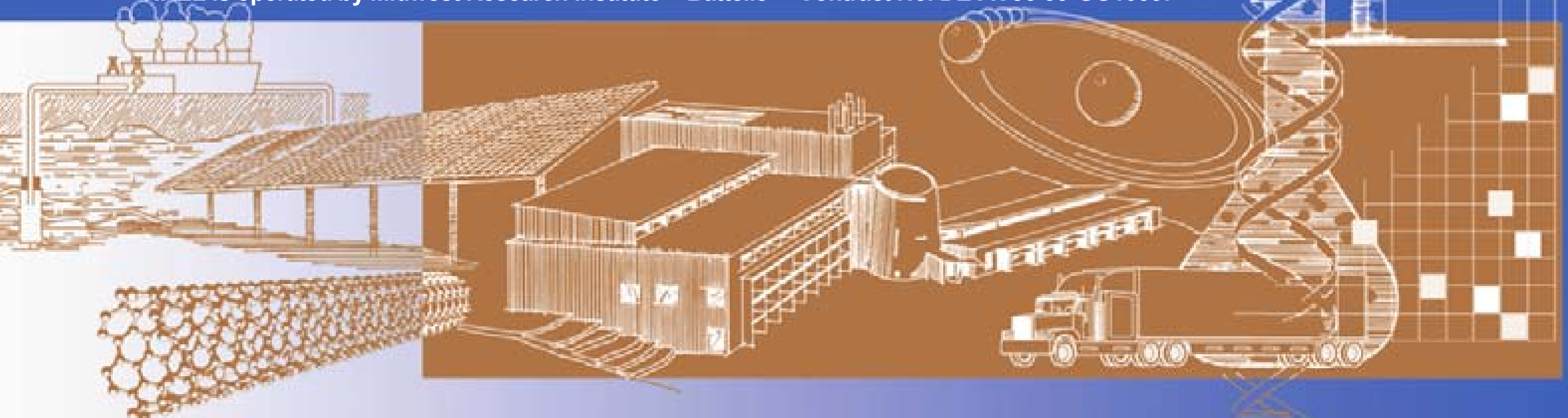

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Nomenclature

AC	alternating current
ACH	air changes per hour
AEO	*Annual Energy Outlook*, from EIA
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BT	Building Technologies Program within DOE/EERE
CBECS	*Commercial Buildings Energy Consumption Survey*
CDD	cooling degree day
CEUS	(California) Commercial End-Use Survey
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
COP	coefficient of performance
DC	direct current
DOE	U.S. Department of Energy
EERE	Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EUI	energy use intensity
FY	Fiscal Year
GDP	Gross Domestic Product
HDD	heating degree day
HRV	heat recovery ventilation (include energy and enthalpy recovery)
HVAC	heating, ventilating, and air-conditioning
LBNL	Lawrence Berkeley National Laboratory
LPD	lighting power density
NO_x	oxides of nitrogen
NREL	National Renewable Energy Laboratory
PDF	probability density function
PV	photovoltaic
R&D	research and development
Sector	Energy consumption in the United States is classified by three *sectors:* transportation, buildings, and industrial.

SEDS	State Energy Consumption, Price, and Expenditure Estimates
Subsector	Disaggregation of the sector energy use. As defined by the *Commercial Buildings Energy Consumption Survey* (CBECS; EIA 2002), there are 20 subsectors, or principle building activities, in commercial buildings. These include retail, office, and food sales buildings, among others. Complete listings are given throughout this report (see, for example Table 4-1).
TAP	Tariff Analysis Project. (See http://tariffs.lbl.gov)
TDD	tubular daylighting device
TMY	typical meteorological year
TOU	time of use
VAV	variable air volume
ZEB	Zero-energy building (or net-zero energy building). A building with net-zero energy consumption over one year. Assumed to be based on net site energy use.

Acknowledgments

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Executive Summary

This report uses EnergyPlus simulations of each building in the 2003 *Commercial Buildings Energy Consumption Survey* (CBECS) to document and demonstrate bottom-up methods of modeling the entire U.S. commercial buildings sector (EIA 2006). CBECS survey results provide the most robust set of data available on the energy performance of the national stock of buildings. The ability to use a whole-building simulation tool to model the entire sector is of interest because the energy models enable us to answer subsequent "what-if" questions that involve technologies and practices related to energy. This report documents how the whole-building models were generated from the building characteristics in 2003 CBECS and compares the simulation results to the survey data for energy use.

Principal Findings

- Methods for generating a large population of detailed EnergyPlus models from the data available about building characteristics from 2003 CBECS were developed to implement a mixture of literature data, assumptions, defaults, and probabilistic assignments. Appendix C of this report documents how data from 2003 CBECS were translated into building descriptions for forward modeling in EnergyPlus.
- Results from the set of 4,820 models are compared to the 2003 survey and overall agreement in site (delivered) energy use intensity is 12%, which is deemed acceptable given the level of scatter in the survey data.
- A by-product of the effort to compare model results to the survey results is the unique analyses of the 2003 CBECS public use data. For example, the modeling effort produced climate zone estimates for the sample buildings so survey results can be organized by climate zone. Appendix A contains plots of survey data in the form of probability density functions and scatter plots, which show that energy use intensity is broadly distributed. The masking of data and shifting of floor area in the samples may have introduced additional errors in area-normalized use intensities that were calculated from public use data.
- The sample size of 4,820 is adequate for characterizing some, but not all, subsets of the commercial sector that are formed by principal building activity and climate.

Research Recommendations

The National Renewable Energy Laboratory's efforts to model the commercial building stock resulted in a number of research recommendations:

- The set of models can serve as the starting point for simulation-based studies of the commercial sector. Such studies require a set of building types and locations. The set developed here has a strong statistical basis because it reuses the sample designed for CBECS. Examples of studies that could be conducted include analysis of retrofit options on existing stock, energy impacts of outside air, and analysis of savings potential in new construction, if one assumes that the distribution of new construction mirrors that of the existing stock.
- The existing stock models could be further refined for future analysis. The current models were based on the building characteristics from 2003 CBECS; the survey results for energy consumption were reserved for validation. Future work could improve the models by forcing the modeled energy consumption to agree with the survey results for each sample. The models would need to be based on the actual sample floor areas rather than on masked data.
- The methodology documented here could be extended to augment survey data in future CBECS. By incorporating EnergyPlus modeling into the analysis and postprocessing of CBECS data, models could facilitate predicting energy end-use distributions, normalizing energy use with

respect to weather, and synthesizing time series data such as peak power demands and hourly load profiles.

- In addition to typical meteorological year weather data, the National Solar Radiation Database historical weather data are practical for modeling the behavior of commercial buildings with respect to periods of real weather such as for 2003. Being able to switch weather data suggests that simulations could be used to normalize survey results with respect to weather.
- The methodology documented here is computationally intensive and appropriate for large research projects only. For routine or widespread use, we recommend developing smaller sets of benchmark models to represent the commercial sector.
- Results from the modeling for energy consumption estimates by end use differ from similar data in the *Building Energy Data Book* (DOE 2006). The current study has significantly lower end uses for service hot water and higher end uses for cooling and fans. More research is needed to resolve these discrepancies. The modeling of service water heating would need to be improved before the method could be applied to evaluate water heating technologies.

1. Introduction

1.1 Problem Definition

The commercial building sector is responsible for 18% of U.S. energy use and is the fastest growing demand sector. The Energy Information Agency's (EIA) *Annual Energy Outlook 2007* (AEO; EIA 2007) projects growth at 1.5% per year. This growth will place an additional burden on the nation's energy system and is driven by economic expansion, which leads to increased commercial floor area. Research and policy efforts aimed at improving the energy performance of the commercial sector could benefit from a better understanding of the myriad details of why, how, when, and where energy is used—and how it can be saved.

The survey conducted by EIA in four-year cycles, called the *Commercial Building Energy Consumption Survey* (CBECS), is used for official government statistics, and is thus an excellent source of real-world data about the energy performance of the commercial sector. The latest survey was conducted for 2003 (2003 CBECS; EIA 2006). CBECS is an important basis for what researchers and analysts know about the commercial sector. However, the types of data collected are fairly limited and do not include temporal details such as peak electricity demand, end uses, or hourly distributions. CBECS helps us to understand the existing stock, but it is less useful for new construction. As a survey, it does not provide predictive capabilities that could answer "what if" questions.

Detailed simulations of the annual energy performance of the buildings can be conducted with computer modeling tools such as EnergyPlus (www.eere.energy.gov/buildings/energyplus/). These models are *forward* in the sense that they take a description of the building and its operation and predict energy performance over a specified time period such as annually. Such tools model system interactions in detail and enable accurate evaluation of alternative technologies and practices. However, such models are inherently resolved at the level of a single building, which creates challenges in using them for large-scale studies that address the entire United States. To use EnergyPlus for a sector-wide study requires developing a sector model that is composed of a number of individual building models that seek to represent the all types of buildings and locations. Once developed, such sets of EnergyPlus models for the whole sector can answer "what if" questions such as, What is the feasibility of net zero-energy buildings? and What is the value of individual energy savings technologies and practices? However, the sector model needs to be validated so that such methods can be used with greater confidence in subsequent studies.

1.2 Project Scope

The principal question being addressed in this report is: "How well do results from a set of EnergyPlus models for the whole sector agree with 2003 CBECS?"

The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Building Technologies Program (DOE/EERE/BT) conducts research in the area of commercial building integration. This study was conducted to further develop and validate a whole-sector analysis methodology based on large numbers of EnergyPlus simulations. Since the survey results from CBECS are the best sources of real-world data about the commercial sector, these data should be used as a check. Although the National Renewable Energy Laboratory's (NREL) overall research efforts currently focus on new construction, this part of the study focuses on existing commercial stock and allows us to compare model results to the 2003 CBECS survey results in an effort to validate the methodology.

NREL used EnergyPlus to produce a data set of energy performance metrics for commercial buildings in various subsectors, climates, and census divisions. We used the information gathered from these data sets to:

- Determine whether EnergyPlus modeling results are reasonably valid.
- Determine whether the whole-sector modeling methodology represents the commercial sector.

1.3 Report Organization

This report is organized into three tiers that contain increasingly technical content:

- The first tier is the Executive Summary.
- The second tier forms the body of the report, and is presented in five sections.
    - Section 1 introduces the problem and methods NREL used in this research.
    - Section 2 summarizes the literature we used to help characterize the commercial sector.
    - Section 3 summarizes the methods we used in this study to model the existing stock.
    - Section 4 presents and discusses selected results from the study.
    - Section 5 is a bibliography.
- The third tier presents significantly more technical detail in three appendices.
    - Appendix A contains expanded results.
    - Appendix B discusses the analysis tools NREL used to perform the study.
    - Appendix C documents translation rules used to develop detailed models from survey data.

2. Background and Literature

This section summarizes the literature and data sources used in the methodology. The primary source of data is EIA's 2003 CBECS. So-called "third party" literature refers to data sources that are external to either EIA's or the authors' current efforts.

2.1 *2003 Commercial Buildings Energy Consumption Survey*

The CBECS is a survey of U.S. buildings that EIA conducts every four years. The latest is the 2003 CBECS. EIA releases a fine-grained data set about the sample buildings for public use. The 2003 CBECS Public Use Microdata set includes data for 4,820 non-mall commercial buildings. A second data set is available that includes malls, but it lacks data on the building characteristics for malls to be included in this study. For each sample, CBECS provides data about building characteristics, including floor area, number of floors, census division, basic climatic design criteria, principal building activity (PBA), number of employees, type of heating and cooling equipment, and weighting factors. The CBECS building characteristics data are the core source used in this study to develop methods for modeling commercial buildings. The CBECS data about energy consumption are compared to model results in an effort to validate the whole-sector modeling approach.

The 2003 CBECS data survey provides the best statistical characterization of the commercial sector available for the United States, but it is not designed to provide the details needed for whole-building energy performance modeling. A methodology was developed to bridge the actual data and the data required for EnergyPlus simulations. Data obtained from separate literature sources, which are the subject of this section, are important to this methodology.

2.2 Internal Gains

The California Energy Commission (CEC) commissioned Itron, Inc., to conduct a large study called the *California Commercial End-Use Survey*, or CEUS, of the commercial sector in California (CEC 2006). The CEUS survey is analogous to EIA's CBECS survey, but focuses on California, specifically the service areas of four major utility companies. CEUS differs from CBECS in several important ways:

- CEUS was not designed with the anonymity that would allow a publicly available, fine-grained data set of the characteristics of individual buildings in the survey to be produced. No data set from CEUS is comparable to the Public Use Microdata from CBECS; there are only aggregated results.
- Building energy performance modeling was closely integrated with the methodology used to conduct the survey. The computer modeling done for CEUS is collected in an analysis framework called "DrCEUS" that is based on the simulation engine DOE 2.2/EQUEST and other proprietary software for non-heating, ventilation, and air-conditioning (HVAC) end uses. Energy model development appears to have had close access to many more details of the individual survey buildings than what are available from 2003 CBECS. Details include monthly billing data (which can be used to calibrate models), event loggers in some buildings to determine occupancy schedules, and more detail about the inventory of the types of non-HVAC devices in the buildings.
- The aggregated results have been transformed to correspond to typical meteorological year (TMY) weather rather than the historical weather from the survey period.

Although the lack of publicly available data limits the usefulness of the study (for those outside of CEC and Itron), there appear to be important lessons (and precedents) for using energy performance simulation as a core part of a methodology for conducting such surveys. The aggregated data from CEUS appear to be the best available for characterizing occupant-driven energy end uses in the commercial sector. To apply the CEUS data, we reason that occupant-driven activities and intensity of use in California commercial buildings are similar to the rest of the U.S. commercial sector and assume that the study will benefit by extrapolating the high-quality data for California to the rest of the United States. Table 2-1 and Table 2-2 summarize CEUS's results (from Table 8-3 in CEC 2006) used in this study to develop input data related to plug and process electricity use as well as commercial refrigeration. The CEUS data listed in Table 2-1 and Table 2-2 are used in the models. Plug and process electricity loads are assumed to be the subtotal of office equipment, miscellaneous, process, cooking, air compressors, and motors. Similarly, Table 2-3 and Table 2-4 summarize CEUS's results (from Table 8-5 in CEC 2006) used here to develop input data related to gas appliance use.

Table 2-1 CEUS Results for Plug and Process and Refrigeration Electricity Use Intensities: IP Units

CEUS Building Type	Office Equipment (kBtu/ft^2·yr)	Miscellaneous (kBtu/ft^2·yr)	Process (kBtu/ft^2·yr)	Cooking (kBtu/ft^2·yr)	Air Compressor (kBtu/ft^2·yr)	Motors (kBtu/ft^2·yr)	Plug and Process Subtotal (kBtu/ft^2·yr)	Refrigeration (kBtu/ft^2·yr)
All	3.31	2.73	0.44	1.94	0.14	1.94	10.51	6.24
Small office	7.47	2.66	0.34	0.34	0.00	0.75	11.57	1.98
Large office	12.22	1.98	0.31	0.41	0.10	2.46	17.47	1.40
Restaurant	2.15	3.86	0.07	35.42	0.03	0.92	42.45	33.68
Retail	1.67	2.35	0.31	0.75	0.17	0.99	6.24	3.51
Food store	1.26	3.24	0.14	6.31	0.03	0.61	11.60	76.50
Refrigerated warehouse	0.58	1.94	0.78	0.14	0.14	6.21	9.79	45.86
Nonrefrigerated warehouse	0.82	1.33	0.20	0.07	0.07	0.99	3.48	0.96
School	1.57	0.85	0.03	0.61	0.00	0.27	3.34	1.71
College	2.46	1.67	0.48	0.92	0.03	1.98	7.54	1.57
Health care	2.93	8.60	0.75	1.47	0.03	2.66	16.45	2.42
Lodging	0.58	3.79	0.07	2.32	0.00	1.64	8.39	3.07
Miscellaneous	1.19	3.41	1.02	0.89	0.41	3.69	10.61	2.93
All offices	10.54	2.22	0.31	0.38	0.07	1.84	15.35	1.60
All warehouses	0.78	1.43	0.27	0.07	0.07	1.77	4.40	7.54

Table 2-2 CEUS Results for Plug and Process and Refrigeration Electricity Use Intensities: SI Units

CEUS Building Type	Office Equipment ($MJ/m^2 \cdot yr$)	Miscellaneous ($MJ/m^2 \cdot yr$)	Process ($MJ/m^2 \cdot yr$)	Cooking ($MJ/m^2 \cdot yr$)	Air Compressor ($MJ/m^2 \cdot yr$)	Motors ($MJ/m^2 \cdot yr$)	Plug and Process Subtotal ($MJ/m^2 \cdot yr$)	Refrigeration ($MJ/m^2 \cdot yr$)
All	37.6	31.0	5.0	22.0	1.6	22.0	119.4	70.9
Small office	84.9	30.2	3.9	3.9	0.0	8.5	131.5	22.5
Large office	138.9	22.5	3.5	4.7	1.1	28.0	198.5	15.9
Restaurant	24.4	43.9	0.8	402.5	0.3	10.5	482.4	382.7
Retail	19.0	26.7	3.5	8.5	1.9	11.3	70.9	39.9
Food store	14.3	36.8	1.6	71.7	0.3	6.9	131.8	869.3
Refrigerated warehouse	6.6	22.0	8.9	1.6	1.6	70.6	111.3	521.1
Nonrefrigerated warehouse	9.3	15.1	2.3	0.8	0.8	11.3	39.5	10.9
School	17.8	9.7	0.3	6.9	0.0	3.1	38.0	19.4
College	28.0	19.0	5.5	10.5	0.3	22.5	85.7	17.8
Health care	33.3	97.7	8.5	16.7	0.3	30.2	186.9	27.5
Lodging	6.6	43.1	0.8	26.4	0.0	18.6	95.3	34.9
Miscellaneous	13.5	38.8	11.6	10.1	4.7	41.9	120.6	33.3
All offices	119.8	25.2	3.5	4.3	0.8	20.9	174.4	18.2
All warehouses	8.9	16.3	3.1	0.8	0.8	20.1	50.0	85.7

Table 2-3 CEUS Results for Gas End Use Intensities: IP Units

CEUS Building Type	Cooking (kBtu/ft²·yr)	Miscellaneous (kBtu/ft²·yr)	Process (kBtu/ft²·yr)	Gas Appliance Subtotal (kBtu/ft²·yr)
All	5.9	0.5	1.5	7.9
Small office	0.1	0.0	0.1	0.2
Large office	0.2	0.1	1.2	1.5
Restaurant	153.3	0.0	0.3	153.6
Retail	0.5	0.3	0.0	0.8
Food store	10.3	0.0	0.1	10.4
Refrigerated warehouse	1.2	0.0	2.8	4.0
Nonrefrigerated warehouse	0.0	0.0	0.0	0.0
School	1.1	0.0	0.1	1.2
College	1.7	0.9	0.0	2.6
Health care	3.4	1.4	5.1	9.9
Lodging	4.4	1.4	0.3	6.1
Miscellaneous	1.0	1.0	4.6	6.6
All offices	0.2	0.1	0.8	1.1
All warehouses	0.2	0.0	0.4	0.6

Table 2-4 CEUS Results for Gas End Use Intensities: SI Units

CEUS Building Type	Cooking (MJ/m²·yr)	Miscellaneous (MJ/m²·yr)	Process (MJ/m²·yr)	Gas Appliance Subtotal (MJ/m²·yr)
All	67	6	17	90
Small office	1	0	1	2
Large office	2	1	14	17
Restaurant	1,742	0	3	1,745
Retail	6	3	0	9
Food store	117	0	1	118
Refrigerated warehouse	14	0	32	45
Nonrefrigerated warehouse	0	0	0	0
School	13	0	1	14
College	19	10	0	30
Health	39	16	58	113
Lodging	50	16	3	69
Miscellaneous	11	11	52	75
All offices	2	1	9	13
All warehouses	2	0	5	7

2.3 Lighting

DOE (2002) commissioned Navigant Consulting, Inc., to characterize the U.S. lighting market. That study used data from 1999 CBECS (EIA 2002) and the XenCap™ energy auditing system to characterize lighting energy in the commercial sector. We assume (out of practical necessity) that Navigant's results still apply when moving from 1999 CBECS to 2003 CBECS. Table 2-5 lists data (from Table 5-11 in DOE 2002) used to develop inputs for lighting installed density in the current methodology. (The energy use intensity for vacant buildings seem to be in error.)

Table 2-5 *U.S. Lighting Market Characterization* Results for Lighting Electricity Use

Subsector (PBA)	Lighting Power Density (W/ft^2)	Lighting Power Density (W/m^2)	Lighting Electricity Use Intensity ($kBtu/ft^2 \cdot yr$)	Lighting Electricity Use Intensity ($MJ/m^2 \cdot yr$)
Office/professional	1.8	19.4	22.9	260
Nonrefrigerated warehouse	1.4	15.1	16.4	186
Education	1.8	19.4	16.7	190
Retail (except malls)	1.9	20.5	23.9	272
Public assembly	1.4	15.1	12.3	140
Service	1.7	18.3	19.4	220
Religious worship	1.4	15.1	8.5	97
Lodging	1.3	14.0	16.0	182
Food services	1.6	17.2	23.9	272
Inpatient health care	1.7	18.3	32.4	368
Public order and safety	1.3	14.0	15.4	175
Food store	1.9	20.5	33.4	380
Outpatient health care	1.7	18.3	19.8	225
Vacant	2.1	22.6	25.6	291
Other	1.7	18.3	20.8	236
Skilled nursing	1.3	14.0	18.4	209
Laboratory	1.7	18.3	28.3	322
Refrigerated warehouse	1.4	15.1	18.1	206

2.4 Envelope

Huang and Franconi (1999) defined performance levels for opaque envelopes as part of their study on component loads. We have used their R-factor assignments as reorganized and presented in Table 2-6 for walls and Table 2-7 for roofs. They divided the United States into two geographic regions, north and south, based on degree days.

Table 2-6 Wall R-Factor Assignments by Building Type, Activity, and Geography (Huang and Franconi 1999)

Building Type	Old Vintage (pre-1980)		New Vintage (post-1980)	
	North Btu/h·ft²·F (W/m²·K)	South Btu/h·ft²·F (W/m²·K)	North Btu/h·ft²·F (W/m²·K)	South Btu/h·ft²·F (W/m²·K)
Small office	4.9 (1.158)	3.9 (1.456)	6.3 (0.901)	5.6 (1.014)
Large office	2.5 (2.271)	2.5 (2.271)	4.6 (1.234)	6.0 (0.946)
Small retail	3.4 (1.67)	2.5 (2.271)	6.6 (0.86)	4.8 (1.183)
Large retail	3.1 (1.832)	3.3 (1.721)	6.4 (0.887)	4.8 (1.183)
Small hotel	3.4 (1.67)	3.4 (1.67)	5.3 (1.071)	5.3 (1.071)
Large hotel	3.6 (1.577)	3.6 (1.577)	6.2 (0.916)	6.2 (0.916)
Fast food restaurant	10.9 (0.521)	10.9 (0.521)	13.2 (0.43)	13.2 (0.43)
Sit down restaurant	10.9 (0.521)	10.9 (0.521)	13.2 (0.43)	13.2 (0.43)
Hospital	4.3 (1.321)	4.3 (1.321)	6.9 (0.823)	6.9 (0.823)
School	2.7 (2.103)	3.4 (1.67)	5.3 (1.07)	5.7 (0.996)
Supermarket	3.3 (1.721)	3.3 (1.721)	5.8 (0.979)	5.8 (0.979)
Warehouse	3.2 (1.774)	2.4 (2.366)	4.6 (1.234)	4.0 (1.42)

Table 2-7 Roof R-Factor Assignments by Building Type, Activity, and Geography (Huang and Franconi 1999)

Building Type	Old Vintage (pre-1980)		New Vintage (post-1980)	
	North Btu/h·ft²·F (W/m²·K)	South Btu/h·ft²·F (W/m²·K)	North Btu/h·ft²·F (W/m²·K)	South Btu/h·ft²·F (W/m²·K)
Small office	11.9 (0.477)	10.5 (0.541)	13.3 (0.427)	12.6 (0.451)
Large office	9.1 (0.624)	11.2 (0.507)	9.1 (0.624)	12.6 (0.451)
Small retail	10.2 (0.557)	9.5 (0.598)	13.2 (0.43)	12.0 (0.473)
Large retail	10.6 (0.536)	11.5 (0.494)	14.0 (0.406)	12.0 (0.473)
Small hotel	9.8 (0.579)	9.8 (0.579)	13.2 (0.43)	13.2 (0.43)
Large hotel	11.8 (0.481)	11.8 (0.481)	14.0 (0.406)	14.0 (0.406)
Fast food restaurant	10.9 (0.521)	10.9 (0.521)	13.2 (0.43)	13.2 (0.43)
Sit down restaurant	10.9 (0.521)	10.9 (0.521)	13.2 (0.43)	13.2 (0.43)
Hospital*	12.3 (0.462)	12.3 (0.462)	11.5 (0.494)	11.5 (0.494)
School	10.9 (0.521)	10.1 (0.562)	12.6 (0.451)	13.3 (0.427)
Supermarket	9.2 (0.617)	9.2 (0.617)	11.5 (0.494)	11.5 (0.494)
Warehouse	7.8 (0.728)	7.6 (0.747)	10.1 (0.562)	10.6 (0.536)

*The roof insulation decreased for new hospitals.

2.5 Outside Air

Outside air is introduced in buildings intentionally as mechanical ventilation and unintentionally as infiltration. Additional research is needed to fully characterize outside air rates across the commercial sector; however, there have been some efforts in the literature to do so. Most such efforts combine mechanical ventilation and infiltration. Orme (2001) estimated the energy impact of controlled (mechanical) and uncontrolled (infiltration) ventilation by assuming air change rates of 0.75 air changes per hour (ACH) for all commercial (service sector) buildings in all climates and all countries. Colliver

(1995) modeled the specific energy requirements of ventilation air per kilogram of ventilation air, but did not extend analyses to include the amount or rates of ventilation air. Fisk (2000) summarized studies of sick building syndrome that reported ventilation rates varying from 0 to 60 liters per second per person (l/s-person), but there is no indication that these ventilation rates are representative of the stock. Seppanen et al. (1999) characterize the normal range of ventilation at 5 to 30 l/s-person.

Chan (2006) reviewed the literature with measured data and modeled air leakage from commercial buildings. He used data about the shapes of commercial buildings in Oklahoma City to arrive at a distribution for the infiltration rates in commercial buildings. Chan's modeling was based on 1999 CBECS; he found that infiltration rates in the commercial sector are distributed according to a probability density function (PDF) defined by a lognormal distribution with a geometric mean of 0.35 ACH and a geometric standard deviation of 2.1 ACH (see Figure 5-22 in Chan 2006). Chan's distribution was selected for use in assigning infiltration rates in the current methodology.

Persily (1998) reviewed literature with measured data about airtightness from a combined total of 139 commercial buildings. As Persily points out, "There is no simple calculation method or rule of thumb to relate envelope tightness to infiltration in commercial buildings…" Because leakiness is evaluated at elevated pressure differences, translating these rates into infiltration rates for use in annual energy modeling is difficult without using detailed airflow network models. Persily found a mean infiltration rate of 27.1 $m^3/h \cdot m^2$ (1.5 cfm/ft^2) at 75 Pa (0.3 in. of water) and concluded that commercial buildings are not tighter than residential buildings. Although the data set is minimal and not formulated from a suitable random sample, he also concluded that there is little evidence to support the notion that age and type of construction affect airtightness.

Turk et al. (1989) used tracer gas techniques to measure ventilation rates in 38 commercial buildings in the Pacific Northwest. Table 2-8 lists the results used in the current study. They found mean ventilation rates of 1.5 ACH or 28 l/s-person and provided a breakdown for five building classifications: educational, libraries, small and large offices, and multi-use. These measured outside air rates are roughly twice those assumed by Orme. These data are based on a relatively small sample size with limited types of buildings and geographic regions, and therefore provide only a rough estimate of actual outside air rates across the sector. However, they appear to be as good as anything available; we adapted them to develop inputs for mechanical ventilation.

Table 2-8 Measured Outside Air Rates (Turk et al. 1989)

Building Classification	N	Outside Air Rate (ACH)	Outside Air Rate (cfm/person)	Outside Air Rate (l/s·person)
Educational	7	1.9	33	15.6
Office/professional < 100,000 ft^2 (9,300 m^2)	8	1.5	75	35.4
Office/professional > 100,000 ft^2 (9,300 m^2)	14	1.8	65	30.7
Libraries	3	0.6	71	33.5
Multi-use	5	1.4	60	28.3
Naturally ventilated	3	0.8	38	17.9

3. Methodology

This section describes the methodology developed to model building energy performance across the entire commercial sector. The basic framework for the analysis is diagrammed in Figure 3-1. This report covers part of a larger study conducted to assess the commercial sector. The second and third parts of the study are included in two separate reports that are closely related to this one. This first report documents the methods used in the second report to analyze the technical potential for net-zero energy buildings (Griffith et al. 2007) and in the third report to explore the energy impacts of outside air (Benne et al. 2008).

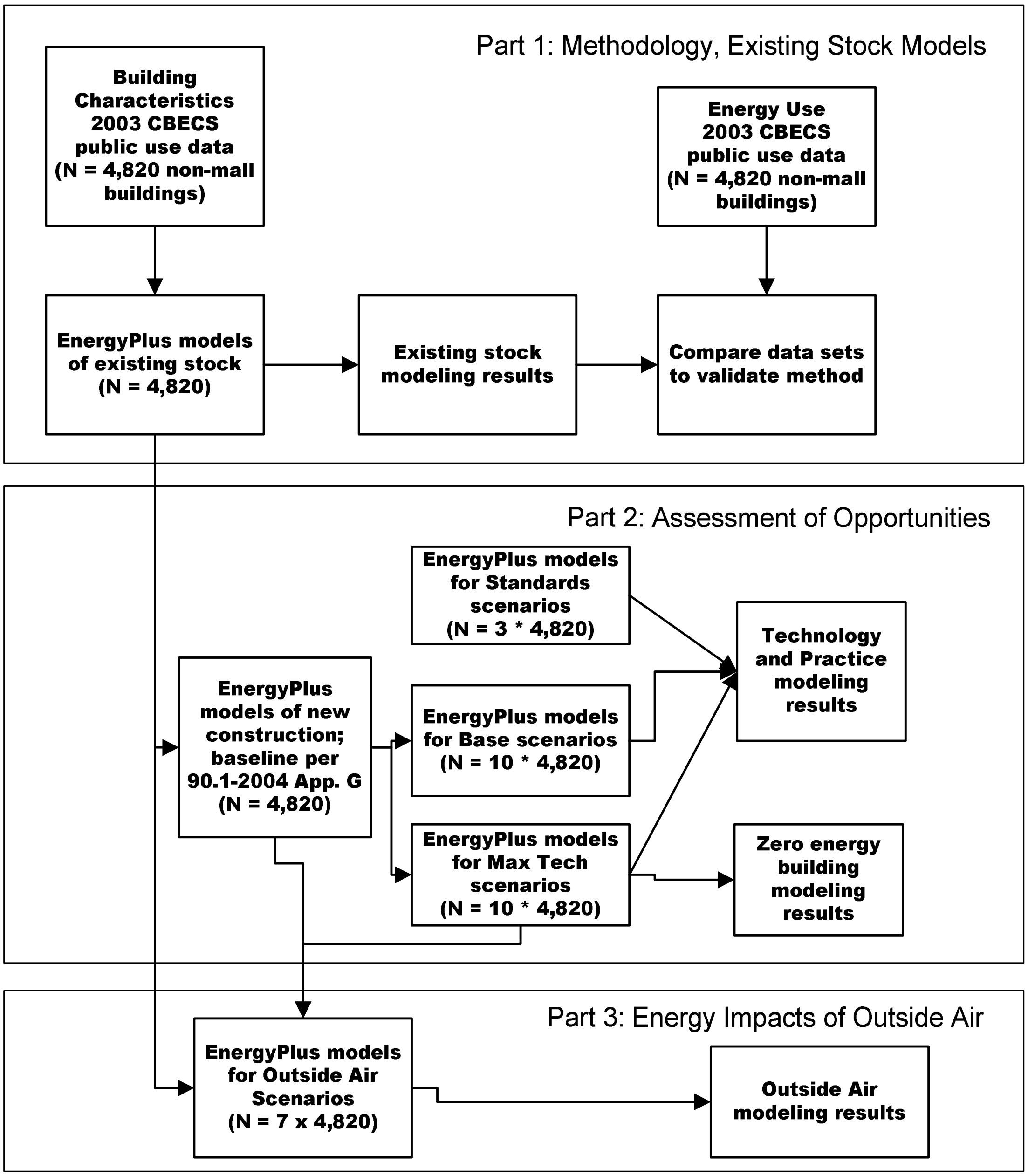

Figure 3-1 Overview of Commercial Sector Assessment

3.1 Background

Whole-building simulation has been in use for approximately 30 years, and researchers have long used such tools to represent large portions of the building stock. Some of the earliest research was conducted at Pacific Northwest National Laboratory (Briggs, Crawley, and Belzer 1987; Briggs, Crawley, and Schliesing 1992; Crawley and Schliesing 1992). A more current example is research by Huang and Franconi (1999) at Lawrence Berkeley National Laboratory (LBNL), who built on this work. The LBNL researchers focused on modeling component loads for the building stock. Moffat (2001) presents a good overview of these methods, which he refers to as stock aggregation, in the context of life-cycle analysis and community planning. Large-scale simulation studies are also common in the history of developing codes and standards. The earlier projects demonstrated the utility of running large numbers of detailed models to address certain questions.

We selected EnergyPlus (DOE 2007) because it is the contemporary DOE/BT energy simulation tool; it accounts for the complex interactions between climate, internal gains, building form and fabric, HVAC systems, and renewable energy systems. The simulations are run with a custom version of EnergyPlus Version 2.0 compiled to run on a 64-bit cluster computer at NREL. EnergyPlus is a heavily tested program; formal BESTEST validation efforts were repeated for every release (Judkoff and Neymark 1995; ASHRAE 2004b).

Defining a building model for the EnergyPlus simulation program requires considerable detail. Table 3-1 lists examples of input parameters we use to structure these details into the following four groups:

- *Program* refers to the *architectural program*, which describes how the building will be used and the services it must deliver to the occupants. From an energy point of view, program decisions influence many important drivers (climate, plug and process loads, ventilation requirements, operating schedules, and comfort tolerances) that will ultimately determine energy performance.
- *Form* refers to the geometry of the building and its elements, and has important energy implications that stem from how the building interacts with the sun and ambient conditions.
- *Fabric* refers to the materials used to construct the building and involves decisions about insulation levels, glazing systems, and thermal mass.
- *Equipment* includes HVAC equipment, lighting systems and controls. Except for plug and process load equipment selected by the occupants, this includes all the energy-consuming equipment that is part of the building.

Table 3-1 Model Parameter Categories with Sample Parameters

Program	Form	Fabric	Equipment
Facility location Total floor area Schedules Plug and process loads Lighting levels Ventilation needs Occupancy Site constraints	Floor plate Number of floors Aspect ratio Window fraction Window locations Shading Floor height Orientation	Exterior walls Roof Windows Interior partitions Internal mass	HVAC system types Component efficiency Control settings Lighting fixtures Lamp types Daylighting controls

3.2 Model Generation

The process used in the methodology is to take each building in the 2003 CBECS public use data files and create an EnergyPlus model that approximates it. A statistical model of the commercial buildings energy sector is formed by the survey's sample buildings, which have weighting factors that indicate how many more such buildings are represented by each sample. Energy consumption data for malls are available from 2003 CBECS, but malls were excluded from the study because their characteristics are not described well in the 2003 CBECS public use data (to preserve anonymity). For each building, we used a variety of CBECS data about floor area, number of floors, census division, basic climatic design criteria, PBA, number of employees, operating hours, type of heating and cooling system, type of windows, and many other variables. However, EnergyPlus models require much more detail about buildings than is available in the 2003 CBECS data. Therefore, an important part of the methodology is to synthesize the additional detail needed in the EnergyPlus input file. This is accomplished by complementing the 2003 CBECS data set with a mixture of literature sources, probabilistic assignments, and assumptions. The details of these translations are lengthy and are only summarized here; more thorough documentation is found in Appendix C.

The process of developing the method included some iteration to target data sources. In most cases, using inverse methods to back out the input that will produce a desired result is too difficult. In targeting occupant-driven plug and process load data from CEUS, the iteration method is used to adjust certain coefficients in the input generating routines. Only energy consumption data were used. All iterations involved rerunning the entire set of models, typically incorporating bug fixes in routines or EnergyPlus routines, or both, and adjusted input modeling coefficients.

3.2.1 Program

The first step in developing a building model is to define the architectural program for the building being evaluated. The type of activity a building is used for is provided directly by CBECS data for PBA and "more specific building activity" (PBAPLUS). Both classification systems were used to generate a variety of model inputs. Locations for all buildings were modeled from CBECS data by finding the weather file location that most closely matched CBECS data for census division and degree days (see Section C.2). These modeled locations are then used to determine a number of model inputs, including climatic design conditions for sizing, ground temperatures, utility tariffs, and source, emission, and water energy factors, that have geographic variation. The total floor area of the building is provided by CBECS. Operating schedules were modeled from a variety of CBECS data for the number of operating hours per week, whether the business is open on weekends, and other factors (see Section C.5). Occupant-driven plug and process loads are modeled from building activity and use data discussed in Section 2 (see Section C.14 for electrical plug and process loads, Section C.21 for service hot water (SHW) loads, Section C.22 for refrigeration, and Section C.23 for gas process loads.

3.2.2 Form

To develop the EnergyPlus models efficiently, we assumed that building floor plates were rectangular, above grade, and uniform from floor to floor. The thermal models use a five-zone per floor zoning pattern. In reality, five thermal zones are too many for buildings with smaller floor plates and too few for large complex buildings, so this is a compromise that can be applied to all buildings. The number of floors is provided directly by CBECS data. The overall shape of the rectangular buildings is described by an aspect ratio, which is the east–west length divided by the north–south length. Probabilistic assignments were used to assign aspect ratios and orientations of the buildings (see Section C.7). The exterior windows were modeled from CBECS data for exterior glazing area with probabilistic assignments, and the locations and shapes of the windows were assumed (see Section C.11). Floor-to-floor heights used probabilistic assignments that varied by PBA (see Section C.9).

3.2.3 Fabric

The materials and constructions used for each building were modeled from CBECS data (see Section C.12). The composition of exterior walls and roofs was developed from CBECS data about the types of construction and R-factor data from Huang and Franconi (1999). The composition of window glazings was modeled from CBECS data about window types and tints or reflective coatings. The compositions of interior partitions and internal mass were assumed.

We used literature data and a combination of a flow per unit area of exterior surfaces and a low-level whole-zone air change rate to model the infiltration behavior of the exterior envelope (see Section C.16).

3.2.4 Equipment

Electric lighting power density (LPD) was set probabilistically by using mean values from literature and assumed standard deviations that varied by PBA (see Section C.15). CBECS data for the type of heating and cooling systems were used to assign HVAC system types. Buildings were assumed to be either entirely conditioned or not conditioned at all; a 25% threshold for the percent conditioned data from CBECS was used to make the determination separately for heating and cooling. Fifty-two HVAC topologies were used in the modeling (See Section C.18). The performance characteristics of the primary components in the HVAC system were modeled from the age of the building by using assumed efficiencies developed from different vintages of building energy standards. A linear function of estimated age of equipment was used to model equipment degradation (see Section C.19). Thermostatic control settings were incorporated into schedules that follow the operating hours and typical setup and setback practices (see Section C.5, Table C-16). Mechanical ventilation was modeled from literature data (see Section C.20).

3.3 Validation

This section describes the process used to validate the methodology. The validity of the method needs to be examined before it is used in studies that address energy performance across the commercial sector.

The overall process used to validate the bottom-up modeling method is to run the models in EnergyPlus and then compare the modeling results to the CBECS survey results. The model development was “blind” in that we did not use 2003 CBECS survey results for energy performance when we developed input data. Instead, we reserved the energy performance results for validation. Although no formal controls were put in place to guarantee “blindness” after the energy performance data were released, the methods for generating inputs were developed during a time when EIA had released only the preliminary data set for building characteristics. (EIA released 2003 CBECS public use data in multiple phases, and the first set did not include the energy consumption results.) However, model input was iterated to target literature data. The authors were experienced in the sector and therefore had general knowledge of typical performance and the results from 1999 CBECS. The process includes four steps:

1. Generate the EnergyPlus models. Computer routines were implemented that automate the creation of model input files, because manual methods would not be feasible for such a large number of building models. The approach documented in this report was used to generate each of the 4,820 models.

2. Simulate the buildings by running the models in EnergyPlus. Computer routines were implemented that manage the execution of each EnergyPlus model. For a fair comparison between the models and the survey, the weather data used in the modeling corresponded to the actual weather of the survey year. These 2003 historical weather files were produced in EnergyPlus format from data in the *National Solar Radiation Database 1991-2005 Update: User Manual* (NREL 2007).

3. Collect and analyze the energy performance results from the modeling. Computer routines were implemented that automate the process of extracting key data from the EnergyPlus output files and storing them in a database. Analysis routines were implemented that allow aggregating results from the different buildings to produce values such as weighted mean, weighted standard deviation, and PDFs for various metrics and output bases. NREL made a key assumption that the CBECS weighting factors were still applicable, although many details of the survey buildings were unknown and were generated synthetically.

4. Collect and analyze the energy performance results from 2003 CBECS public use data. Computer routines were implemented that allow aggregating the results from the survey in the

same ways as the results from the modeling. The survey results were also normalized to calculate energy use intensity (EUI) so the performance can be compared across different sized buildings. Survey public use data from EIA does not directly include EUI or ASHRAE climate zone; values in this report survey EUI and climate were modeled from other survey results.

The validity of the method was then examined by comparing the results from the existing stock models to the survey results in an effort to explore the validity of the bottom-up method being used to model the sector. We used the following metrics for the comparisons (for more on metric definitions see Barley et al. [2005]):

- *Total site EUI* is the sum of all the energy used by the building normalized by the total floor area of the building. Electricity and gas are combined without regard for their production and delivery. This metric ignores any energy produced at the site.
- *Electricity use intensity* is the sum of all electricity used by the building, normalized by the total floor area of the building.
- *Natural gas use intensity* is the sum of all natural gas used by the building, normalized by the total floor area of the building.
- *Energy cost intensity* is the sum of the costs of all energy used by the building, normalized by the total floor area of the building. The costs are the results of detailed tariff modeling; realistic utility rates were calculated for each building model. The tariff structures vary by location and reflect the complexities of demand charges and time-of-use (TOU) rates. These data were compiled from Web sources (Tariff Analysis Project, utilities, and EIA) and made into EnergyPlus input objects.

For this study, the methodology is to be considered valid if the weighted mean results from the models agree with the survey to within:

- One weighted standard deviation in the survey results
- 15% absolute EUI
- 20% absolute electricity use intensity
- 20% absolute natural gas use intensity
- 15% absolute energy cost intensity.

4. Results and Discussion

In this section we compare results from the modeling effort and 2003 CBECS. The comparisons are generally based on averages of large numbers of buildings, because individual samples vary too widely. The intensity metrics used for results are normalized by building floor area so different buildings can be combined in weighted averages. The populations of buildings were examined in different ways, including by subsector where buildings are grouped by PBA, by climate zone where buildings are grouped by climate zones assigned to samples in this study, and by census division. Individual subsections examine different metrics such as total energy use, electricity use, natural gas use, and total energy costs.

4.1 Total Energy Use

Figure 4-1 shows results by subsector for the weighted mean results for total site EUI. The numeric values are provided in Table A-4 along with the weighted standard deviation of the EUI values. Overall, the models agree to within 12%. The modeling tends to track the survey results fairly well across different subsectors, except for education, food service, inpatient health, and public order and safety.

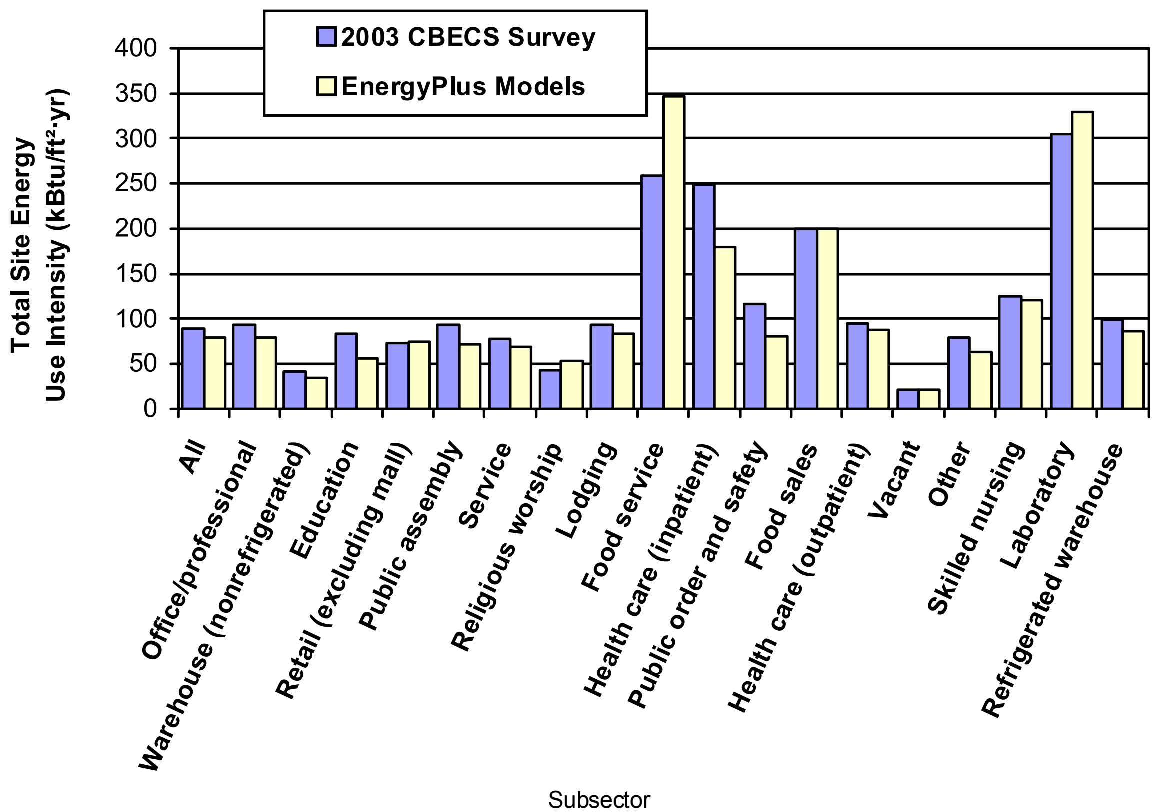

Figure 4-1 Total EUI: 2003 CBECS Survey and Modeling by Subsector

Figure 4-2 shows results by climate zone for the weighted mean results for total site EUI. Table A-5 contains the values along with the weighted standard deviation in the EUI values and the number of buildings. The climate zone classification is defined in ANSI/ASHRAE Standard 169-2006 (ASHRAE 2006) and shown in Figure 4-3. The climate zone data here are extrapolated from 2003 CBECS and are not part of the CBECS public data set. NREL assigned a 169-2006 climate zone to each sample building by fitting survey data for heating degree days (HDDs) and cooling degree days (CDDs). We used degree days from 2003 historical weather data rather than typical or average conditions. The 2003 CBECS survey was not organized around these climate zones, and some of these classifications, including 1A, 2B, 3C, 4B, 4C, and 7, have too few samples to be statistically valid. The main body of results here used historical weather data for 2003, but Figure 4-2 also shows modeling results with TMY data. The modeling results track survey results for climate zones 2A, 3B, 3C, 6A, 6B, and 5B, but not 1A, 4B, 4C, or 7A. The climate zones with the poorest agreement are those with the fewest buildings in the set.

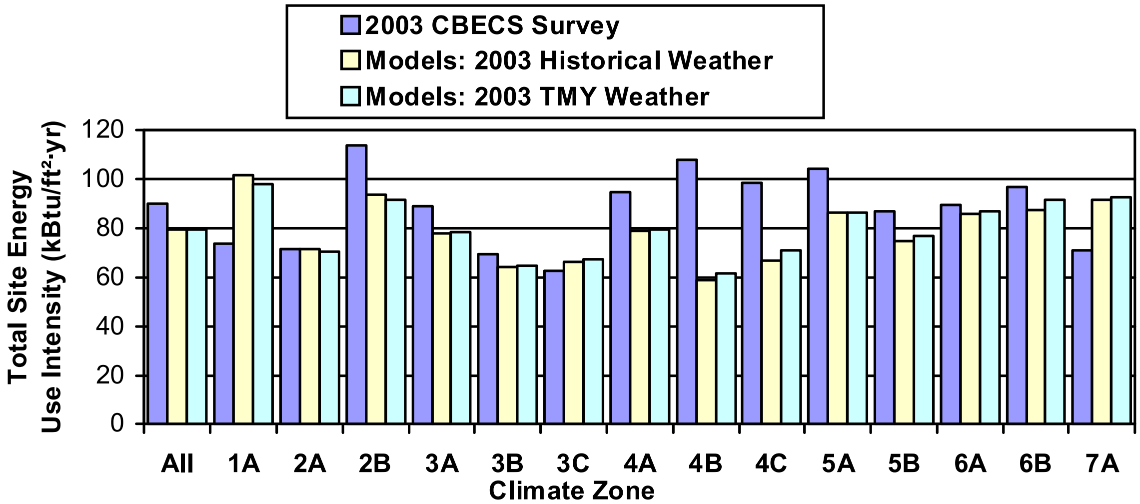

Figure 4-2 Total EUI: 2003 CBECS Survey and Modeling by Climate Zone

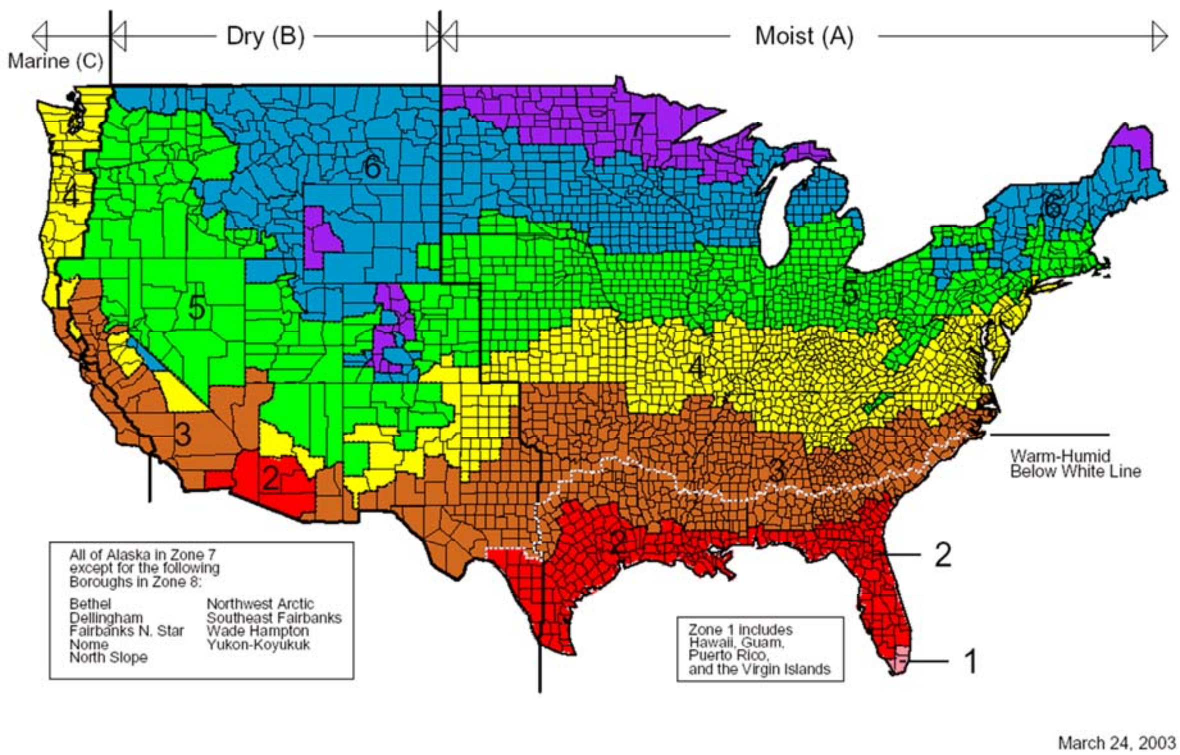

Figure 4-3 Map of ASHRAE 169-2006 Climate Zones

(Figure reprinted from www.energycodes.gov/implement/pdfs/color_map_climate_zones_Mar03.pdf)

Figure 4-4 shows results by census division for the weighted mean results for total site EUI. (Table A-6 has the values along with the weighted standard deviation in the EUI values and the number of buildings.) Census divisions are defined by the U.S. Department of Commerce. Relatively good agreement was obtained for Pacific, West South Central, New England, and South Atlantic census divisions. The two census divisions with relatively poor agreement are East North Central and Mountain.

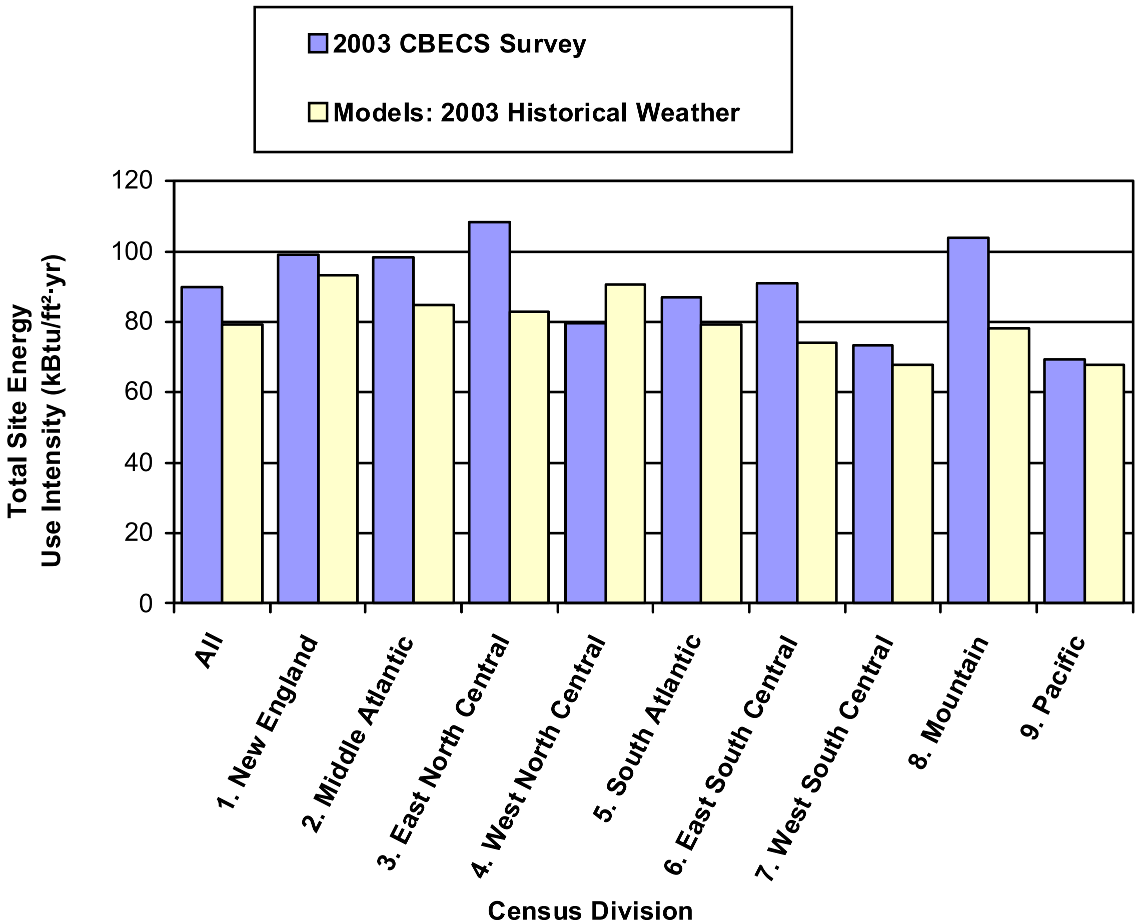

Figure 4-4 Total EUI: 2003 CBECS Survey and Modeling by Census Division

Mean values for net EUI values from 2003 CBECS are provided in Table 4-1 and Table 4-3 by subsector and climate zone. Table 4-2 and Table 4-4 list the net EUI values for the existing stock models. These tables also include values for the weighted standard deviation (σ) in the results. The gray boxes indicate there are no models because the 2003 CBECS sample did not include any buildings in that particular category. The number of models and samples for each category are listed in Table 4-5. The comparison between models and survey requires a relatively large number of samples, but many categories do not have sufficient numbers. A specific criterion for how many samples are required for meaningful averages is difficult to determine. But because of the masking and shifting of floor area in CBECS public use data, the criterion for number of samples for area normalized intensity metrics is currently estimated at 100. Table 4-6 lists the percentage differences in total EUI between the model and survey results.

Table 4-1 2003 CBECS Weighted Mean EUI and Standard Deviation by Subsector and Climate Zone: IP Units kBtu/ft²·yr

Subsector	Climate Zone														
	All	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
All	90 σ = 97	74 σ = 98	72 σ = 88	114 σ = 92	89 σ= 105	70 σ = 98	62 σ = 54	95 σ= 105	108 σ= 104	99 σ = 89	104 σ = 99	87 σ = 85	89 σ = 90	97 σ = 73	71 σ = 70
Office/professional	93 σ = 68	42 σ = 66	82 σ = 62	72 σ = 40	88 σ = 52	70 σ = 38	58 σ = 19	97 σ = 76	143 σ = 72	95 σ = 43	107 σ = 70	66 σ = 43	110 σ = 93	114 σ = 67	68 σ = 37
Nonrefrig. warehouse	42 σ = 56	22 σ = 21	16 σ = 14		22 σ = 27	21 σ = 19	20 σ = 37	39 σ = 49	29 σ = 26	37 σ = 29	79 σ = 83	60 σ = 58	37 σ = 36	58 σ = 75	33 σ = 31
Education	83 σ = 68	52 σ = 24	73 σ = 60	160 σ = 73	62 σ = 41	74 σ = 70	105 σ = 76	102 σ= 115	38 σ = 22	58 σ = 27	87 σ = 40	79 σ = 45	90 σ = 52	90 σ = 52	84 σ = 28
Retail (except malls)	74 σ = 75	61 σ = 52	93 σ= 135	129 σ= 102	60 σ = 45	50 σ = 39	31 σ = 16	65 σ = 58	100 σ = 90		88 σ = 90	80 σ = 49	93 σ = 86	97 σ = 78	102 σ = 75
Public assembly	94 σ = 85	75 σ = 15	60 σ = 63		112 σ= 137	48 σ = 48	45 σ = 26	110 σ = 87	44 σ = 31	249 σ= 179	103 σ = 76	97 σ = 87	88 σ = 57	102 σ = 52	97 σ= 112
Service	77 σ = 97	60 σ = 6	53 σ = 50		49 σ = 50	61 σ= 166	27 σ = 16	82 σ= 107	83 σ = 90		80 σ = 77	101 σ= 108	88 σ= 140	99 σ = 62	65 σ = 69
Religious worship	44 σ = 34		31 σ = 11		28 σ = 20	31 σ = 28		47 σ = 30	56 σ = 44		52 σ = 43	39 σ = 21	53 σ = 41	34 σ = 19	
Lodging	94 σ = 63	81 σ = 47	91 σ = 61		98 σ = 44	57 σ = 30		92 σ = 56	264 σ = 80	54 σ = 5	89 σ = 53	65 σ = 27	108 σ = 51	93 σ = 50	68 σ = 52
Food services	258 σ= 233	393 σ= 133	208 σ= 190		423 σ= 278	393 σ= 242	82 σ = 21	234 σ= 242		260 σ= 199	258 σ= 220	228 σ= 293	203 σ= 188	236 σ= 353	192 σ= 129
Inpatient health care	249 σ= 126	200 σ = 49	246 σ = 88	360 σ= 295	205 σ = 58	257 σ= 203	204 σ = 78	248 σ= 119	163 σ = 71		294 σ= 147	245 σ = 83	240 σ= 135	235 σ= 108	256 σ = 57
Public order and safety	116 σ = 57		91 σ = 23		160 σ= 126	79 σ = 21		129 σ = 71			108 σ = 41	94 σ = 54	126 σ = 44	148 σ = 3	
Food sales	200 σ= 122		166 σ= 135		212 σ = 76	183 σ = 93	120 σ = 25	242 σ= 170			203 σ = 99	147 σ= 151	242 σ= 113		199 σ= 115
Outpatient health care	95 σ = 81	19 σ = 44	77 σ = 49		55 σ = 48	106 σ = 89		70 σ = 62	190 σ= 120		111 σ = 83	120 σ = 85	112 σ= 110	91 σ = 80	166 σ = 73
Vacant	21 σ = 31		4 σ = 12	47 σ = 21	4 σ = 9	6 σ = 7	0 σ = 1	40 σ = 41	3 σ = 10	60 σ = 12	21 σ = 26	93 σ = 70	22 σ = 25		55 σ =72
Other	79 σ = 73		48 σ = 59		100 σ= 143	175 σ= 110		71 σ = 73	26 σ = 8		94 σ = 80	92 σ = 39	69 σ = 62	85 σ = 9	57 σ =32
Skilled nursing	125 σ = 63		71 σ = 34		84 σ = 46	85 σ = 74		148 σ = 71			148 σ = 56	153 σ = 81	118 σ = 42	134 σ = 76	
Laboratory	305 σ= 170				242 σ = 61	170 σ = 82		600 σ= 367			370 σ= 138		268 σ = 35	115 σ = 15	
Refrigerated warehouse	99 σ = 72							120 σ = 49			68 σ = 35	51 σ = 67	62 σ = 60		

Table 4-2 Existing Stock Models EUI by Subsectors and Climate Zones: IP Units (kBtu/ft^2·yr)

Subsector	Climate Zone														
	All	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
All	79 σ = 74	102 σ= 133	72 σ = 76	94 σ = 73	78 σ = 85	64 σ = 70	66 σ = 58	79 σ = 66	59 σ = 39	67 σ = 61	86 σ = 75	75 σ = 61	86 σ = 82	87 σ = 49	92 σ = 85
Office/professional	79 σ = 34	78 σ = 17	79 σ = 34	73 σ = 18	68 σ = 24	64 σ = 26	63 σ = 16	81 σ = 36	68 σ = 30	68 σ = 25	86 σ = 36	61 σ = 17	85 σ = 37	82 σ = 36	101 σ = 40
Nonrefrig. warehouse	34 σ = 24	35 σ = 29	23 σ = 19		26 σ = 22	30 σ = 18	31 σ = 36	31 σ = 22	31 σ = 25	37 σ = 16	43 σ = 24	40 σ = 22	40 σ = 31	45 σ = 40	42 σ = 16
Education	55 σ = 31	96 σ = 70	60 σ = 46	107 σ = 49	42 σ = 22	46 σ = 20	39 σ = 13	57 σ = 28	36 σ = 14	40 σ = 13	55 σ = 27	57 σ = 27	66 σ = 30	63 σ = 28	74 σ = 11
Retail (except malls)	75 σ = 34	58 σ = 62	62 σ = 27	93 σ = 29	65 σ = 30	58 σ = 17	57 σ = 8	74 σ = 31	70 σ = 17		87 σ = 36	77 σ = 29	89 σ = 39	103 σ = 47	136 σ = 24
Public assembly	72 σ = 44	73 σ = 29	57 σ = 47		75 σ = 41	56 σ = 44	55 σ = 14	67 σ = 29	55 σ = 41	99 σ = 64	78 σ = 44	76 σ = 36	84 σ = 35	72 σ = 20	98 σ= 115
Service	70 σ = 36	74 σ = 10	56 σ = 31		53 σ = 31	44 σ = 31	36 σ = 9	71 σ = 31	44 σ = 14		79 σ = 34	66 σ = 33	69 σ = 47	91 σ = 29	84 σ = 44
Religious worship	53 σ = 43		33 σ = 16		27 σ = 19	33 σ = 26		53 σ = 45	76 σ = 46		69 σ = 50	43 σ = 21	71 σ = 43	52 σ = 27	
Lodging	83 σ = 42	102 σ = 44	88 σ = 31		66 σ = 26	47 σ = 13		102 σ = 53	65 σ = 9	80 σ = 56	75 σ = 26	82 σ = 42	90 σ = 41	108 σ = 37	78 σ = 42
Food services	347 σ= 124	589 σ= 334	326 σ =107		324 σ= 128	388 σ = 75	243 σ = 6	338 σ= 119		462 σ= 182	354 σ= 131	293 σ= 108	371 σ = 91	218 σ = 90	489 σ= 195
Inpatient health care	181 σ= 100	197 σ= 132	184 σ= 79	217 σ= 120	143 σ = 35	161 σ = 48	123 σ = 26	175 σ = 61	132 σ = 13		201 σ = 93	196 σ = 76	234 σ= 249	172 σ = 57	377 σ = 61
Public order and safety	80 σ = 41		61 σ = 25		59 σ = 14	98 σ = 31		72 σ = 37			96 σ = 43	102 σ = 74	82 σ = 44	101 σ = 33	
Food sales	201 σ = 53		193 σ = 23		193 σ = 35	154 σ = 59	147 σ = 32	206 σ = 43			203 σ = 56	206 σ = 46	259 σ = 88		214 σ = 31
Outpatient health care	88 σ = 42	87 σ = 22	66 σ = 23		59 σ = 14	92 σ = 39		77 σ = 38	111 σ = 58		108 σ = 53	67 σ = 27	97 σ = 36	94 σ = 34	116 σ = 39
Vacant	22 σ = 34		3 σ = 3	36 σ = 14	8 σ = 9	12 σ = 12	2 σ=0.04	18 σ = 20	3 σ = 5	11 σ = 23	29 σ = 31	17 σ = 12	26 σ = 38		104 σ = 95
Other	62 σ = 26		56 σ = 35		39 σ = 21	56 σ = 17		67 σ = 21	42 σ = 0.4		64 σ = 31	40 σ = 15	61 σ = 24	104 σ = 66	57 σ = 36
Skilled nursing	121 σ = 26		115 σ = 6		122 σ = 40	107 σ = 11		123 σ = 21			121 σ = 21	125 σ = 31	120 σ = 33	180 σ = 33	
Laboratory	330 σ = 65				352 σ = 4	315 σ = 95		268 σ = 54			327 σ = 70		334 σ = 65	265 σ = 74	
Refrigerated warehouse	86 σ = 25							80 σ = 7			70 σ = 11	85 σ = 34	112 σ = 39		

Table 4-3 2003 CBECS EUI by Subsectors and Climate Zones
SI Units (MJ/m²·yr)

Subsector	Climate Zone														
	All	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
All	1,021 σ =1106	838 σ=1118	813 σ=1001	1,290 σ=1041	1,011 σ=1195	791 σ=1117	708 σ=618	1,076 σ=1191	1,226 σ=1184	1,120 σ=1016	1,186 σ=1125	986 σ=969	1,016 σ=1021	1,097 σ=832	806 σ=801
Office/professional	1,055 σ=773	476 σ=751	930 σ=703	814 σ=451	996 σ=586	798 σ=434	655 σ=214	1,099 σ=863	1,619 σ=818	1,080 σ=489	1,219 σ=800	754 σ=488	1,253 σ=1061	1,298 σ=757	773 σ=425
Nonrefrig. warehouse	481 σ=638	244 σ=239	177 σ=164		254 σ=309	243 σ=213	223 σ=421	442 σ=557	325 σ=300	422 σ=332	897 σ=938	685 σ=661	423 σ=413	655 σ=853	379 σ=356
Education	944 σ=774	585 σ=269	824 σ=684	1,822 σ=834	700 σ=466	846 σ=795	1,192 σ=862	1,161 σ=1303	433 σ=252	660 σ=311	988 σ=455	900 σ=512	1,026 σ=588	1,025 σ=592	949 σ=314
Retail (except malls)	840 σ=858	690 σ=589	1,052 σ=1533	1,464 σ=1159	680 σ=511	570 σ=449	354 σ=176	742 σ=657	1,131 σ=1021		996 σ=1026	911 σ=559	1,057 σ=976	1,104 σ=891	1,160 σ=847
Public assembly	1,068 σ=967	853 σ = 170	684 σ=718		1,269 σ=1552	545 σ=544	509 σ=294	1,245 σ=990	500 σ=354	2,825 σ=2029	1,172 σ=867	1,107 σ=992	1,004 σ=649	1,155 σ=592	1,104 σ=1275
Service	875 σ=1108	679 σ=66	604 σ=567		562 σ=565	688 σ=1886	310 σ=180	936 σ=1217	937 σ=1017		913 σ=874	1,150 σ=1230	995 σ=1588	1,119 σ=705	741 σ=783
Religious worship	494 σ=391		354 σ=126		320 σ=232	347 σ=316		535 σ=343	635 σ=505		591 σ=489	448 σ=237	606 σ=465	386 σ=216	
Lodging	1,070 σ=717	918 σ=536	1,037 σ=699		1,118 σ=504	646 σ=339		1,050 σ=635	2,995 σ=914	617 σ=57	1,010 σ=604	740 σ=308	1,227 σ=585	1,061 σ=571	768 σ=591
Food services	2,935 σ=2642	4,461 σ=1514	2,367 σ=2165		4,803 σ=3161	4,461 σ=2755	930 σ=238	2,660 σ=2752		2,950 σ=2259	2,928 σ=2500	2,596 σ=3327	2,310 σ=2132	2,679 σ=4007	2,176 σ=1471
Inpatient health care	2,831 σ=1432	2,270 σ=562	2,798 σ=1005	4,094 σ=3353	2,329 σ=655	2,920 σ=2304	2,319 σ=888	2,820 σ=1349	1,852 σ=808		3,341 σ=1667	2,785 σ=945	2,730 σ=1538	2,675 σ=1232	2,908 σ=650
Public order and safety	1,316 σ = 647		1,039 σ = 264		1,820 σ=1429	894 σ = 242		1,468 σ = 805			1,229 σ = 460	1,062 σ = 609	1,437 σ = 500	1,681 σ = 29	
Food sales	2,269 σ = 1388		1,888 σ=1537		2,413 σ = 859	2,080 σ=1060	1,364 σ=286	2,753 σ=1927			2,305 σ=1129	1,675 σ=1717	2,745 σ=1286		2,257 σ=1309
Outpatient health care	1,075 σ = 919	211 σ = 505	880 σ = 558		625 σ = 544	1,199 σ=1017		790 σ = 701	2,153 σ=1361		1,262 σ = 938	1,358 σ = 964	1,267 σ=1252	1,032 σ = 911	1,887 σ = 833
Vacant	237 σ = 357		42 σ = 135	539 σ = 239	45 σ = 97	71 σ = 75	2 σ = 9	457 σ = 463	34 σ = 118	680 σ = 137	235 σ = 294	1,060 σ = 799	250 σ = 281		621 σ = 823
Other	902 σ = 827		544 σ = 675		1,131 σ=1624	1,987 σ=1253		809 σ = 829	290 σ = 96		1,068 σ = 906	1,044 σ = 440	780 σ = 702	960 σ = 106	643 σ = 369
Skilled nursing	1,416 σ = 715		806 σ = 391		949 σ = 524	967 σ = 842		1,687 σ = 808			1,686 σ = 632	1,735 σ = 925	1,346 σ = 477	1,517 σ = 861	
Laboratory	3,471 σ = 1928				2,752 σ = 696	1,928 σ = 934		6,816 σ=4174			4,202 σ=1564		3,047 σ = 400	1,307 σ = 171	
Refrigerated warehouse	1,119 σ = 815							1,361 σ = 561			776 σ = 394	575 σ = 759	707 σ = 686		

Table 4-4 Existing Stock Models EUI by Subsectors and Climate Zones: SI Units (MJ/m^2·yr)

Subsector	Climate Zone														
	All	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
All	900 σ = 843	1,154 σ=1507	814 σ = 867	1,063 σ = 828	887 σ = 962	730 σ = 792	752 σ = 659	898 σ = 752	667 σ = 448	759 σ = 696	982 σ = 856	849 σ = 693	974 σ = 933	989 σ = 557	1,040 σ = 961
Office/professional	892 σ = 387	886 σ = 192	896 σ = 384	827 σ = 204	767 σ = 273	730 σ = 298	712 σ = 181	925 σ = 410	767 σ = 346	771 σ = 288	974 σ = 412	693 σ = 196	963 σ = 417	934 σ = 407	1,148 σ = 454
Nonrefrig. warehouse	387 σ = 272	402 σ = 326	258 σ = 221		297 σ = 249	336 σ = 201	356 σ = 414	354 σ = 255	346 σ = 281	420 σ = 187	490 σ = 273	455 σ = 254	457 σ = 356	513 σ = 459	477 σ = 186
Education	628 σ = 352	1,095 σ = 797	677 σ = 522	1,213 σ = 556	479 σ = 245	522 σ = 231	446 σ = 153	649 σ = 316	408 σ = 163	456 σ = 150	627 σ = 309	643 σ = 309	751 σ = 342	710 σ = 314	840 σ = 130
Retail (except malls)	848 σ = 388	664 σ = 708	698 σ = 302	1,060 σ = 332	739 σ = 340	664 σ = 190	642 σ = 96	845 σ = 349	793 σ = 192		987 σ = 404	874 σ = 326	1,016 σ = 441	1,172 σ = 532	1,544 σ = 272
Public assembly	821 σ = 497	824 σ = 328	646 σ = 537		846 σ = 465	631 σ = 502	624 σ = 157	755 σ = 328	629 σ = 464	1,119 σ = 732	884 σ = 495	862 σ = 413	955 σ = 403	820 σ = 222	1,116 σ=1306
Service	791 σ = 404	836 σ = 115	634 σ = 352		600 σ = 347	502 σ = 350	405 σ = 99	802 σ = 348	495 σ = 159		899 σ = 383	752 σ = 380	778 σ = 534	1,036 σ = 333	954 σ = 505
Religious worship	603 σ = 484		379 σ = 176		306 σ = 211	375 σ = 291		603 σ = 513	864 σ = 523		786 σ = 572	486 σ = 236	801 σ = 492	594 σ = 309	
Lodging	947 σ = 472	1,154 σ = 497	996 σ = 352		753 σ = 301	537 σ = 150		1,158 σ = 598	735 σ = 99	910 σ = 640	846 σ = 300	931 σ = 480	1,019 σ = 465	1,230 σ = 423	886 σ = 476
Food services	3,944 σ=1413	6,691 σ=3792	3,708 σ=1219		3,685 σ=1449	4,405 σ = 851	2,765 σ = 66	3,844 σ=1348		5,253 σ=2067	4,021 σ=1490	3,326 σ=1222	4,212 σ=1038	2,475 σ=1026	5,551 σ=2217
Inpatient health care	2,051 σ=1136	2,243 σ=1505	2,094 σ = 901	2,464 σ=1363	1,627 σ = 396	1,824 σ = 541	1,401 σ = 290	1,992 σ = 693	1,495 σ = 143		2,288 σ=1053	2,224 σ = 861	2,659 σ=2824	1,951 σ = 645	4,280 σ = 694
Public order and safety	913 σ = 462		687 σ = 280		671 σ = 161	1,108 σ = 350		813 σ = 421			1,086 σ = 492	1,161 σ = 837	934 σ = 504	1,142 σ = 378	
Food sales	2,278 σ = 608		2,195 σ = 261		2,194 σ = 396	1,747 σ = 669	1,674 σ = 361	2,342 σ = 491			2,305 σ = 641	2,338 σ = 524	2,941 σ=1001		2,434 σ = 355
Outpatient health care	997 σ = 480	988 σ = 246	755 σ = 263		674 σ = 157	1,049 σ = 449		873 σ = 433	1,261 σ = 657		1,223 σ = 599	761 σ = 302	1,106 σ = 411	1,070 σ = 389	1,318 σ = 438
Vacant	244 σ = 384		31 σ = 35	403 σ = 156	91 σ = 98	136 σ = 135	19 σ = 0.5	208 σ = 229	39 σ = 61	122 σ = 259	325 σ = 355	187 σ = 134	292 σ = 428		1,176 σ=1085
Other	709 σ = 294		633 σ = 398		443 σ = 233	641 σ = 195		762 σ = 238	474 σ = 5		727 σ = 354	449 σ = 170	697 σ = 271	1,180 σ = 756	649 σ = 409
Skilled nursing	1,375 σ = 292		1,302 σ = 68		1,389 σ = 452	1,216 σ = 126		1,392 σ = 238			1,374 σ = 242	1,425 σ = 351	1,369 σ = 372	2,041 σ = 380	
Laboratory	3,747 σ = 733				3,998 σ = 51	3,579 σ=1077		3,046 σ = 615			3,710 σ = 800		3,792 σ = 740	3,016 σ = 843	
Refrigerated warehouse	977 σ = 286							910 σ = 75			797 σ = 120	966 σ = 382	1,269 σ = 447		

Table 4-5 Number of Samples and Models by Subsectors and Climate Zones

Subsector	Climate Zone														
	All	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
All	4,820	40	542	24	464	452	52	982	64	50	1,152	262	519	120	97
Office/professional	976	6	99	7	73	108	18	211	6	21	253	33	93	26	22
Nonrefrig. warehouse	473	5	77	0	49	50	2	93	6	6	94	21	50	10	10
Education	649	4	91	5	62	59	8	124	9	8	139	58	61	17	4
Retail (except malls)	355	4	34	2	52	36	4	80	6	0	73	23	27	7	7
Public assembly	279	3	36	0	25	26	3	47	5	5	62	14	37	6	9
Service	370	2	20	0	43	21	2	76	5	0	100	20	54	13	13
Religious worship	311	0	31	0	35	29	0	64	6	0	82	11	45	6	0
Lodging	260	7	31	0	20	22	0	58	7	3	51	15	26	8	10
Food services	242	2	34	0	27	22	2	49	0	2	57	12	28	2	4
Inpatient health care	217	2	25	3	19	22	5	45	2	0	53	12	21	6	2
Public order and safety	85	0	7	0	4	4	0	23	0	0	22	9	9	3	0
Food sales	125	0	13	0	16	8	2	23	0	0	35	8	13	0	4
Inpatient health care	144	3	15	0	10	15	0	28	4	0	35	10	12	7	2
Vacant	134	0	17	2	18	10	2	24	3	2	29	3	20	0	3
Other	64	0	6	0	3	4	0	10	2	0	21	4	8	2	4
Skilled nursing	73	0	5	0	5	7	0	16	0	0	22	6	8	3	0
Laboratory	43	0	0	0	2	8	0	5	0	0	19	0	4	2	0
Refrigerated warehouse	20	0	0	0	0	0	0	6	0	0	5	3	3	0	0

Table 4-6 Energy Percent Difference between Models and Survey by Subsectors and Climate Zones

Subsector	Climate Zone														
	All	1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7
All	12%	-38%	0%	18%	12%	8%	-6%	17%	46%	32%	17%	14%	4%	10%	-29%
Office/professional	15%	-86%	4%	-2%	23%	9%	-9%	16%	53%	29%	20%	8%	23%	28%	-49%
Nonrefrig. warehouse	19%	-65%	-46%		-17%	-38%	-60%	20%	-6%	0%	45%	34%	-8%	22%	-26%
Education	34%	-87%	18%	33%	32%	38%	63%	44%	6%	31%	37%	29%	27%	31%	11%
Retail (except malls)	-1%	4%	34%	28%	-9%	-16%	-82%	-14%	30%		1%	4%	4%	-6%	-33%
Public assembly	23%	3%	6%		33%	-16%	-23%	39%	-26%	60%	25%	22%	5%	29%	-1%
Service	10%	-23%	-5%		-7%	27%	-31%	14%	47%		2%	35%	22%	7%	-29%
Religious worship	-22%		-7%		4%	-8%		-13%	-36%		-33%	-9%	-32%	-54%	
Lodging	11%	-26%	4%		33%	17%		-10%	75%	-48%	16%	-26%	17%	-16%	-15%
Food services	-34%	-50%	-57%		23%	1%	-197%	-45%		-78%	-37%	-28%	-82%	8%	-155%
Inpatient health care	28%	1%	25%	40%	30%	38%	40%	29%	19%		32%	20%	3%	27%	-47%
Public order and safety	31%		34%		63%	-24%		45%			12%	-9%	35%	32%	
Food sales	0%		-16%		9%	16%	-23%	15%			0%	-40%	-7%		-8%
Outpatient health care	7%	-369%	14%		-8%	13%		-10%	41%		3%	44%	13%	-4%	30%
Vacant	-3%		25%	25%	-102%	-92%	-972%	54%	-15%	82%	-39%	82%	-17%		-89%
Other	21%		-16%		61%	68%		6%	-63%		32%	57%	11%	-23%	-1%
Skilled nursing	3%		-61%		-46%	-26%		17%			18%	18%	-2%	-35%	
Laboratory	-8%				-45%	-86%		55%			12%		-24%	-131%	
Refrigerated warehouse	13%							33%			-3%	-68%	-80%		

Appendix A also provides plots of the probability density functions (PDFs) for the modeled and survey data by subsector in Figure A-2 to Figure A-20. These PDFs show that EUI varies widely across the sector. The survey results are broader than the models, but the PDFs tend to have the same shapes. Although the simplest way to compare large numbers of results is to look at the averages (weighted mean), the weighted standard deviations and PDFs show that these mean values should be viewed as fairly broad measures. The low number of samples in some climate zones is problematic, because a single model or sample can have an unduly large effect on results for mean values. For example, the PDFs for the 64 buildings in Climate Zone 4B (shown in Figure A-2) reveal that the mean survey results are shifted high by an unusually high fraction at an EUI of around 300 $kBtu/ft^2 \cdot yr$. This was traced to the influence of a single sample building (ID #5207, a 1 million ft^2 hotel with a weighting factor of 134) and demonstrates that a sample size of 64 is probably not sufficient when working with the 2003 CBECS public use data. A similar situation in the Climate Zone 7 classification occurs in the survey where an unusually large weight is put on one sample with a relatively low EUI (ID #2164, a 1.4 million ft^2 warehouse built in 1940 with a weighting factor of 154.5). These examples show the difficulty of generating meaningful weighted mean values with low sample sizes.

Individually, the models and samples do not agree well. Appendix A provides scatter plots that compare total EUI results at the individual building level for each subsector in Figure A-21 to Figure A-39. This scatter is expected because of the lack of data in CBECS and the probabilistic assignments used to generate input. These plots also show a large spread in performance in commercial buildings.

4.2 Electricity Use

2003 CBECS survey results include the breakdown by fuel type, and this section focuses on electricity consumed by the whole building. Overall, the models overpredict electricity use by 10%. Figure 4-5 shows the results for electricity use by subsector. (Table A-7 lists the numeric values.) The models tend to track the survey results fairly well for offices, outpatient health care, food sales, inpatient health care, and public assembly. Subsectors where the model results are far above the survey results include skilled nursing, laboratory, vacant, and religious worship.

Figure 4-6 shows the results for electricity use by climate zone (Table A-8 provides related values). The climate zones that show good agreement include 2A, 3A, 4A, and 5B. Relatively poor agreement is observed for Climate Zones 3B, 3C, 6B, and 7A. Interestingly, in Climate Zone 3C the model results for electricity are significantly higher than the survey, but because gas use is underpredicted, the whole-building EUI is in much better agreement.

Figure 4-7 shows the results for electricity use by census division (Table A-9 provides values). Census divisions with relatively good agreement include East North Central, South Atlantic, East South Central, and West South Central. Relatively poor agreement is observed for New England, Middle Atlantic, and West North Central.

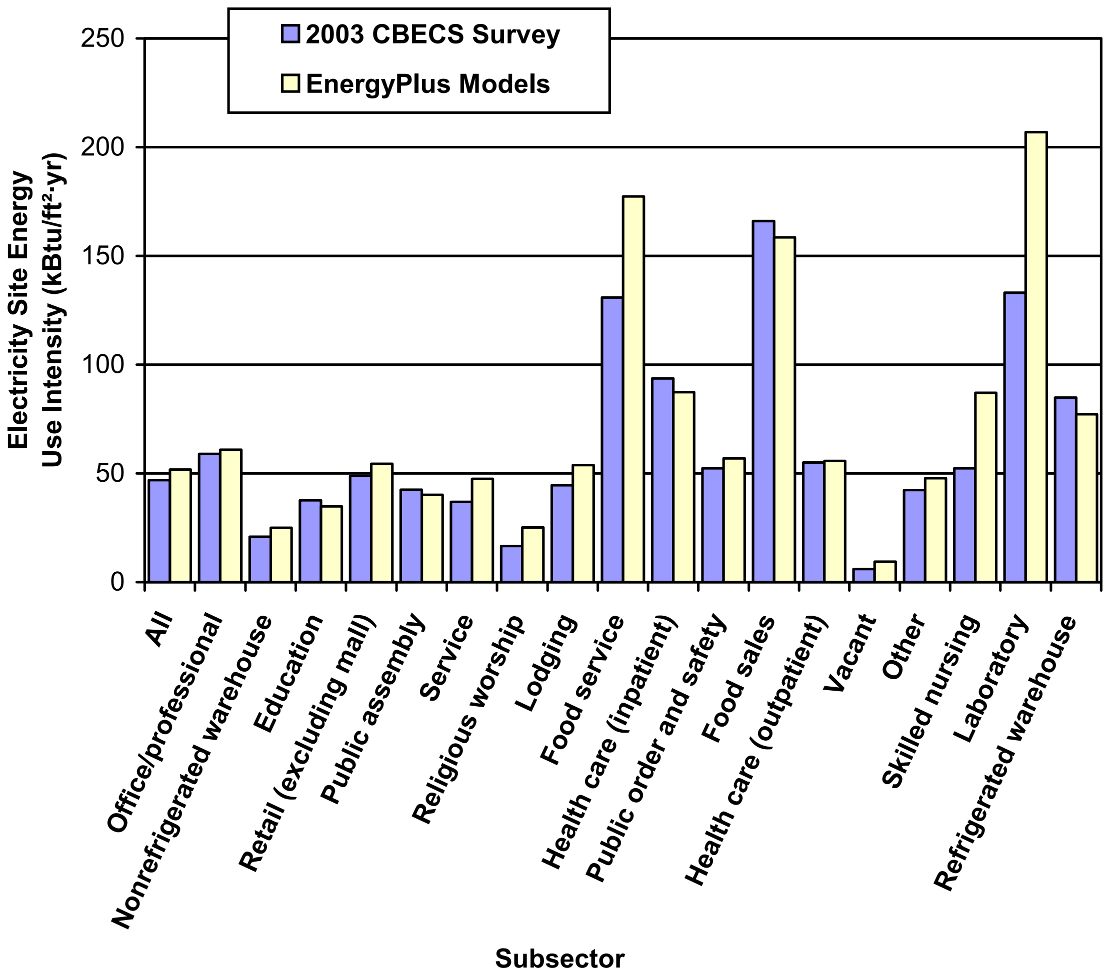

Figure 4-5 Electricity Use Intensity: 2003 CBECS Survey and Modeling by Subsector

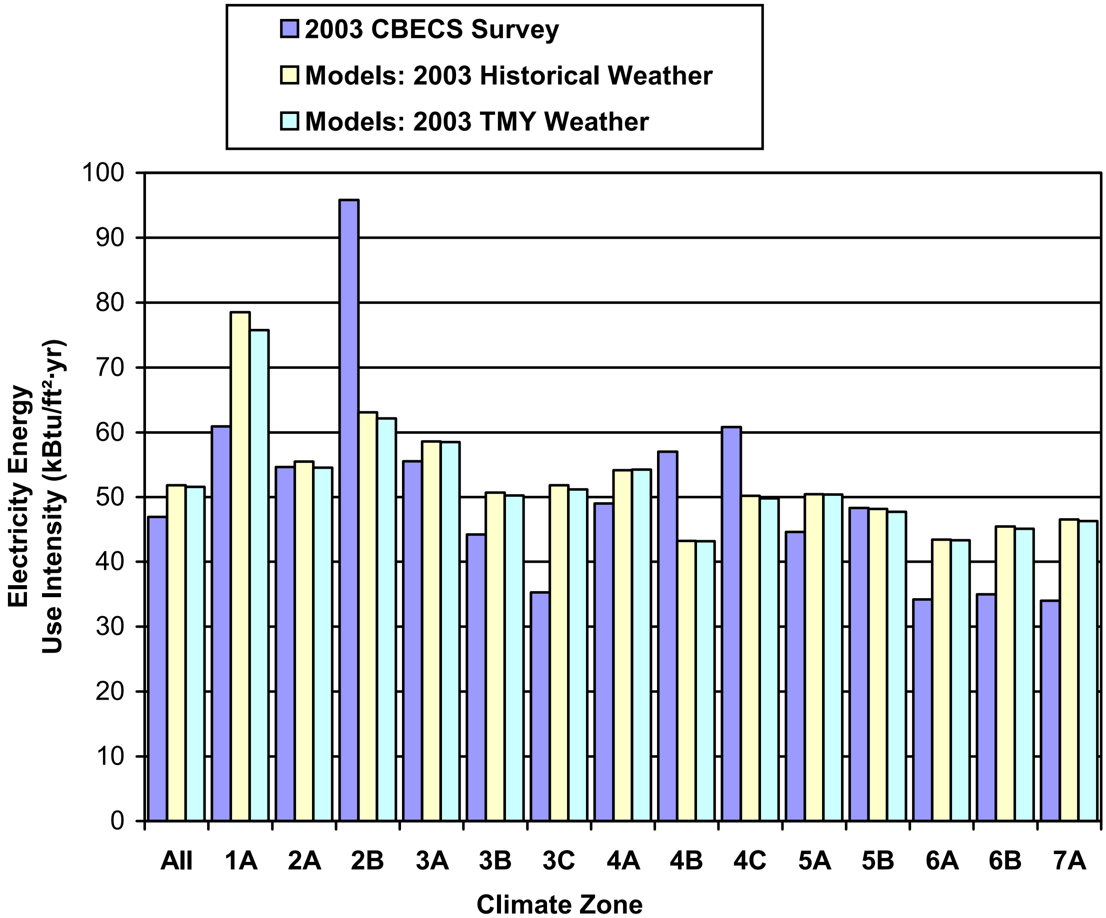

Figure 4-6 Electricity Use Intensity: 2003 CBECS Survey and Modeling by Climate Zone

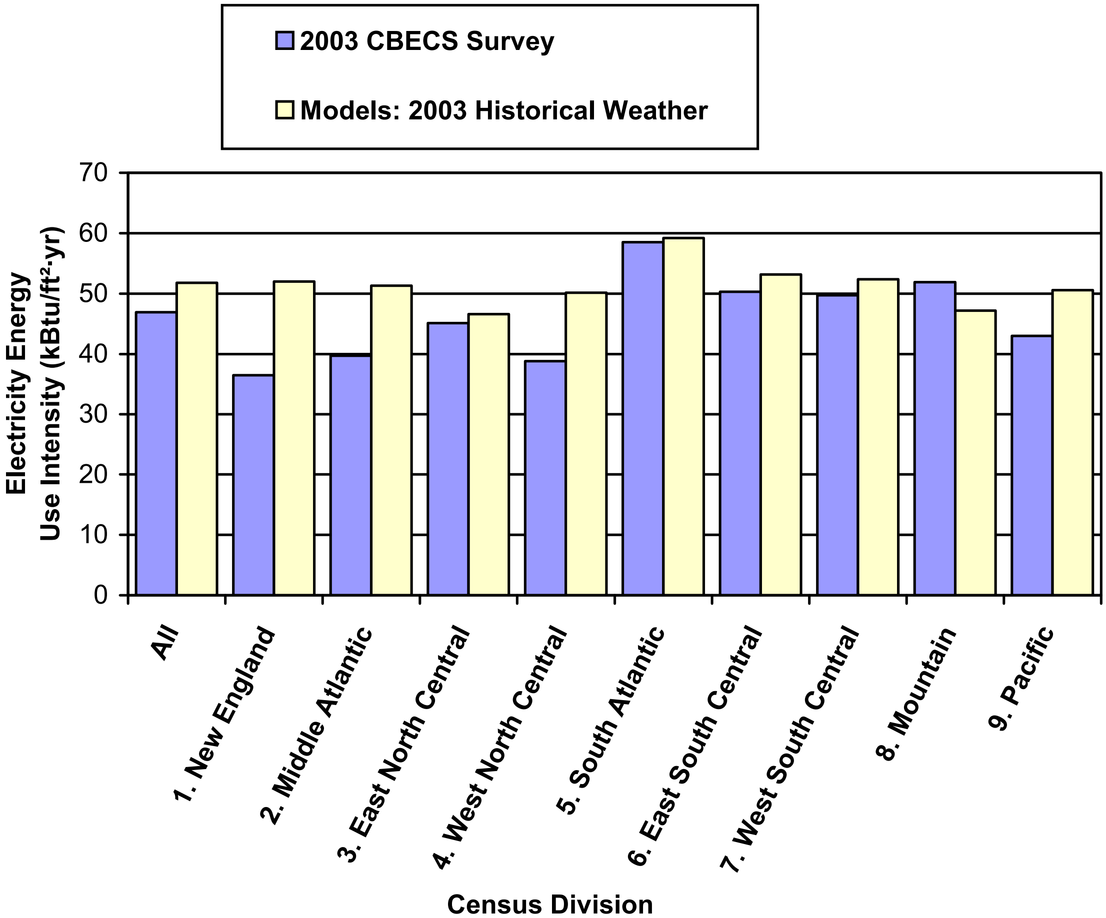

Figure 4-7 Electricity Use Intensity: 2003 CBECS Survey and Modeling by Census Division

4.3 Natural Gas Use

2003 CBECS survey results include the breakdown by fuel type; this section focuses on natural gas consumption. Overall, the models underpredict natural gas use by 23%. Figure 4-8 shows the results for natural gas use by subsector (Table A-10 lists the numeric values). Results for natural gas use do not track across subsectors as well as other metrics such as total energy or electricity. Subsectors where the model results are far above the survey results include laboratory, food sales, food services, and religious worship. Subsectors where model results are far below the survey include skilled nursing, other, lodging, education, and nonrefrigerated warehouse.

Figure 4-9 shows the results for natural gas use by climate zone (Table A-11 provides related values). The climate zones that show good agreement include 2A, 2B, 4C, and 6A. Relatively poor agreement is observed for Climate Zones 7A, 4B, and 3B. Interestingly, the survey results by climate zone show some unusual results that are hard to explain, such as relatively high gas use in Climate Zone 4B and relatively low gas use intensity in Climate Zone 7A.

Figure 4-10 shows the results for natural gas use by census division (Table A-12 provides related values). Census divisions with relatively good agreement include South Atlantic. Relatively poor agreement is observed for Mountain, East South Central, West South Central, New England, Middle Atlantic, and East North Central.

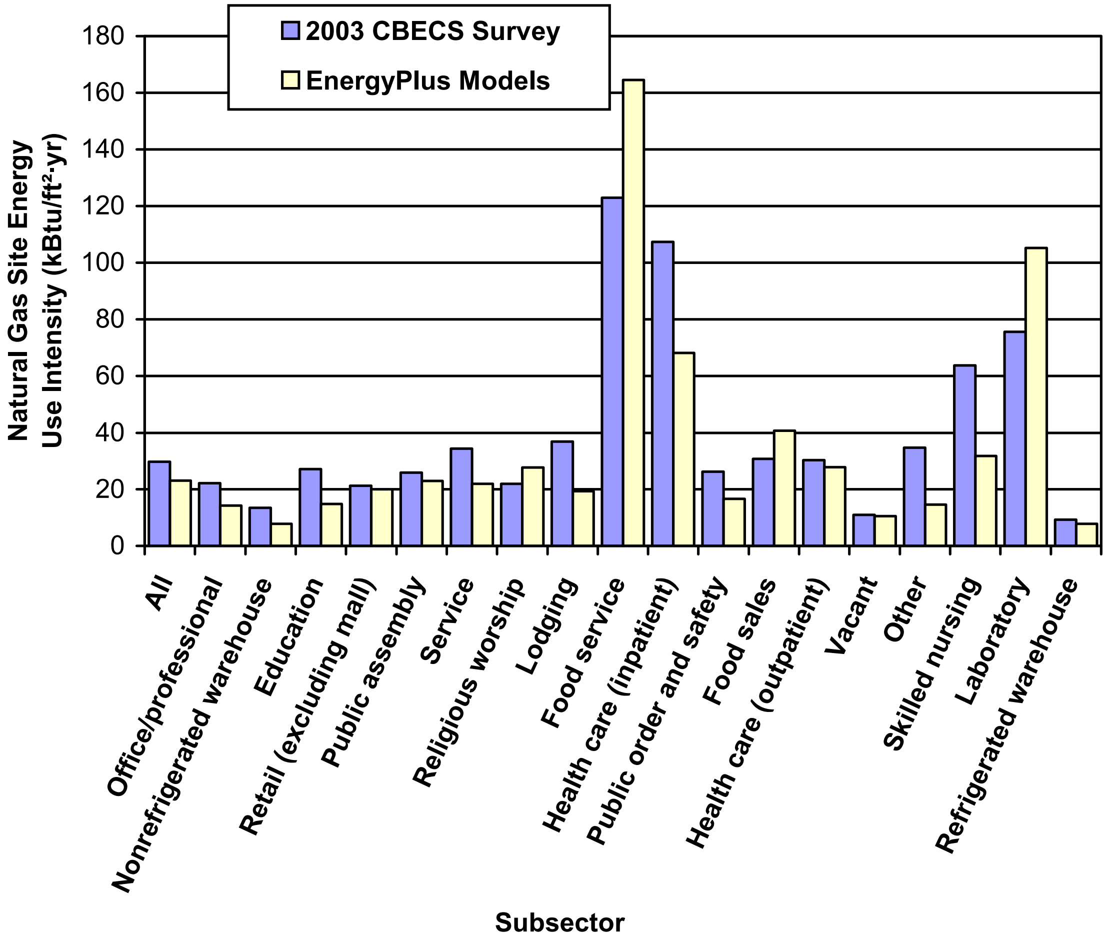

Figure 4-8 Natural Gas Use Intensity: 2003 CBECS Survey and Modeling by Subsector

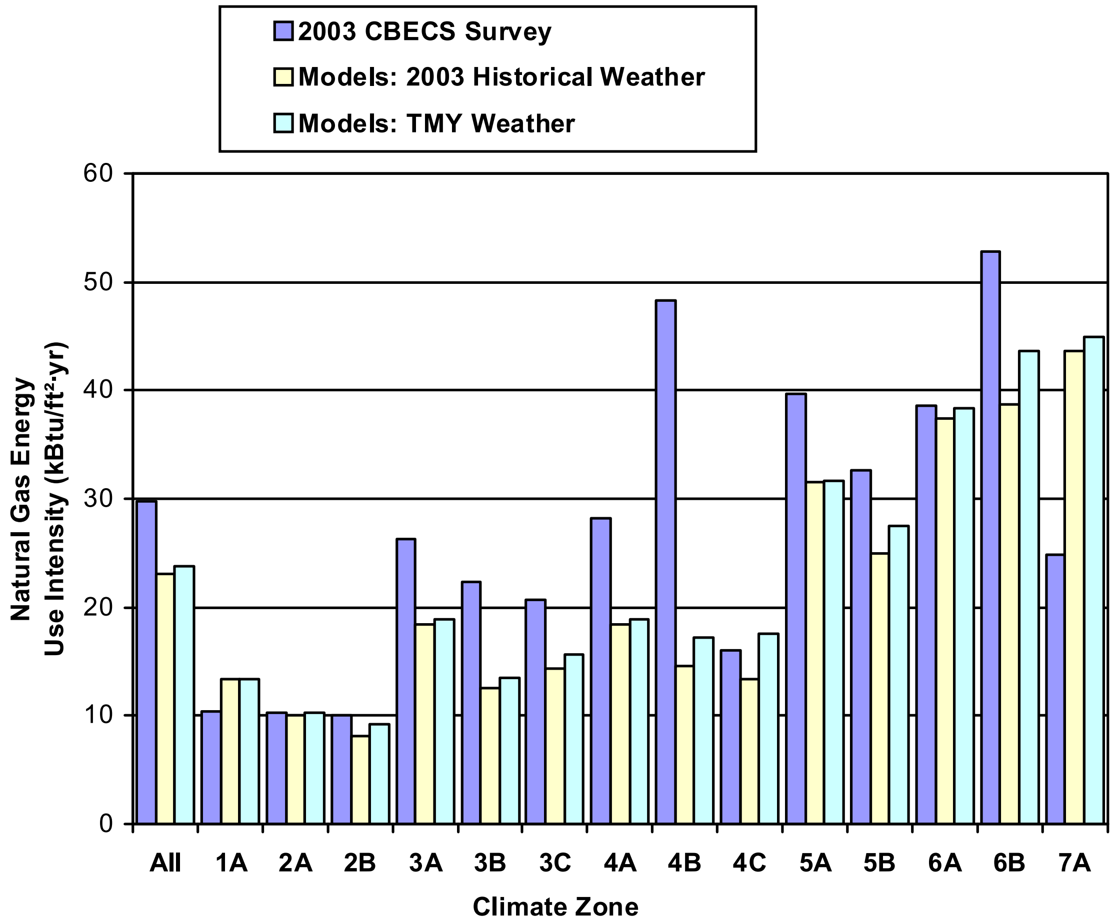

Figure 4-9 Natural Gas Use Intensity: 2003 CBECS Survey and Modeling by Climate Zone

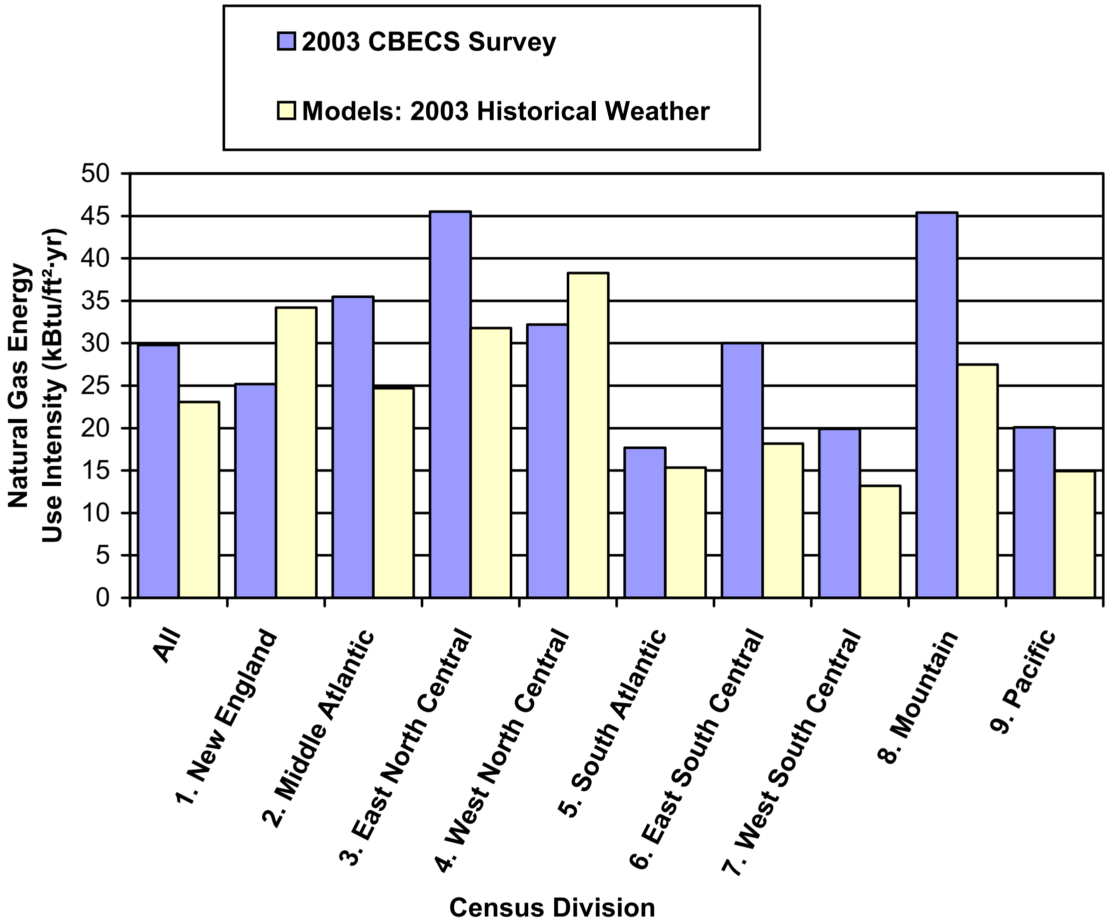

Figure 4-10 Natural Gas Use Intensity: 2003 CBECS Survey and Modeling by Census Division

4.4 Energy Costs

2003 CBECS survey results include annual expenditures for energy. Overall, the models overpredict energy costs by 8%. Figure 4-11 shows the results for energy cost intensity by subsector (Table A-13 lists the numeric values). Results for energy costs track across subsectors fairly well. Relatively good agreement is observed for office, food sales, outpatient health care, inpatient health care, and lodging. Subsectors where the model results are far above the survey results include religious worship, food services, and skilled nursing.

Figure 4-12 shows the results for energy costs by climate zone (Table A-14 provides related values). The climate zones that show good agreement include 1A, 5B, and 6B. Relatively poor agreement is observed for Climate Zones 7A, 4C, and 3C. The survey results by climate zone show some unusual results that are hard to explain, such as relatively high energy cost intensity in Climate Zones 2B and 4C.

Figure 4-13 shows the results for energy costs by census division (Table A-15 provides related values). Census divisions with relatively good agreement include South Atlantic, East South Central, East North Central, and Pacific. Relatively poor agreement is observed for Middle Atlantic, West South Central, and Mountain.

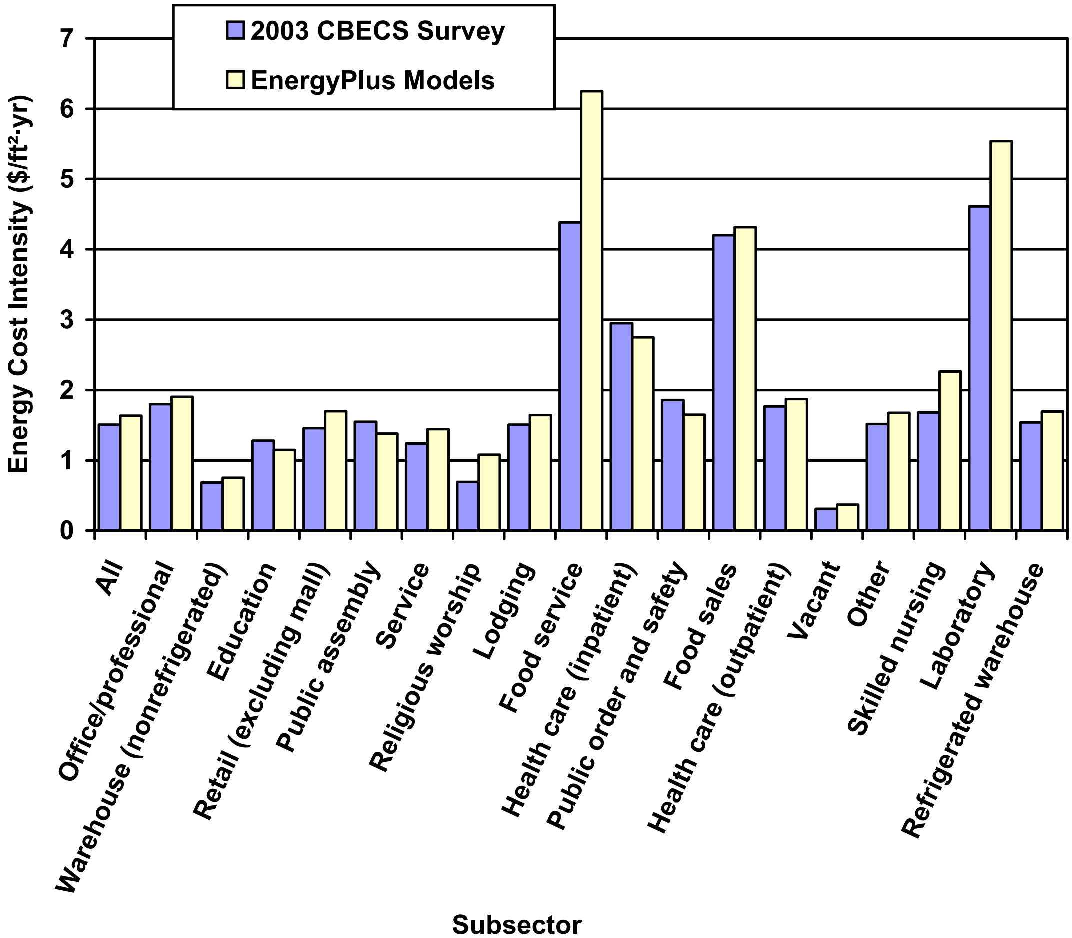

Figure 4-11 Energy Cost Intensity: 2003 CBECS Survey and Modeling by Subsector

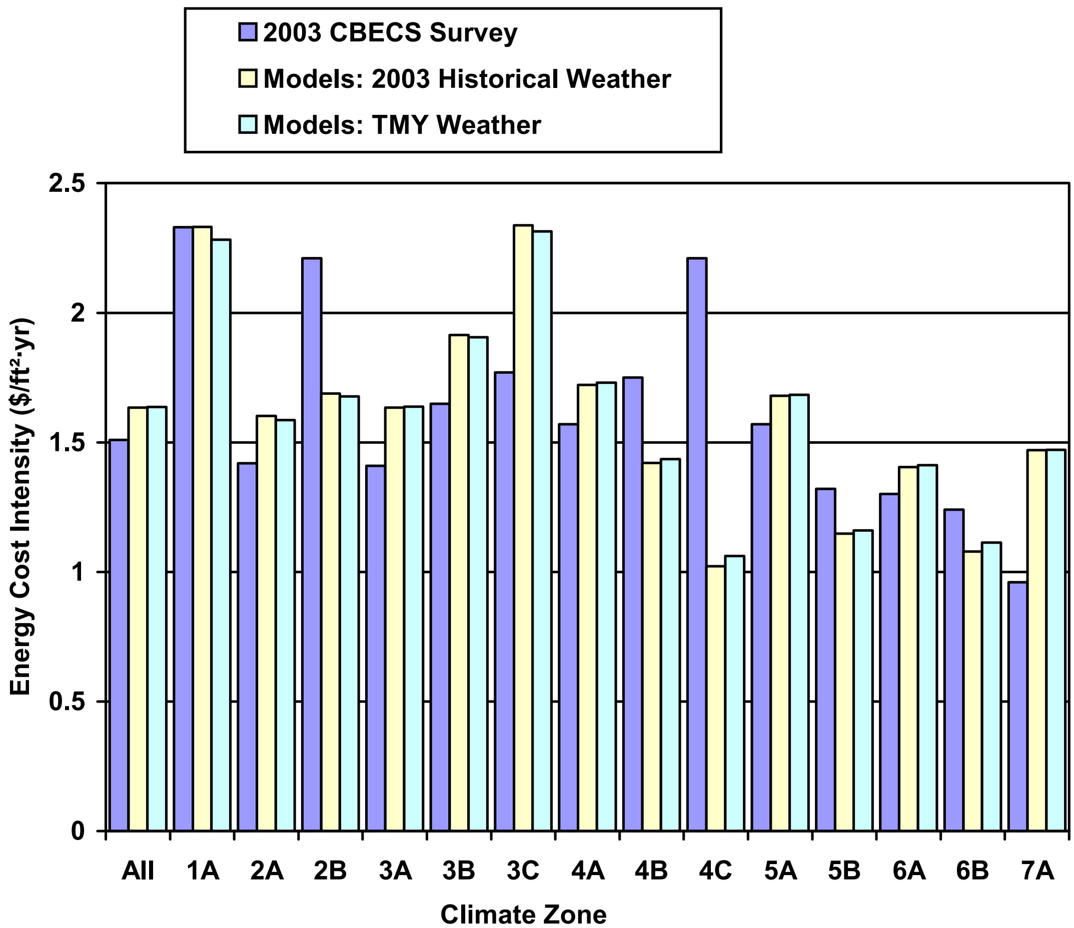

Figure 4-12 Energy Cost Intensity: 2003 CBECS Survey and Modeling by Climate Zone

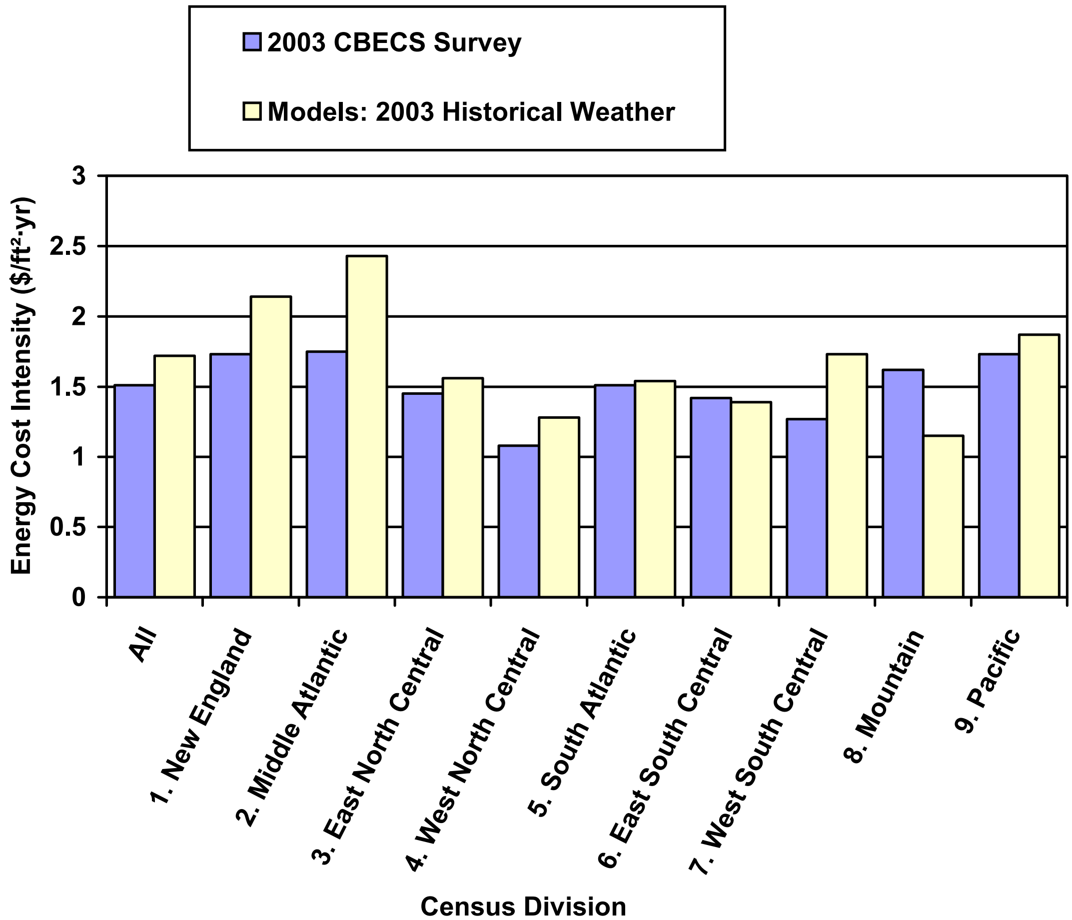

Figure 4-13 Energy Cost Intensity: 2003 CBECS Survey and Modeling by Census Division

4.5 Literature Comparisons

Beyond the core source of data from 2003 CBECS, a number of literature sources were used to develop input data for the model. This section presents comparisons between the models and some of the literature data. These comparisons generally involve examining how well the model results actually match the targets for certain loads. Model inputs for loads such as plug and process and outside air were adjusted through an iterative process in an effort to match the data presented in Section 2. But because each iteration is computationally expensive, the process was terminated after eight iterations. This section presents results that examine the levels of agreement.

Table 4-7 lists the electricity end use intensities for plug and process loads. The iterative process for plug and process loads used the methods described in Section C.14 to adjust power density and diversity factors to match the results from CEUS (CEC 2006) listed in Table 2-1. The agreement is fairly good except for the education and refrigerated warehouse subsectors. Plug and process loads for these should be iterated further to improve agreement. Many other subsectors are not represented in CEUS data and so are difficult to judge.

Table 4-7 Plug and Process Electricity Results from CUES Survey and Modeling

Subsector (PBA)	CEUS Survey kBtu/ft²·yr (MJ/m²·yr)	Models kBtu/ft²·yr (MJ/m²·yr)	Percent Difference
All	10.5 (119)	10.1 (115)	4%
Office/professional	15.4 (175)	14.7 (167)	5%
Warehouse	3.5 (40)	3.2 (36)	9%
Education	3.3 (38)	4.1 (47)	-24%
Retail (except malls)	6.2 (70)	6.4 (73)	-3%
Public assembly	N/A	9.3 (106)	N/A
Service	N/A	9.6 (109)	N/A
Religious worship	N/A	2.7 (31)	N/A
Lodging	8.4 (95)	8.6 (98)	-2%
Food services	42.4 (482)	33.8 (384)	20%
Inpatient health care	16.4 (186)	16.6 (189)	-1%
Public order and safety	N/A	22.8 (259)	N/A
Food sales	11.6 (132)	10.9 (124)	6%
Outpatient health care	N/A	9.4 (107)	N/A
Vacant	N/A	3.6 (41)	N/A
Other	10.6 (120)	10.5 (119)	1%
Skilled nursing	N/A	31.8 (361)	N/A
Laboratory	N/A	95.6 (1,086)	N/A
Refrigerated warehouse	9.8 (111)	2.2 (25)	78%

Table 4-8 lists the electricity end use intensities for commercial refrigeration. The algorithms for generating model inputs for refrigeration use results from CEUS (CEC 2006) listed in Table 2-1 to derive power densities. The agreement is generally fairly good for the individual subsectors (except lodging), but agreement is not as good for all the buildings. This probably stems from CEUS covering a smaller array of the different types of buildings compared to CBECS.

Table 4-8 Refrigeration Electricity Results from CUES Survey and Modeling

Subsector (PBA)	CEUS Survey Refrigeration Electricity Intensity kBtu/ft²·yr (MJ/m²·yr)	Modeled Refrigeration Electricity Intensity kBtu/ft²·yr (MJ/m²·yr)	Percent Difference
All	6.2 (70)	4.4 (50)	29%
Office/professional	1.6 (18)	1.6 (18)	0%
Warehouse	1.0 (11)	0.9 (10)	10%
Education	1.7 (19)	1.5 (17)	12%
Retail (except malls)	3.5 (40)	3.5 (40)	0%
Public assembly	N/A	0.7 (8)	N/A
Service	N/A	2.7 (31)	N/A
Religious worship	N/A	0.7 (8)	N/A
Lodging	3.1 (35)	3.8 (43)	-23%
Food services	33.7 (383)	33.5 (381)	1%
Inpatient health care	2.4 (27)	2.5 (28)	-4%
Public order and safety	N/A	1.6 (18)	N/A
Food sales	76.5 (869)	75.0 (852)	2%
Outpatient health care	n/a	2.2 (25)	N/A
Vacant	N/A	0.0 (0)	N/A
Other	2.9 (33)	2.6 (30)	10%
Skilled nursing	N/A	2.5 (28)	N/A
Laboratory	N/A	8.3 (94)	N/A
Refrigerated warehouse	45.9 (522)	45.8 (520)	0%

Table 4-9 lists the electricity end use intensities for interior lighting. The algorithms for generating model inputs for lighting use data from the *U.S. Lighting Market Characterization* (DOE 2002) listed in Table 2-5. The agreement is generally fairly good for the individual subsectors, except for warehouse and vacant. (The comparison for the vacant subsector is not a concern because the literature values seems to be an error.) These differences appear to stem from differences in operating schedules where the current methodology uses a different approach that generates schedules directly from CBECS data.

Table 4-9 Interior Lighting Electricity Results from *U.S. Lighting Market Characterization* and Modeling

Subsector (PBA)	***U.S. Lighting Market Characterization*** **Lighting Electricity Intensity kBtu/ft²·yr (MJ/m²·yr)**	**Modeled Lighting Electricity Intensity kBtu/ft²·yr (MJ/m²·yr)**	**Percent Difference**
All	N/A	18.2 (207)	N/A
Office/professional	22.9 (260)	23.2 (264)	1%
Warehouse	16.4 (186)	14.4 (164)	-12%
Education	16.7 (190)	16.9 (192)	1%
Retail (except malls)	23.9 (272)	24.1 (274)	1%
Public assembly	12.3 (140)	12.3 (140)	0%
Service	19.4 (220)	19.8 (225)	2%
Religious worship	8.5 (97)	8.7 (99)	2%
Lodging	16.0 (182)	16.2 (184)	1%
Food services	23.9 (272)	23.0 (261)	-4%
Inpatient health care	32.4 (368)	32.7 (372)	1%
Public order and safety	15.4 (175)	15.5 (176)	1%
Food sales	33.4 (380)	34.0 (386)	2%
Outpatient health care	19.8 (225)	19.7 (224)	-1%
Vacant	25.6 (291)	2.1 (24)	-92%
Other	20.8 (236)	22.1 (251)	6%
Skilled nursing	18.4 (209)	18.5 (210)	1%
Laboratory	28.3 (322)	28.6 (325)	1%
Refrigerated warehouse	18.1 (206)	18.8 (214)	4%

Figure 4-14 plots the distribution of infiltration rates in the models and compares them to the modeling results from Chan (2006). The current study distributions are PDFs that are obtained by using a bin size of 0.05 ACH. The PDF for Chan's results was obtained by normalizing the lognormal distribution that corresponds to a geometric mean of 0.35 and a geometric standard deviation of 2.1 ACH (so the area under the curve equals 1.0). The results show reasonable agreement for the most likely value for infiltration at 0.225 ACH, but Chan's lognormal distribution has a much longer tail at the higher rates. Chan's distribution is by number of buildings in the sector, whereas the current result's PDF is by floor area in the sector.

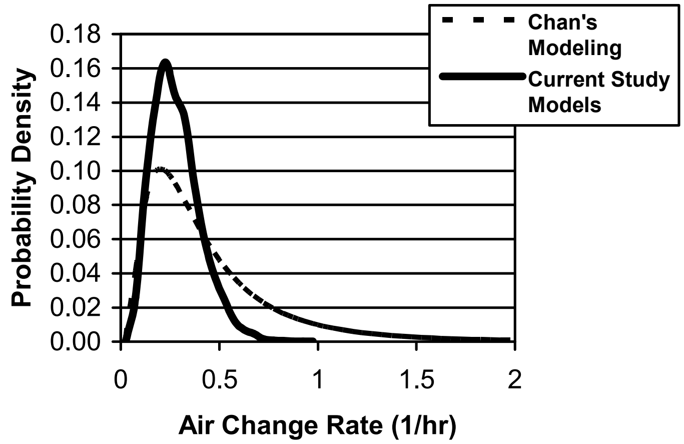

Figure 4-14 PDFs of Infiltration Rates from Chan (2006) and Models

The *2006 Building Energy Data Book* (DOE 2006) combines a number of data sources and provides values for end use splits for the year 2004. Because 2003 CBECS does not provide data on end use breakdowns, the best source of national data on end uses appears to be the *Building Energy Data Book*. Table 4-10 compares literature data and model results for how site energy use is distributed across end use categories. The literature data are mapped to end use categories used in this study and recalculated to remove the SEDS adjustment (SEDS is the State "Energy Consumption, Price, and Expenditure Estimates" and EIA uses this to handle discrepancies between sources of energy data). Here we assume the SEDS adjustment accounts for energy use outside the building envelope such as street lighting. The biggest discrepancy is in energy for service water heating, where the literature data show considerably more energy use. Other differences include the models predicting higher splits for lighting, fans, and space cooling and lower splits for heating and process gas.

Table 4-10 Site Energy End Use Splits from 2006 *Building Energy Data Book* and Modeling

End Use	2006 *Building Energy Data Book*	Existing Stock Models 2003 Historical Weather	Existing Stock Models TMY Weather
Lighting	19.9%	24.8%	24.9%
Space heating	27.3%	22.9%	24.0%
Space cooling	8.8%	14.0%	13.5%
Refrigeration	5.2%	6.0%	6.0%
Water heating	11.6%	3.3%	3.4%
Fans	4.8%	8.1%	7.2%
Process gas	9.5%	7.2%	7.2%
Plug and process electricity	12.9%	13.7%	13.8%

4.6 Historical Weather versus Typical Meteorological Year

The entire set of 4,820 models was run twice, once with 2003 historical weather data and a second time with TMY weather data. This section compares the results. The modeling uses 181 unique weather locations.

Overall, the results agree to within 0.5% for total site energy use, 0.4% for electricity, 3% for natural gas, and 0.6% for energy costs.

The resulting differences between TMY and 2003 historical weather are provided by climate zone for mean total site EUI in Figure 4-2 (and Table A-5), for electricity use intensity in Figure 4-6 (and Table A-8), for natural gas use intensity in Figure 4-9 (and Table A-11), and for total energy cost intensity in Figure 4-12 (and Table A-14). The results show relatively minor differences for most climate zones. An example of one of the larger differences is natural gas use for Climate Zone 4C, where 2003 results are 31% lower than the TMY results.

Figure 4-15 shows an X-Y scatter plot that compares results for all 4,820 buildings with TMY weather on the X-axis and 2003 historical weather on the Y-axis. A simple (unweighted) analysis of the deviations suggests that on average the choice of weather is a 0.9% effect across the whole sector. However, individual variations go higher and lower, and the average of absolute percent changes indicates that weather is typically a 3.3% effect on a given building. Some buildings are apparent outliers, but suggest that weather may have a significant effect. Figure 4-16 shows a PDF of the change in EUI between TMY and 2003 historical weather.

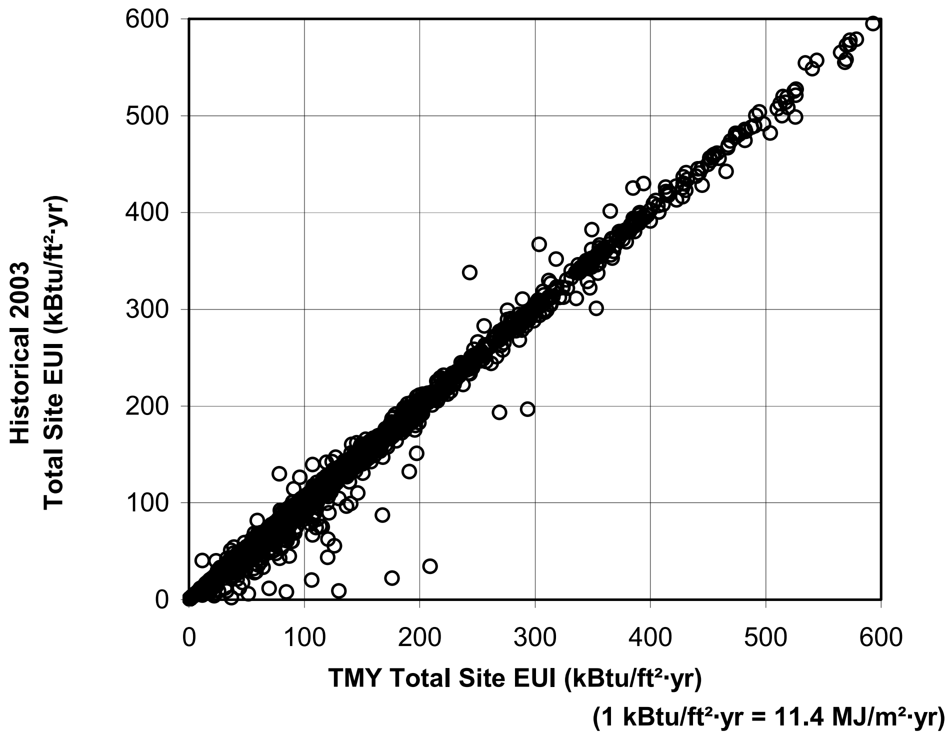

Figure 4-15 Weather Data Scatter Plot: 2003 Historical versus TMY Total EUI

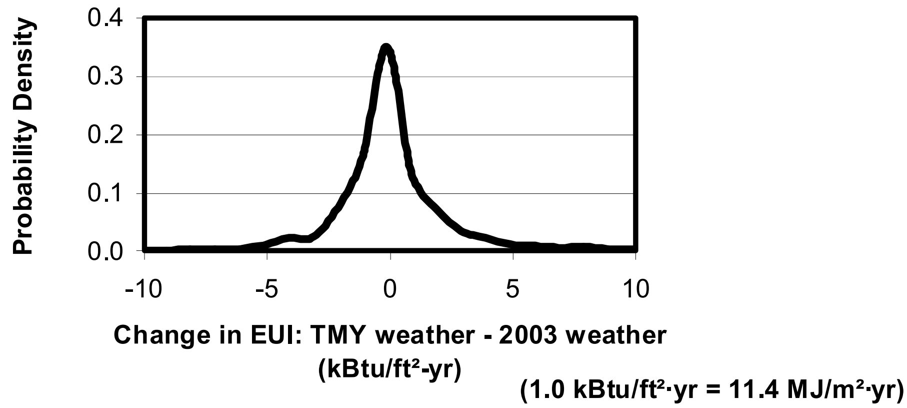

Figure 4-16 PDF of Change in Site EUI from Weather

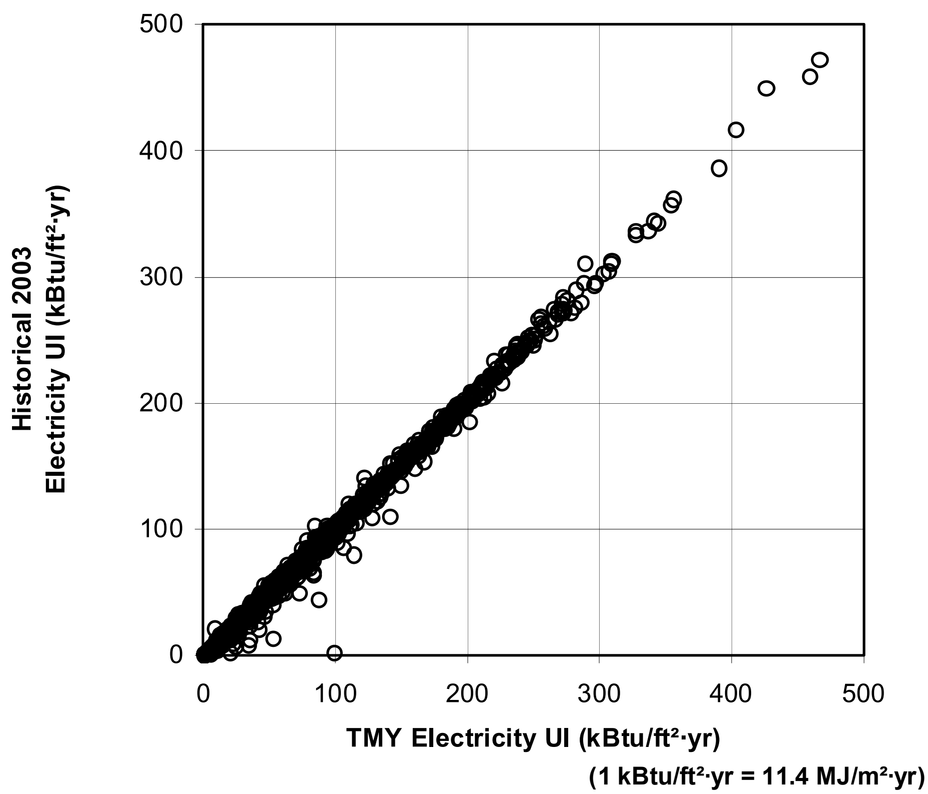

Figure 4-17 Weather Data Scatter Plot: 2003 Historical versus TMY Electricity Use Intensity

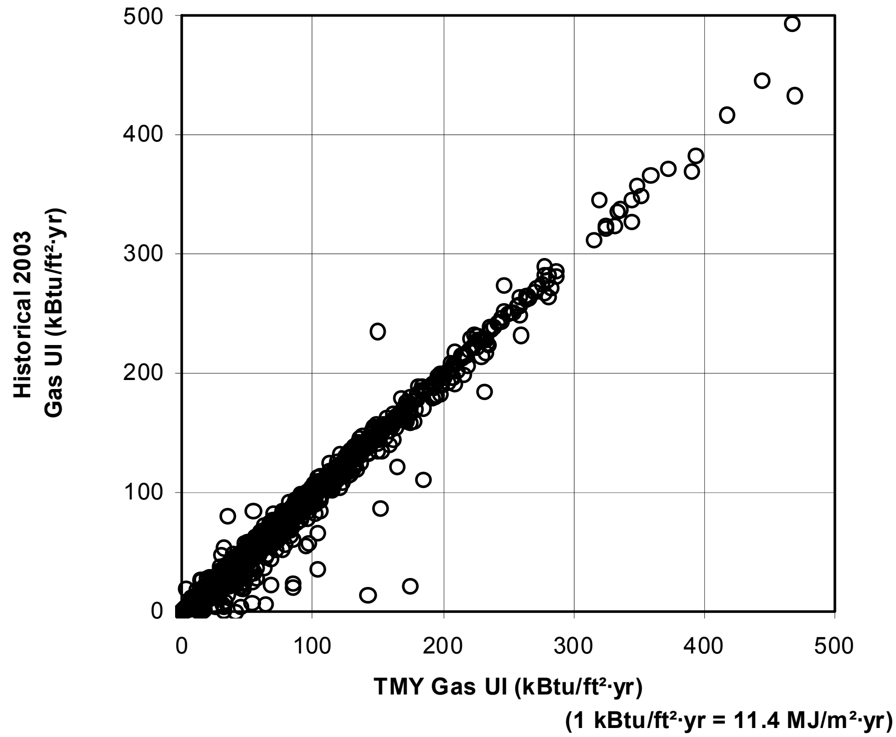

Figure 4-18 Weather Data Scatter Plot: 2003 Historical versus TMY Natural Gas Use Intensity

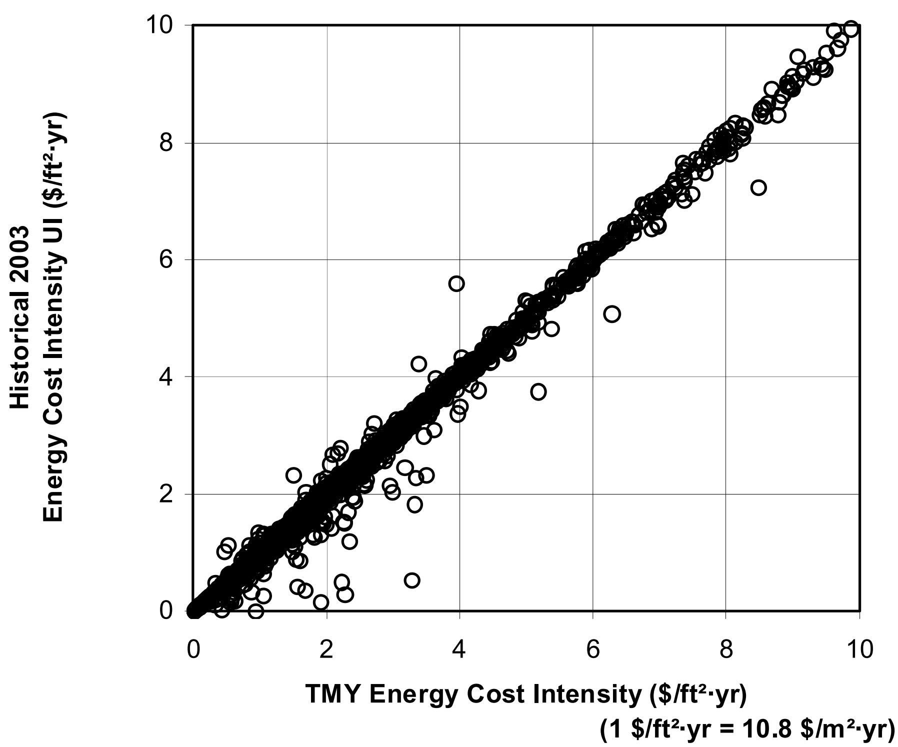

Figure 4-19 Weather Data Scatter Plot: 2003 Historical versus TMY Energy Cost Intensity

4.7 Discussion

This section discusses how well the results from the EnergyPlus models agree with the 2003 CBECS and some of the important lessons learned from conducting the study.

4.7.1 Validation

Section 3.3 presented five criteria for determining whether the methodology should be considered valid:

1. The weighted mean results from the models agree with the survey to within one standard deviation of the survey results. This criterion was easily met because the survey data are widely scattered and have relatively large standard deviations. The deviations between model and survey results are well within one standard deviation, and are typically within one-tenth of a weighted standard deviation. Given the wide range of performance levels in the survey data shown by the broad standard deviations, we conclude that the performance levels predicted in the models are generally adequate.
2. The weighted mean results for EUI agree to within 15%. This criterion is met for the sector as a whole; modeling results are 12% lower than the survey results. Some subsectors do not meet the criteria. The modeling results for education are 34% too high, food services are 34% too low, public order and safety are 31% too high, and inpatient health care is 28% too low.
3. The mean results for total site electricity use intensity agree to within 20%. This criterion is met for the sector as a whole; modeling results are 10% over survey. Again, many subsectors do not meet the criteria on their own.
4. The mean results for total site gas use intensity agree to within 20%. This criterion was not met for the sector as a whole; modeling results are 23% lower than the survey. Natural gas use is underpredicted by more than 40% in lodging, nonrefrigerated warehouse, education, other, and skilled nursing. The gas criterion was missed by 3%, which in EUI magnitude is only 0.75 $kBtu/ft^2 \cdot yr$ ($8.4\ MJ/m^2 \cdot yr$). Because the weighted standard deviation in the survey results for gas is quite large at 53.8 $kBtu/ft^2 \cdot yr$ ($613\ MJ/m^2 \cdot yr$), we conclude that the survey mean results are too imprecise to support such a tight criterion. Because most natural gas consumption is used for space and water heating, and the results shown in Table 4-10 strongly suggest that the models underestimated energy consumption for water heating, the modeling of service water heating should be improved before the method can be applied in subsequent studies that evaluate water heating technologies. Although gas use modeling needs improvement, we conclude that the overall method is still reasonably valid for most technologies.
5. Mean results for energy cost intensity agree to within 15%. This criterion is met for the sector as a whole; the model results are 8% higher than the survey. Because the results for both energy costs and total energy use align reasonably well with the survey results, we conclude that the utility tariff input data and EnergyPlus calculations are reasonably valid.

4.7.2 Sector Representation

The results can also be examined in terms of how well the modeling reflects how energy performance is distributed across the sector. The mean values tell one fairly simple story; but the distributions have more involved information about the widely varying sector. The models have more central tendency than the survey. The weighted standard deviations show that both the survey and models are broadly distributed, but that the models are narrower than the survey. The survey results for EUI show more variability than the models; the survey shows a weighted standard deviation in total EUI of 97.4 $kBtu/ft^2 \cdot yr$ ($1,107\ MJ/m^2 \cdot yr$), and the models 79.6 $kBtu/ft^2 \cdot yr$ ($904\ MJ/m^2 \cdot yr$). The PDFs in Appendix A also show more central tendency, but overall, the distributions compare fairly well for subsets with large numbers of models and samples. Based on comparing PDFs of the modeling and the survey, we conclude that the modeling methodology is a reasonably valid method of representing the entire commercial sector and that the models show less scatter than does the survey.

4.7.3 Critical Review

Although results show that the methodology is reasonably valid, the modeling could be improved. Basing the methodology on EnergyPlus means that there is almost no limit to how much the individual models could be improved in terms of detail and accuracy. The models in this study are simple compared to the sort of models that are typical for analyzing individual building projects. This simplicity stems primarily from the limited data available on the sample buildings from CBECS, but also from the practical challenges of creating and working with such large numbers of EnergyPlus input files. Nevertheless, the modeling methods and input assumptions could be improved in numerous ways and the following are, in no particular order, high-priority areas for improvement that have been identified through the course of this research project and critical review.

- The energy consumption results from 2003 CBECS are a rich source of data about the individual samples. The effort to use the energy results to validate data hinders their use in developing improved input on an individual basis. Future efforts should consider abandoning the blind validation approach and use the energy consumption data directly in an iterative process to improve each model.
- The simplification that buildings are either completely conditioned or not conditioned should be relaxed so that the survey responses for percent conditioned are used directly. The input file generation routines could be expanded to model the buildings with nonuniform conditioning systems and internal gains.
- The results for natural gas shown in Section 4.3 indicate that improvements need to be made in the modeling of natural gas process loads. The results suggest that gas-fired process loads are significantly underrepresented in subsectors such as laboratory, skilled nursing, health care, and food service. Although service water heating is included in the models, independent data about the rates of hot water use are scant. Additional literature searching and new research are needed to provide independent guidance about how to improve inputs for service water heating. The service water heating inputs need to be improved before the methodology can be considered appropriate for subsequent study of water heating technologies.
- The schedules created from CBECS data variables lack diversity and realism. The profiles used to create schedules are generally square-shaped, or “top hat,” and do not reflect the shapes and magnitudes observed anecdotally in real buildings. Improved methods are needed to generate schedules that are more realistic.
- HVAC component performance levels are based on assumption, and more research is needed to understand the installed performance of components in existing buildings. For example, fan efficiencies are probably too high; the model inputs should be revised to use lower efficiencies for fans. Building faults (duct leakage, improper schedules, low refrigerant charge, economizer issues, etc.) are also a significant issue with serious modeling challenges—see for example TIAX (2005).
- HVAC system topologies are simplified and automatically sized. More detailed designs for systems and discrete equipment sizes would be an improvement.
- The assumption that the weighting factors from CBECS still apply to the synthetic buildings generated by probabilistic assignments could be investigated by oversampling with the models. The inputs are assigned by using density functions on a building-by-building case; the building weighting factors are applied to the outputs. Hence, the aggregated results could be skewed by particularly extreme random assignments that happen to be for buildings with high weighting

factors. This and other effects of the random assignments for input could be investigated further by repeatedly generating and running entire sets of models and examining how results vary. However, this would require enormous computational resources.

- The weighted standard deviations of the CBECS data are relatively large, in some cases larger than the mean. The analysis of PDFs shows that EUIs are not distributed normally. Future analysis should consider EUIs as log-normal rather than normal distributions and use weighted geometric mean and weighted geometric standard deviations to characterize data sets.

4.7.4 Lessons for Future Surveys

For future versions of CBECS, EIA could consider incorporating portions of the methodology used in the recent California CEUS (CEC 2006) and adding the following variables for the next round of CBECS:

- **ASHRAE climate zones**. Use the system of climate zones in Standard 169-2006 (ASHRAE 2006) to organize the survey and report results.
- **Mechanical ventilation.** Develop questions that seek to improve understanding of the type of outdoor air systems in use, the HVAC equipment related to mechanical ventilation, and how the outdoor air system might be operated.
- **Monthly demand and energy.** Examine monthly billing data and compile monthly data about the energy and peak power for each building. These data are valuable for comparisons to simulation results because they help identify how weather affects energy performance.
- **Building shape and orientation.** Develop questions that seek to improve understanding of the overall shape and orientation of the building. Final data would include:
    - The ratio between the length and width (aspect ratio)
    - An indication of the orientation of the long axis with respect to north
    - The height of the building or the typical floor-to-floor height
    - A roof shape and orientation type (flat, tilted, etc.; important for solar systems).
- **Utility Tariffs.** Examine billing data and compile data about the rate schedules for utilities. Either identify the utility company and schedule, or provide numeric data for the rate structure.
- **Change CDD to base 50°F.** A base of 65°F is currently used for CBECS, but this is considered less appropriate than a base of 50°F for commercial buildings.

Many of the real-world data underlying building science and energy modeling are based on anecdotal studies of relatively small numbers of buildings. A well-coordinated, statistically robust survey of the stock that includes detailed on-site measurements would be invaluable to researchers and would help to improve simulation practices that are being increasingly used by analysts to rate the energy performance of buildings (e.g., for tax credits). An aggressive (and very costly) expansion of the scope of future survey efforts would be a significant aid to the buildings industry, and researchers. Entities engaged in future surveys of commercial buildings should consider the following activities (in order of priority):

1. Submeter end uses.
2. Measure fan system static pressures and efficiencies.
3. Develop energy modeling inputs during site visits.
4. Measure outdoor air change rates.
5. Measure lighting conditions (levels).
6. Measure thermal comfort conditions.

7. Measure hot and cold water use.
8. Measure moisture performance (indoor relative humidity, equipment for humidification and/or dehumidification).
9. Measure air quality.

5. Conclusions and Recommendations

A methodology for analyzing the energy performance of commercial buildings was developed and examined for its ability to represent the entire sector. This report documents how the method uses the building characteristic data for each sample in the 2003 CBECS public use data to create EnergyPlus models and how well the models agree with the energy consumption data from CBECS that were reserved for validation. We make the following conclusions:

- Bottom-up modeling of the commercial sector is doable and appears able to capture the breadth of variation in whole-building energy performance. The main goal of this study was to evaluate the methodology for modeling the sector, and we conclude that method is valid. The statistical sample of buildings from 2003 CBECS can be extrapolated to develop a large-N sector model based on a set of EnergyPlus models. This sector model can be used for subsequent research to assess energy performance in the commercial buildings sector.
- Using a large-N sector model requires considerable computing resources. Using 4,820 EnergyPlus models requires about 400 hours of simulation run time for each scenario (3-gigahertz processors, 2-gigabyte random access memory). The method is not for the faint of heart and appears most applicable in a research setting with access to cluster computing. Experience suggests that smaller-N sector models (around 200) should be developed to reduce the computational burden of future analyses of the entire sector. The current method is suggested for producing reference data sets and for validating smaller models of the sector.
- EnergyPlus model results can be roughly consistent with 2003 CBECS. Individually, the models and survey sample building results do not agree well because there are insufficient data in CBECS to produce an accurate model. But when aggregating large numbers of models, the overall magnitudes and trends agree as well as can be expected. Although modeling tools are often used only in differential manner, the absolute values for predictions of annual fuel use and expenditures are encouraging. The model results often deviate from the survey, but the comparison to survey results provides a useful check against reality, and the 12% overall agreement in site EUI demonstrates much better than an "order of magnitude" validation of EnergyPlus model predictions.
- The model input and detail could be improved in many ways. One could use the survey results for energy consumption to continue to refine model input assignments. We used only the building characteristics data from 2003 CBECS to derive the models in the current study in an effort to validate such modeling. The current effort selected many details at random, but an additional effort could search unknown input parameters for those that agree with the survey energy results. There would still be insufficient data to model particular end uses without suitable end-use submetering.
- Though less robust than the whole-building data from 2003 CBECS, data for end uses from the *Building Energy Data Book* suggest that more research is needed to improve understanding of energy end uses. Research is needed to better understand the source of the differences in water heating, space cooling, and fans between this study and the *Building Energy Data Book*. This research should evaluate which one is more accurate and therefore help assess how effectively the methodology evaluated in this study can be used to evaluate the energy savings potential of end use-specific technologies and design approaches.

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Appendix A. Expanded Results, Tables, and Figures

This appendix contains ancillary results that augment results presented in the main body of the report.

A.1 EnergyPlus Modeling Outcomes

This subsection provides ancillary data about the modeling methods. Table A-1 provides summary data about the EnergyPlus simulation run times we observed. One issue involved with the chosen methodology is the computational burden associated with using so many EnergyPlus models. Each scenario or iteration involves running 4,820 models and requires roughly 15 days of processor time (3-gigahertz processors). Scenarios also need to be repeated many times to iterate input data. Distributed computing was necessary to complete the work in a reasonable amount of calendar time by running multiple models at the same time on different processors.

Table A-1 EnergyPlus Modeling Simulation Run Times by Subsector

Subsector (PBA)	2003 Historical Weather		TMY Weather	
	Weighted Mean Run Time (s)	Weighted Standard Deviation (s)	Weighted Mean Run Time (s)	Weighted Standard Deviation (s)
All	210	148	218	148
Office/professional	281	134	292	130
Nonrefrigerated warehouse	97	77	105	76
Education	218	125	226	126
Retail (except malls)	148	97	155	96
Public assembly	226	138	230	133
Service	130	85	134	86
Religious worship	203	113	201	106
Lodging	337	208	357	203
Food services	209	177	212	183
Inpatient health care	364	140	397	127
Public order and safety	234	126	246	129
Food sales	125	69	137	72
Outpatient health care	251	164	247	151
Vacant	134	115	145	114
Other	187	129	187	125
Skilled nursing	265	152	270	152
Laboratory	390	139	384	119
Refrigerated warehouse	107	64	112	80

The methods discussed in Section 2.5, Section C.16, and Section C.20 were used to assign outside air change rates; the results for outside air are summarized in Table A-2 by subsector and in Table A-3 by climate zone. Various input assumptions that define the rates of outside air in the modeling result in sector-wide air change rates of 0.8 ACH with 66% from mechanical ventilation and 34% from infiltration.

Table A-2 Average Occupied Outside Air Rates in Modeling by Subsector

Subsector (PBA)	N	Mechanical Ventilation		Infiltration		Combined Mechanical and Infiltration	
		Weighted Mean (ACH)	Weighted Standard Deviation (ACH)	Weighted Mean (ACH)	Weighted Standard Deviation (ACH)	Weighted Mean (ACH)	Weighted Standard Deviation (ACH)
All	4,820	0.53	0.91	0.27	0.14	0.79	0.92
Office/professional	976	0.52	0.41	0.27	0.14	0.79	0.39
Nonrefrigerated warehouse	473	0.04	0.05	0.23	0.13	0.26	0.14
Education	649	0.63	0.62	0.28	0.11	0.92	0.65
Retail (except malls)	355	0.36	0.21	0.32	0.11	0.68	0.21
Public assembly	279	0.46	0.68	0.26	0.11	0.72	0.70
Service	370	0.11	0.00	0.33	0.00	0.44	0.20
Religious worship	311	0.33	0.13	0.30	0.14	0.63	0.43
Lodging	260	0.60	0.39	0.24	0.09	0.84	0.34
Food services	242	2.79	0.36	0.42	0.11	3.21	2.85
Inpatient health care	217	2.72	2.81	0.15	0.12	2.87	1.92
Public order and safety	85	0.34	1.93	0.24	0.07	0.59	0.29
Food sales	125	0.46	0.00	0.38	0.00	0.84	0.25
Outpatient health care	144	0.82	0.25	0.35	0.14	1.16	0.54
Vacant	134	0.04	0.25	0.04	0.11	0.08	0.24
Other	64	0.11	0.57	0.25	0.12	0.36	0.17
Skilled nursing	73	0.78	0.18	0.28	0.10	1.06	0.43
Laboratory	43	1.47	0.15	0.18	0.12	1.65	0.90
Refrigerated warehouse	20	0.07	0.44	0.24	0.10	0.30	0.11

Table A-3 Average Occupied Outside Air Rates in Modeling by Climate Zone: 2003 Historical Weather

Climate Zone	N	Mechanical Ventilation		Infiltration		Combined Mechanical and Infiltration	
		Weighted Mean (ACH)	Weighted Standard Deviation (ACH)	Weighted Mean (ACH)	Weighted Standard Deviation (ACH)	Weighted Mean (ACH)	Weighted Standard Deviation (ACH)
All	4,820	0.53	0.91	0.27	0.14	0.79	0.92
1A	40	0.73	1.86	0.28	0.10	1.01	1.89
2A	542	0.65	1.08	0.27	0.14	0.92	1.10
2B	24	0.59	1.04	0.26	0.15	0.85	1.04
3A	464	0.53	0.81	0.28	0.14	0.81	0.82
3B	452	0.65	1.18	0.27	0.14	0.92	1.20
3C	52	0.75	0.67	0.19	0.13	0.94	0.69
4A	982	0.49	0.77	0.26	0.13	0.75	0.78
4B	64	0.64	0.74	0.26	0.17	0.90	0.75
4C	50	0.56	2.07	0.28	0.15	0.84	2.10
5A	1,152	0.48	0.84	0.25	0.13	0.73	0.84
5B	262	0.54	0.73	0.31	0.14	0.86	0.74
6A	519	0.44	0.79	0.26	0.13	0.70	0.81
6B	120	0.56	0.74	0.32	0.13	0.88	0.74
7A	97	0.30	0.73	0.26	0.15	0.57	0.78
8A	0	N/A	N/A	N/A	N/A	N/A	N/A

A.2 Table Data for Figures in Section 4

This section provides tables of results that correspond to figures presented in Section 4.0. These data tables augment the plots and add weighted standard deviations and calculated percent differences.

Table A-4 Total EUI Results from 2003 CBECS Survey and Modeling by Subsector

Subsector (PBA)	N	2003 CBECS Survey		Models 2003 Historical Weather		% Difference in Mean EUI
		Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	
All	4,820	89.8	97.4	79.2	74.2	12%
Office/professional	976	92.9	68.1	78.5	34.0	16%
Nonrefrigerated warehouse	473	42.3	56.1	34.1	23.9	19%
Education	649	83.1	68.2	55.2	31.0	34%
Retail (except malls)	355	73.9	75.5	74.6	34.1	-1%
Public assembly	279	93.9	85.1	72.3	43.8	23%
Service	370	77.0	97.5	69.6	35.6	10%
Religious worship	311	43.5	34.4	53.0	42.6	-22%
Lodging	260	94.1	63.1	83.3	41.6	11%
Food services	242	258.3	232.5	347.0	124.3	-34%
Inpatient health care	217	249.2	126.0	180.5	99.9	28%
Public order and safety	85	115.8	56.9	80.3	40.6	31%
Food sales	125	199.7	122.1	200.5	53.5	0%
Outpatient health care	144	94.6	80.9	87.8	42.2	7%
Vacant	134	20.9	31.5	21.5	33.8	-3%
Other	64	79.4	72.8	62.4	25.9	21%
Skilled nursing	73	124.6	62.9	121.0	25.7	3%
Laboratory	43	305.4	169.6	329.7	64.5	-8%
Refrigerated warehouse	20	98.5	71.7	86.0	25.2	13%

Table A-5 Total EUI Results from CBECS Survey and Modeling by Climate Zone and Weather Data

Zone	N	2003 CBECS Survey		Models 2003 Historical Weather		Models TMY Weather	
		Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	Weighted Mean EUI (kBtu/ft²·yr)	% Difference from Survey in Mean EUI	Weighted Mean EUI (kBtu/ft²·yr)	% Difference from Survey in Mean EUI
All	4,820	89.8	97.4	79.2	12%	79.6	11%
1A	40	73.7	98.3	101.5	-38%	97.7	-33%
2A	542	71.6	88.0	71.7	0%	70.4	2%
2B	24	113.5	91.6	93.5	18%	91.6	19%
3A	464	89.0	105.2	78.0	12%	78.4	12%
3B	452	69.6	98.3	64.3	8%	64.8	7%
3C	52	62.3	54.4	66.1	-6%	67.0	-8%
4A	982	94.7	104.8	79.0	17%	79.5	16%
4B	64	107.9	104.2	58.7	46%	61.4	43%
4C	50	98.6	89.4	66.8	32%	70.8	28%
5A	1,152	104.4	99.0	86.4	17%	86.4	17%
5B	262	86.8	85.3	74.7	14%	76.9	11%
6A	519	89.4	89.8	85.7	4%	86.6	3%
6B	120	96.6	73.2	87.0	10%	91.6	5%
7A	97	71.0	70.5	91.5	-29%	92.6	-30%
8A	0	N/A	N/A	N/A	N/A	N/A	N/A

Table A-6 Total EUI Results from CBECS Survey and Modeling by Census Division

Census Division	N	2003 CBECS Survey (except Malls)		Models 2003 Historical Weather		% Difference in Mean EUI
		Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	
All	4,820	89.8	97.4	79.2	74.2	12%
1. New England	195	99.0	109.9	93.0	86.5	6%
2. Middle Atlantic	641	98.3	104.1	84.7	71.8	14%
3. East North Central	860	108.1	99.0	82.7	69.1	23%
4. West North Central	452	79.5	73.9	90.5	82.8	-14%
5. South Atlantic	912	86.8	98.2	79.2	79.8	9%
6. East South Central	279	91.1	114.5	74.1	62.7	19%
7. West South Central	579	73.4	92.6	67.7	74.0	8%
8. Mountain	305	103.8	86.9	78.1	52.4	25%
9. Pacific	597	69.4	87.6	67.7	74.7	2%

Table A-7 Electricity EUI Results from 2003 CBECS Survey and Modeling by Subsector

Subsector (PBA)	N	2003 CBECS Survey		Models 2003 Historical Weather		% Difference in Mean EUI
		Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	
All	4,820	46.9	53.8	51.8	42.7	-10%
Office/professional	976	58.9	39.4	60.8	25.3	-3%
Nonrefrigerated warehouse	473	20.9	27.9	25.0	17.9	-19%
Education	649	37.6	29.7	34.9	16.2	7%
Retail (except malls)	355	48.8	56.8	54.4	22.6	-12%
Public assembly	279	42.5	57.1	40.2	25.1	6%
Service	370	36.9	39.4	47.5	26.2	-29%
Religious worship	311	16.6	14.9	25.2	17.4	-52%
Lodging	260	44.6	34.6	53.8	21.7	-21%
Food services	242	130.9	132.5	177.4	67.1	-36%
Inpatient health care	217	93.7	40.7	87.4	25.3	7%
Public order and safety	85	52.3	28.7	56.9	26.3	-9%
Food sales	125	166.1	101.5	158.5	38.0	5%
Outpatient health	144	55.0	40.4	55.8	24.3	-1%
Vacant	134	6.0	11.3	9.4	11.6	-57%
Other	64	42.3	50.5	47.8	21.1	-13%
Skilled nursing	73	52.4	30.1	87.0	21.1	-66%
Laboratory	43	133.1	62.6	207.0	59.4	-55%
Refrigerated warehouse	20	84.9	71.0	77.3	15.6	9%

Table A-8 Electricity EUI Results from CBECS Survey and Modeling by Climate Zone and Weather Data

Zone	N	2003 CBECS Survey		Models 2003 Historical Weather		Models TMY Weather	
		Weighted Mean EUI (kBtu/ ft²·yr)	Weighted Standard Deviation (kBtu/ ft²·yr)	Weighted Mean EUI (kBtu/ ft²·yr)	% Difference from Survey in Mean EUI	Weighted Mean EUI (kBtu/ ft²·yr)	% Difference from Survey in Mean EUI
All	4,820	46.9	53.8	51.8	-10%	51.6	-10%
1A	40	60.9	70.6	78.5	-29%	75.8	-24%
2A	542	54.6	65.0	55.4	-2%	54.5	0%
2B	24	95.8	54.1	63.1	34%	62.1	35%
3A	464	55.5	66.3	58.6	-6%	58.5	-5%
3B	452	44.2	48.5	50.7	-15%	50.2	-14%
3C	52	35.3	28.2	51.8	-47%	51.2	-45%
4A	982	49.0	53.3	54.1	-10%	54.2	-11%
4B	64	57.0	53.9	43.2	24%	43.2	24%
4C	50	60.8	86.2	50.2	18%	49.8	18%
5A	1,152	44.6	50.2	50.4	-13%	50.4	-13%
5B	262	48.3	50.0	48.1	0%	47.7	1%
6A	519	34.2	40.1	43.4	-27%	43.3	-27%
6B	120	35.0	33.2	45.4	-30%	45.1	-29%
7A	97	34.0	41.5	46.5	-37%	46.3	-36%
8A	0	N/A	N/A	N/A	N/A	N/A	N/A

Table A-9 Electricity EUI Results from CBECS Survey and Modeling by Census Division

Census Division	N	2003 CBECS Survey		Models 2003 Historical Weather		% Difference in Mean EUI
		Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	
All	4,820	46.9	53.8	51.8	42.7	-10%
1. New England	195	36.5	49.8	52.0	53.8	-43%
2. Middle Atlantic	641	39.7	47.5	51.3	36.3	-29%
3. East North Central	860	45.1	50.2	46.6	37.1	-3%
4. West North Central	452	38.8	40.8	50.2	39.3	-29%
5. South Atlantic	912	58.5	66.3	59.2	49.4	-1%
6. East South Central	279	50.3	58.8	53.2	40.4	-6%
7. West South Central	579	49.7	55.4	52.3	49.0	-5%
8. Mountain	305	51.9	54.0	47.2	29.6	9%
9. Pacific	597	43.0	45.5	50.6	42.5	-18%

Table A-10 Natural Gas EUI Results from 2003 CBECS Survey and Modeling by Subsector

Subsector (PBA)	N	2003 CBECS Survey		Models 2003 Historical Weather		% Difference in Mean EUI
		Weighted Mean Gas EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	Weighted Mean Gas EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	
All	4,820	29.8	53.8	23.1	40.7	23%
Office/professional	976	22.1	40.6	14.2	20.8	36%
Nonrefrigerated warehouse	473	13.4	25.3	7.7	13.6	42%
Education	649	27.2	35.5	14.7	18.9	46%
Retail (except malls)	355	21.2	38.9	19.9	24.6	6%
Public assembly	279	25.9	40.2	22.9	33.6	12%
Service	370	34.4	75.2	21.9	23.1	36%
Religious worship	311	21.9	31.0	27.7	36.0	-27%
Lodging	260	36.9	41.5	19.3	23.5	48%
Food services	242	122.9	137.2	164.5	85.1	-34%
Inpatient health care	217	107.3	84.3	68.2	89.5	36%
Public order and safety	85	26.3	39.2	16.6	26.9	37%
Food sales	125	30.8	45.6	40.8	35.2	-32%
Outpatient health care	144	30.4	47.7	27.8	30.3	8%
Vacant	134	10.9	20.3	10.5	25.6	4%
Other	64	34.8	44.6	14.6	18.9	58%
Skilled nursing	73	63.8	49.8	31.8	23.3	50%
Laboratory	43	75.6	135.9	105.2	24.2	-39%
Refrigerated warehouse	20	9.2	10.4	7.7	20.5	16%

Table A-11 Natural Gas EUI Results from CBECS Survey and Modeling by Climate Zone and Weather Data

Zone	N	2003 CBECS Survey		Models 2003 Historical Weather		Models TMY Weather	
		Weighted Mean EUI (kBtu/ ft²·yr)	Weighted Standard Deviation (kBtu/ ft²·yr)	Weighted Mean EUI (kBtu/ ft²·yr)	% Difference from Survey in Mean EUI	Weighted Mean EUI (kBtu/ ft²·yr)	% Difference from Survey in Mean EUI
All	4,820	29.8	53.8	23.1	23%	23.8	20%
1A	40	10.4	39.4	13.4	-29%	13.4	-29%
2A	542	10.2	29.2	10.0	2%	10.3	-1%
2B	24	10.0	40.2	8.1	19%	9.1	9%
3A	464	26.3	50.9	18.4	30%	18.9	28%
3B	452	22.3	59.7	12.5	44%	13.4	40%
3C	52	20.6	39.9	14.3	31%	15.6	24%
4A	982	28.2	57.0	18.4	35%	18.9	33%
4B	64	48.3	58.4	14.5	70%	17.2	64%
4C	50	16.0	26.9	13.4	16%	17.5	-10%
5A	1,152	39.7	56.1	31.5	21%	31.6	20%
5B	262	32.6	51.7	24.9	24%	27.5	16%
6A	519	38.6	57.5	37.4	3%	38.3	1%
6B	120	52.9	55.3	38.8	27%	43.6	18%
7A	97	24.8	38.5	43.6	-76%	44.9	-81%
8A	0	N/A	N/A	N/A	N/A	N/A	N/A

Table A-12 Natural Gas EUI Results from CBECS Survey and Modeling by Census Division

Census Division	N	2003 CBECS Survey		Models 2003 Historical Weather		% Difference in Mean EUI
		Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	Weighted Mean EUI (kBtu/ft²·yr)	Weighted Standard Deviation (kBtu/ft²·yr)	
All	4,820	29.8	53.8	23.1	40.7	23%
1. New England	195	25.2	50.2	34.2	40.4	-36%
2. Middle Atlantic	641	35.5	62.6	24.7	47.7	30%
3. East North Central	860	45.5	59.4	31.8	42.2	30%
4. West North Central	452	32.2	43.8	38.3	52.6	-19%
5. South Atlantic	912	17.7	40.7	15.4	35.0	13%
6. East South Central	279	30.0	62.5	18.2	29.1	39%
7. West South Central	579	19.9	46.1	13.2	30.6	34%
8. Mountain	305	45.4	54.5	27.5	32.5	39%
9. Pacific	597	20.1	53.0	14.9	36.8	26%

Table A-13 Total Energy Cost Intensity Results from 2003 CBECS Survey and Modeling by Subsector

Subsector (PBA)	N	2003 CBECS Survey		Models 2003 Historical Weather		% Difference in Mean Cost Intensity
		Weighted Mean Cost Intensity ($\$/ft^2 \cdot yr$)	Weighted Standard Deviation ($\$/ft^2 \cdot yr$)	Weighted Mean Cost Intensity ($\$/ft^2 \cdot yr$)	Weighted Standard Deviation ($\$/ft^2 \cdot yr$)	
All	4,820	1.51	1.62	1.63	1.44	-8%
Office/professional	976	1.80	1.17	1.90	0.95	-6%
Nonrefrigerated warehouse	473	0.68	0.71	0.76	0.55	-11%
Education	649	1.28	1.27	1.15	0.59	10%
Retail (except malls)	355	1.46	1.38	1.70	0.79	-17%
Public assembly	279	1.55	1.82	1.38	0.92	11%
Service	370	1.24	1.28	1.44	0.76	-16%
Religious worship	311	0.69	0.44	1.08	0.77	-56%
Lodging	260	1.51	1.09	1.65	0.95	-9%
Food services	242	4.38	4.02	6.25	2.85	-43%
Inpatient health care	217	2.95	1.39	2.75	1.55	7%
Public order and safety	85	1.86	0.82	1.65	0.87	11%
Food sales	125	4.20	2.82	4.31	1.84	-3%
Outpatient health care	144	1.77	1.25	1.87	0.95	-6%
Vacant	134	0.31	0.43	0.37	0.46	-19%
Other	64	1.52	1.82	1.68	0.94	-10%
Skilled nursing	73	1.68	0.89	2.27	0.85	-35%
Laboratory	43	4.61	2.33	5.54	2.20	-20%
Refrigerated warehouse	20	1.54	1.12	1.69	0.69	-10%

Table A-14 Total Energy Cost Intensity Results from CBECS Survey and Modeling by Climate Zone and Weather Data

Zone	N	2003 CBECS Survey		Models 2003 Historical Weather		Models TMY Weather	
		Weighted Mean Cost Intensity (\$/ft²·yr)	Weighted Standard Deviation (\$/ft²·yr)	Weighted Mean Cost Intensity (\$/ft²·yr)	% Difference from Survey in Mean Cost Intensity	Weighted Mean Cost Intensity (\$/ft²·yr)	% Difference from Survey in Mean Cost Intensity
All	4,820	1.51	1.62	1.72	-14%	1.71	-13%
1A	40	2.33	2.62	2.22	5%	2.16	7%
2A	542	1.42	1.60	1.62	-14%	1.60	-13%
2B	24	2.21	1.30	1.68	24%	1.69	24%
3A	464	1.41	1.53	1.65	-17%	1.65	-17%
3B	452	1.65	1.84	2.02	-22%	2.00	-21%
3C	52	1.77	1.20	2.40	-36%	2.39	-35%
4A	982	1.57	1.72	1.81	-15%	1.80	-15%
4B	64	1.75	1.79	1.53	13%	1.56	11%
4C	50	2.21	3.93	1.12	49%	1.14	48%
5A	1,152	1.57	1.49	1.79	-14%	1.79	-14%
5B	262	1.32	1.52	1.18	11%	1.19	10%
6A	519	1.30	1.35	1.55	-19%	1.54	-18%
6B	120	1.24	1.04	1.09	12%	1.11	10%
7A	97	0.96	0.98	1.68	-75%	1.65	-72%
8A	0	N/A	N/A	N/A	N/A	N/A	N/A

Table A-15 Total Energy Cost Intensity Results from CBECS Survey and Modeling by Census Division

Census Division	N	2003 CBECS Survey (except Malls)		Models 2003 Historical Weather		% Difference in Mean Cost Intensity
		Weighted Mean Cost Intensity (\$/ft²·yr)	Weighted Standard Deviation (\$/ft²·yr)	Weighted Mean Cost Intensity (\$/ft²·yr)	Weighted Standard Deviation (\$/ft²·yr)	
All	4,820	1.51	1.62	1.72	1.33	-14%
1. New England	195	1.73	1.89	2.14	1.65	-24%
2. Middle Atlantic	641	1.75	1.93	2.43	1.58	-39%
3. East North Central	860	1.45	1.29	1.56	1.10	-8%
4. West North Central	452	1.08	0.97	1.28	0.85	-19%
5. South Atlantic	912	1.51	1.58	1.54	1.15	-2%
6. East South Central	279	1.42	1.59	1.39	0.99	2%
7. West South Central	579	1.27	1.44	1.73	1.43	-36%
8. Mountain	305	1.62	1.60	1.15	0.71	29%
9. Pacific	597	1.73	2.03	1.87	1.53	-8%

A.3 Probability Distributions

The U.S. commercial sector is large and diverse, and its buildings have a wide variety of activities, sizes, shapes, locations, etc., that lead to wide variation in EUI. The previous section focused on the average results (weighted means) for entire portions of the commercial sector, but this should not be taken to imply that there is much uniformity in the energy performance of buildings. The large-N sector model used in this study allows us to examine variations in EUI across the sector. This section presents the distribution in results for a fuller understanding of how performance varies across the sector.

The plots in Figure A-1 to Figure A-20 present probability density functions (PDFs) that show how EUIs for all types of buildings are distributed for each climate zone. The plots are all normalized PDFs for how EUI is distributed in the commercial sector. PDFs are calculated from the 2003 CBECS public use data (survey) and from the EnergyPlus models with 2003 historical weather (models). Figure A-1 is for all the buildings the study. The remaining figures provide thumbnails of PDF plots to illustrate results by PBA and by climate zone. Each figure covers a PBA category and contains a group of plots for different climate zones. The upper left plot shows results for all climates taken together. The remaining 14 plots show results that are sorted by the individual ASHRAE climate zones (see Figure 4-3). The survey results are in red and the model results are in green. The number of samples (N) in each category is provided in the plot label above each graph. For categories with 21 or more samples, the PDFs are continuous and calculated from histograms by using a fixed bin size of 20 kBtu/ft^2·yr (227 MJ/m^2·yr). When a category has 20 or fewer samples, the PDFs are discrete and each sample building is plotted individually. Some categories have no samples (N = 0) and indicate that the CBECS sample did not cover them.

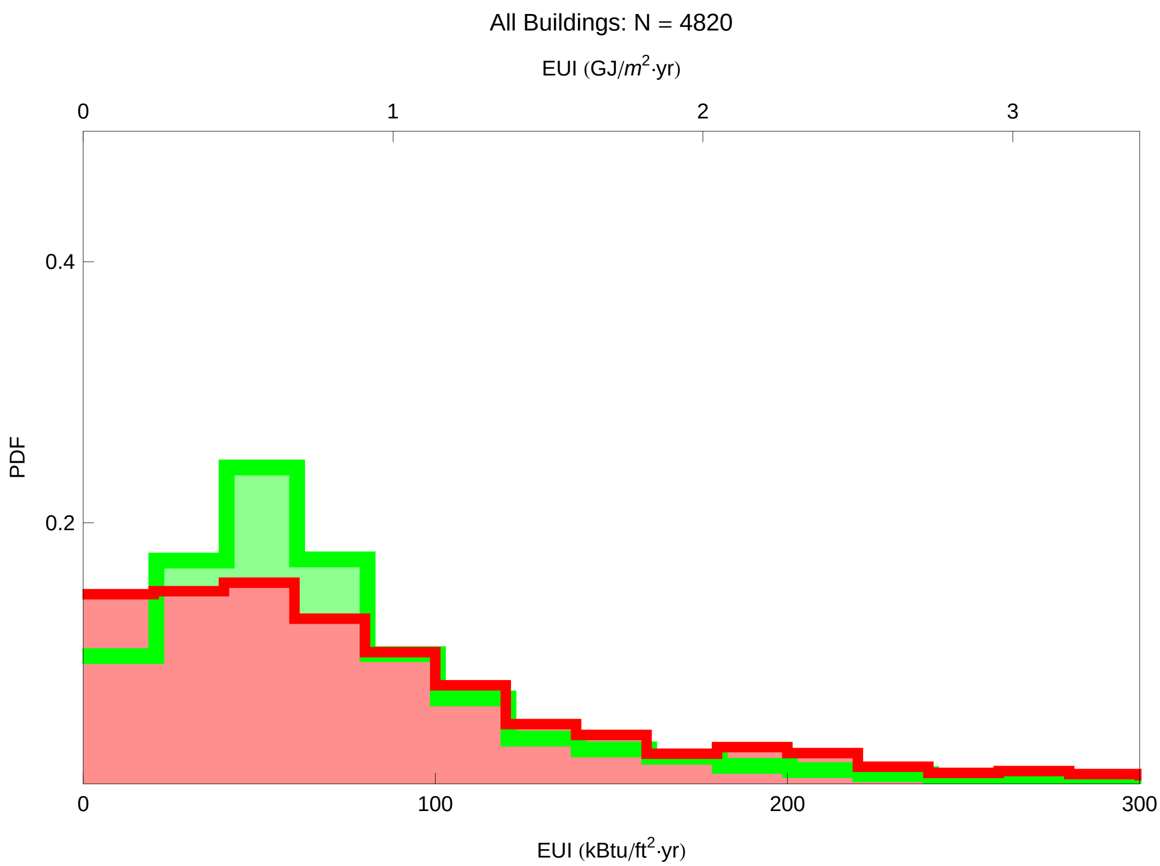


Figure A-1 PDFs for All Buildings:
Survey Results in Red, Model Results in Green

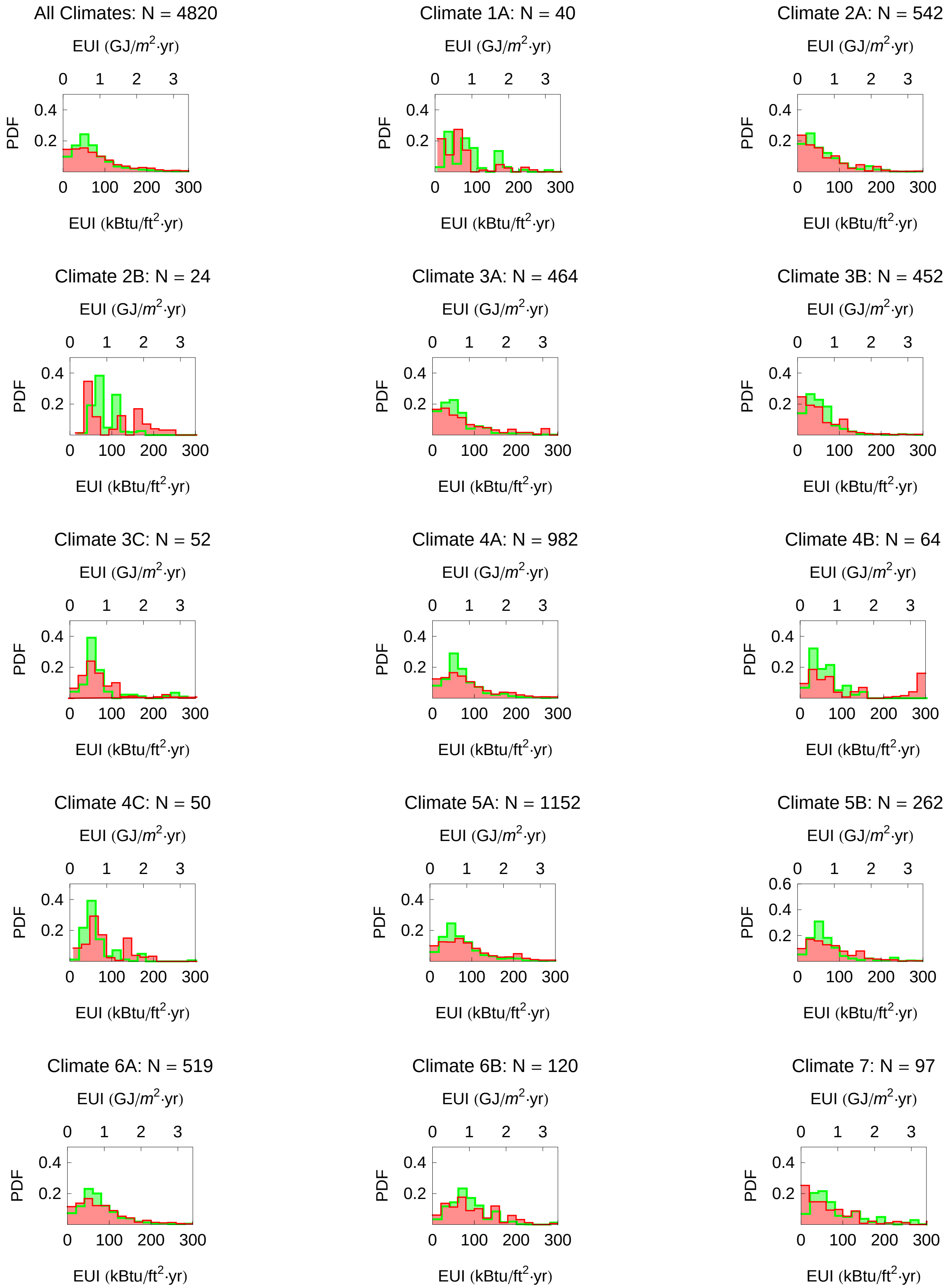


Figure A-2 PDFs for All Buildings in Various Climates:
Survey Results in Red, Model Results in Green

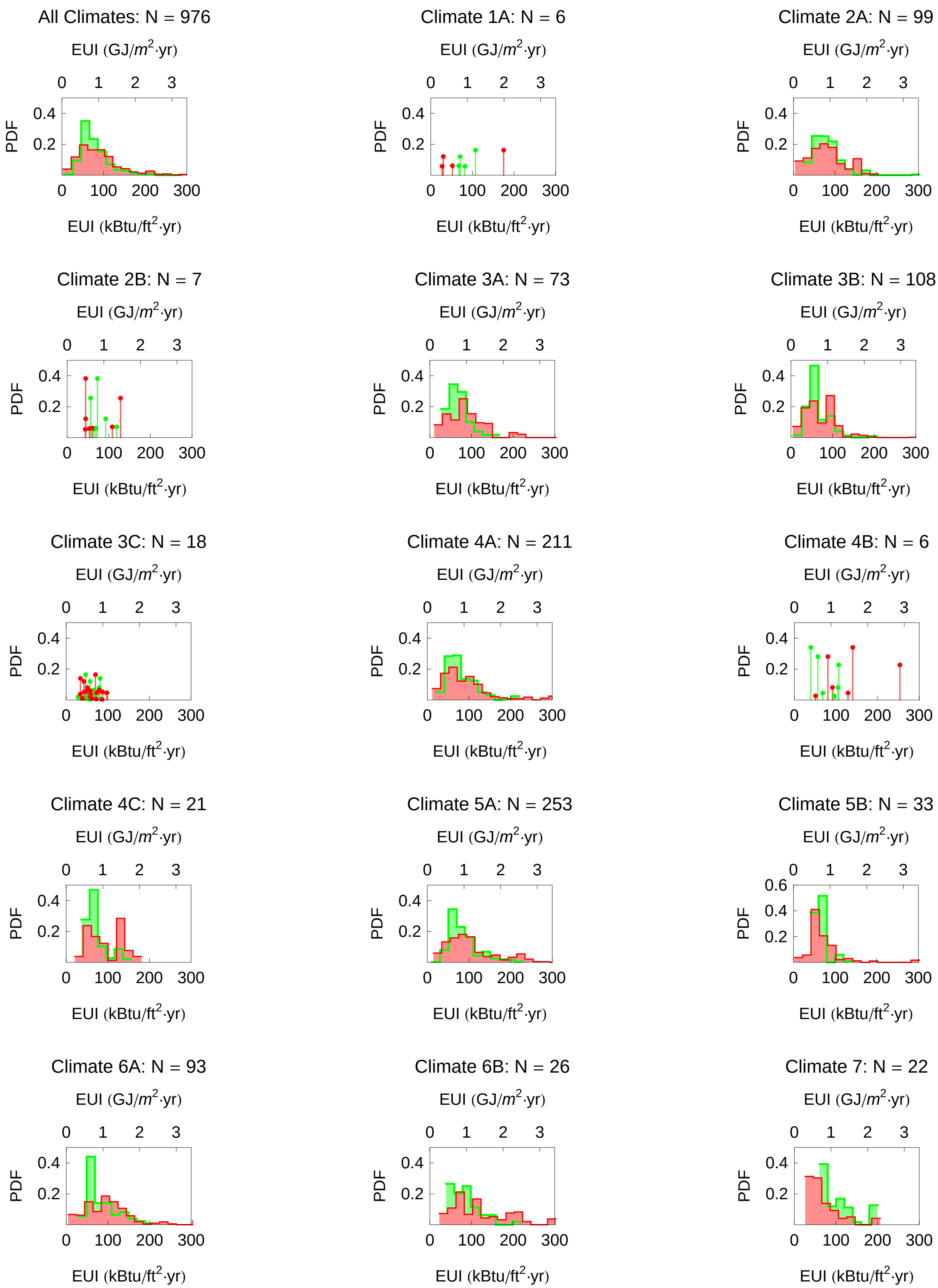


Figure A-3 PDFs for Office Buildings in Various Climates: Survey Results in Red, Model Results in Green

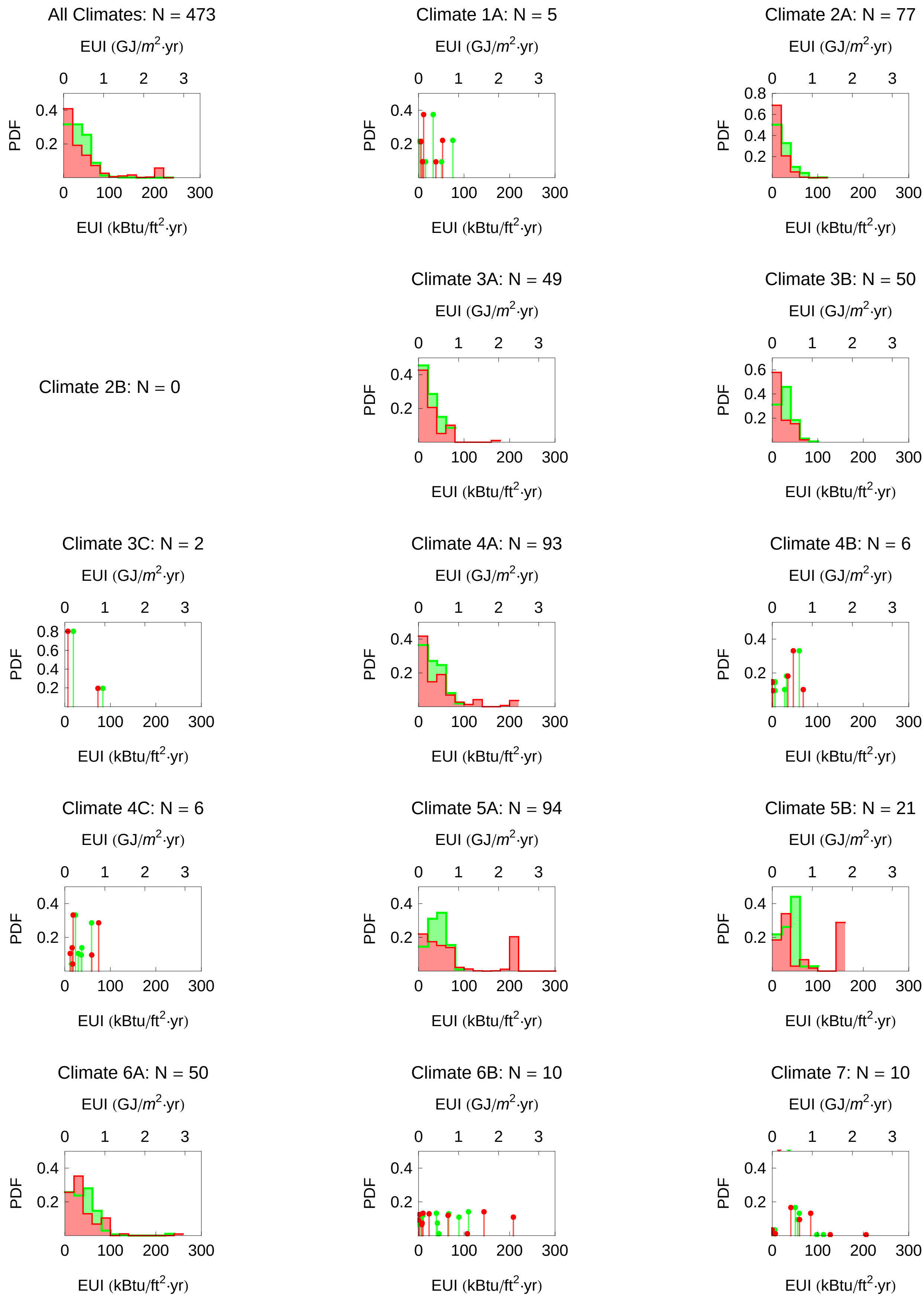


Figure A-4 PDFs for Nonrefrigerated Warehouse Buildings in Various Climates: Survey Results in Red, Model Results in Green

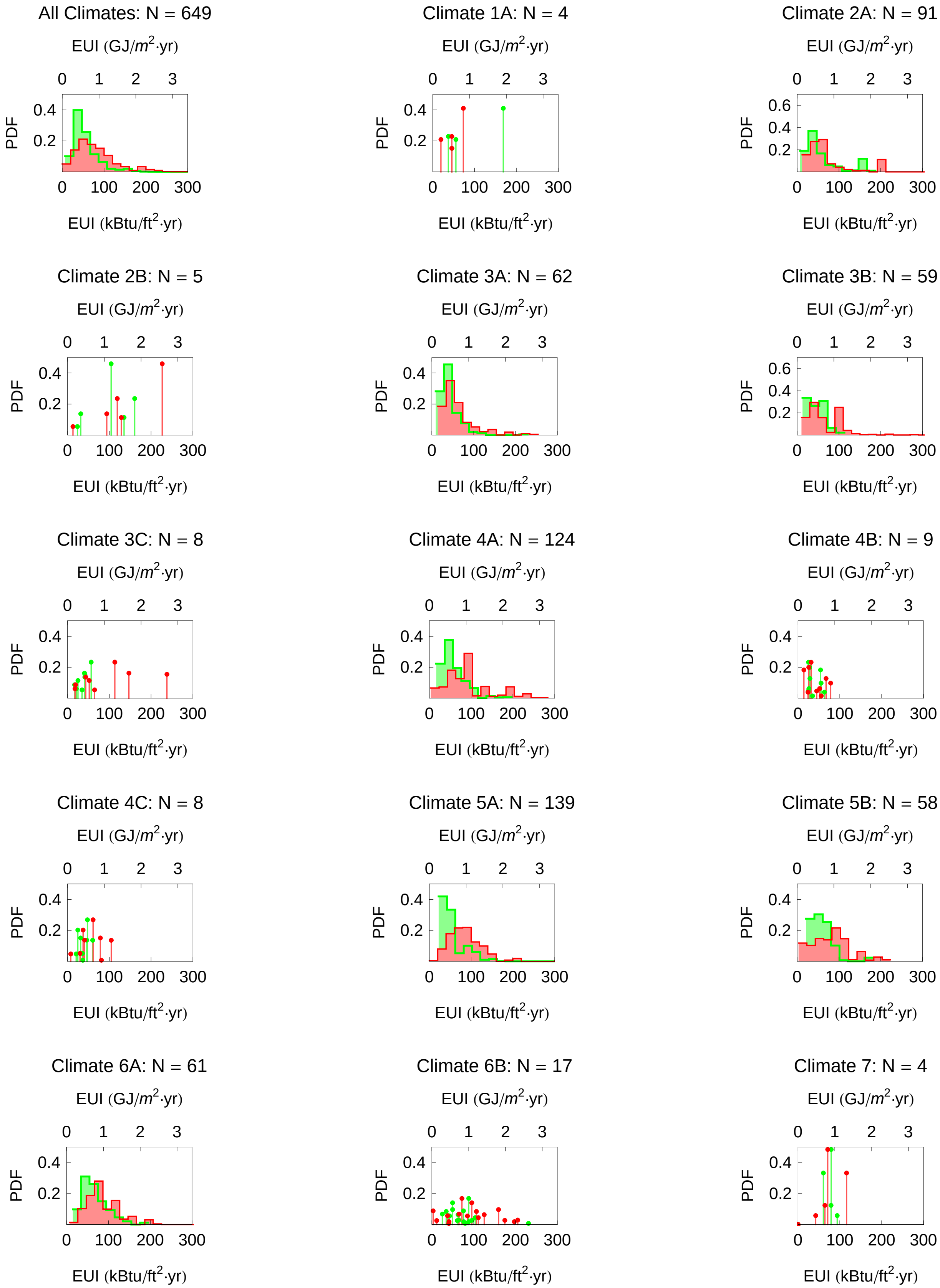


Figure A-5 PDFs for Education Buildings in Various Climates: Survey Results in Red, Model Results in Green

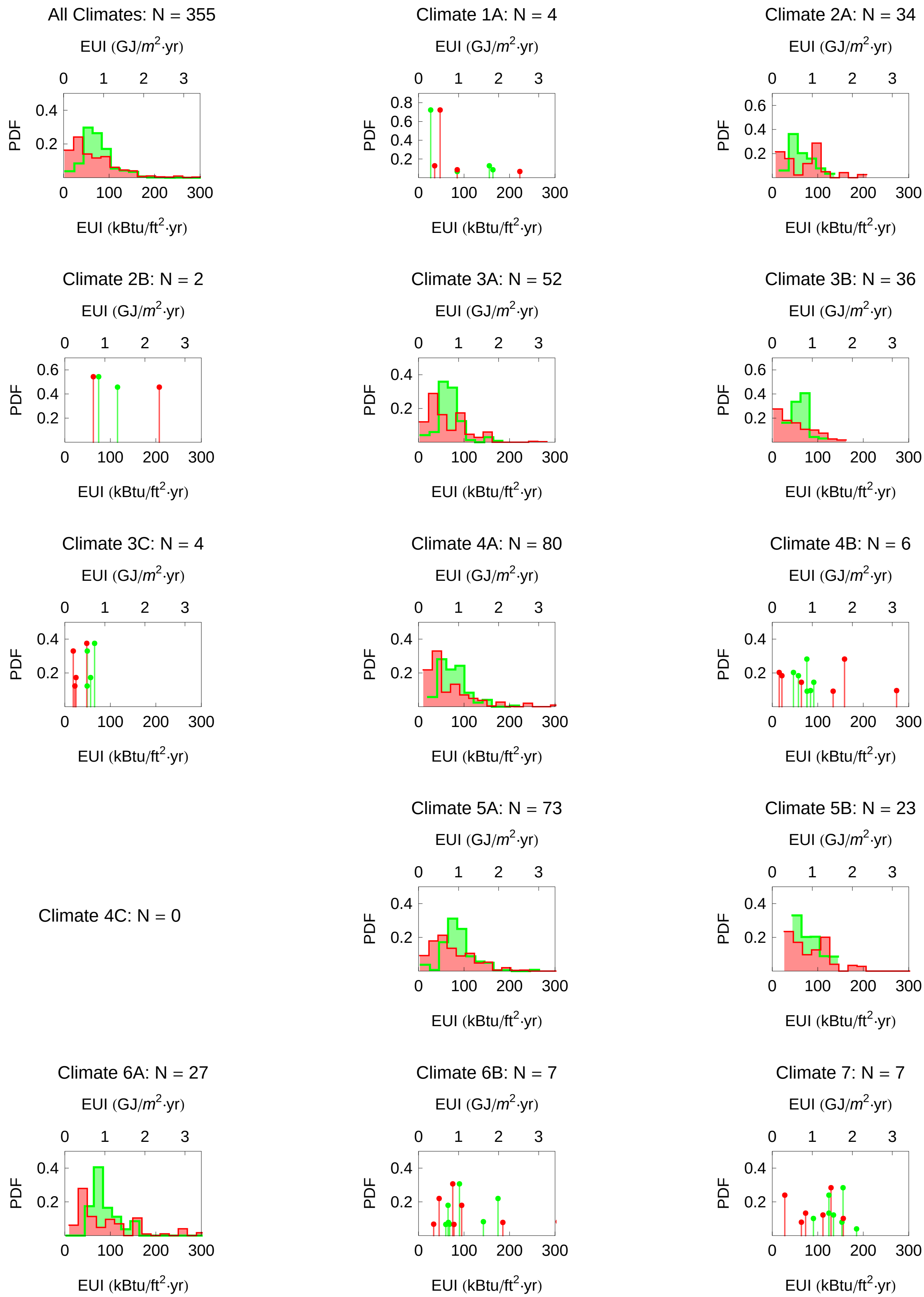


Figure A-6 PDFs for Retail (except Malls) Buildings in Various Climates: Survey Results in Red, Model Results in Green

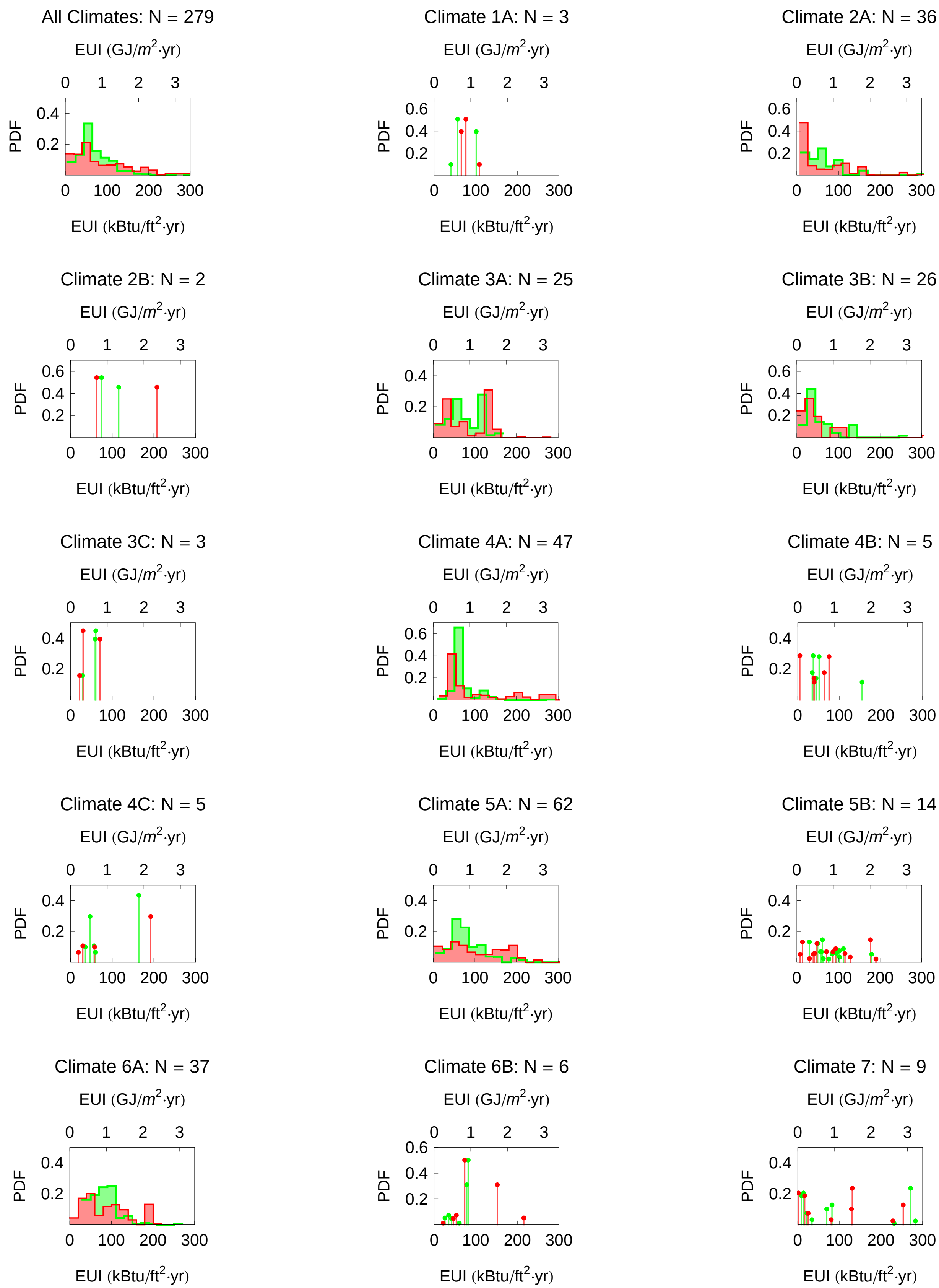


Figure A-7 PDFs for Public Assembly Buildings in Various Climates: Survey results in red, Model results in Green

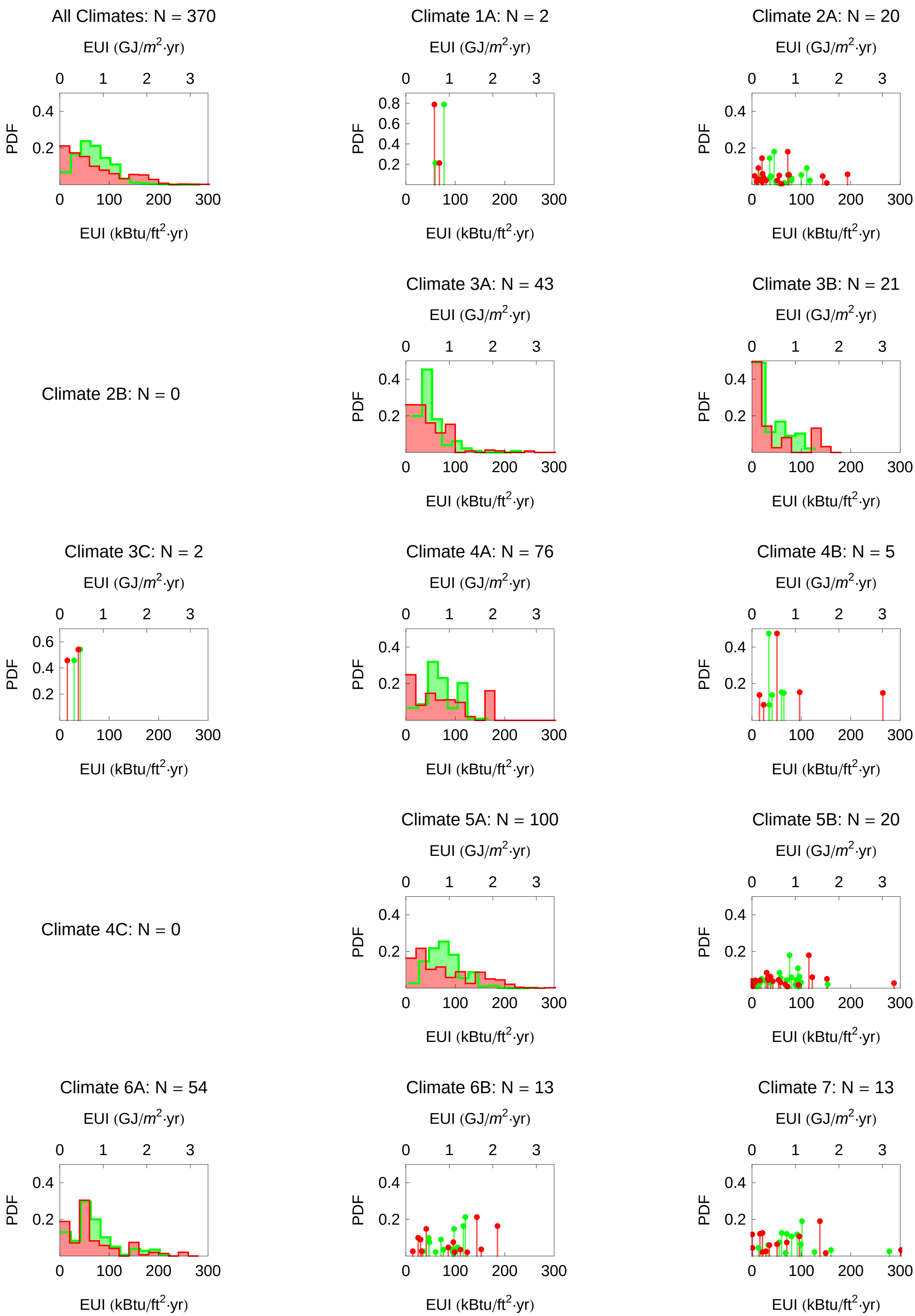


Figure A-8 PDFs for Service Buildings in Various Climates: Survey Results in Red, Model Results in Green

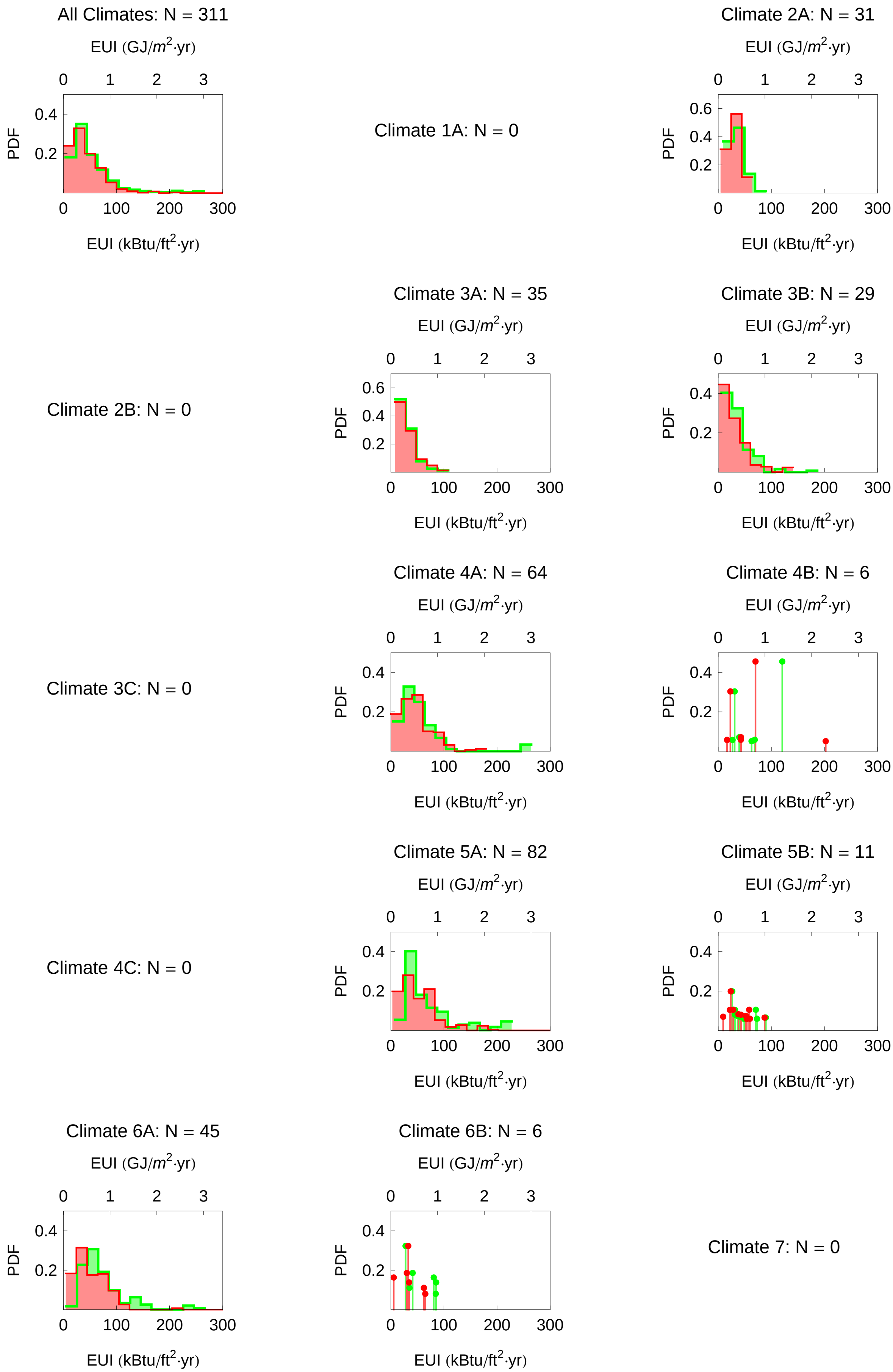


Figure A-9 PDFs for Religious Worship Buildings in Various Climates: Survey Results in Red, Model Results in Green

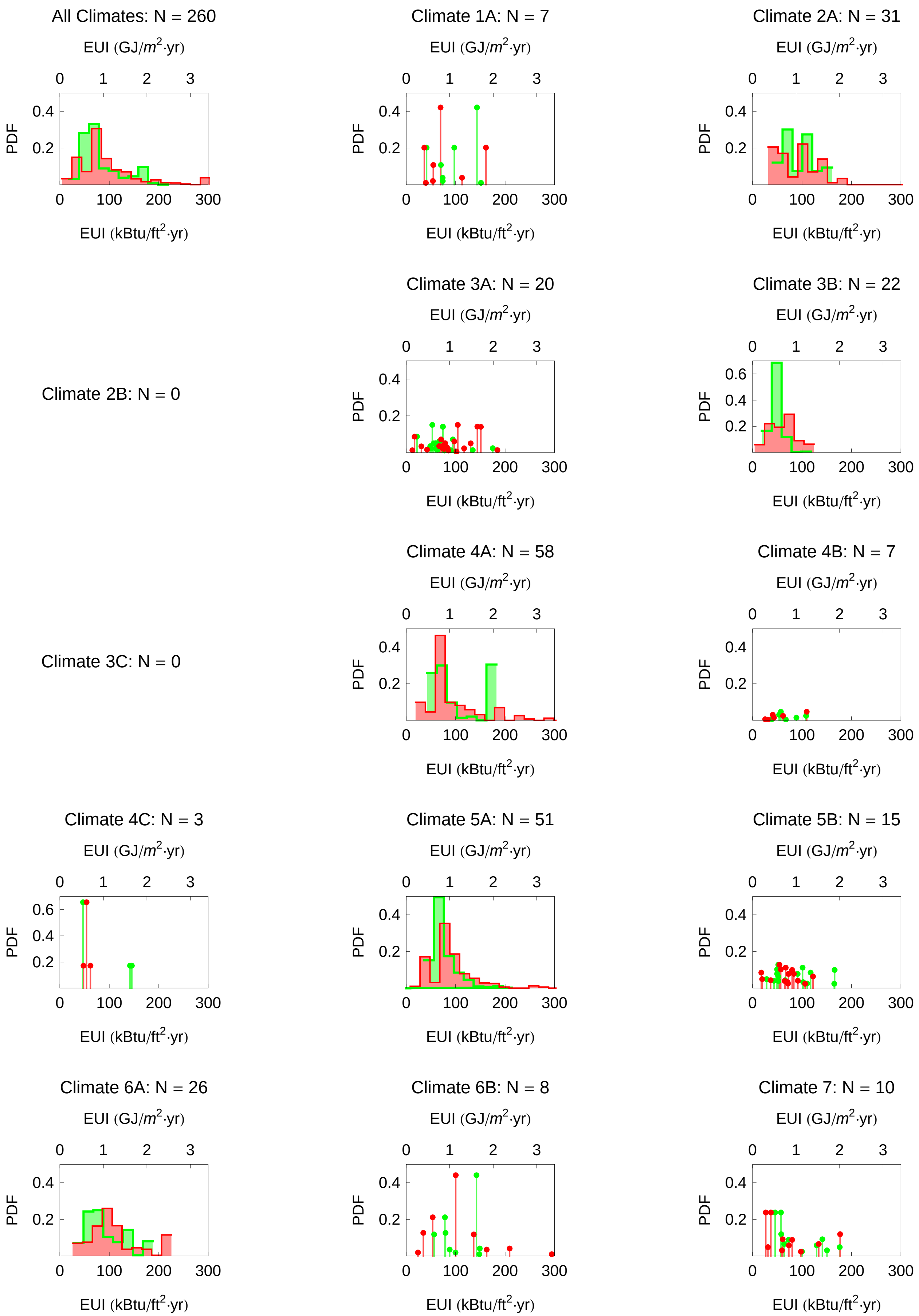


Figure A-10 PDFs for Lodging Buildings in Various Climates:
Survey Results in Red, Model Results in Green

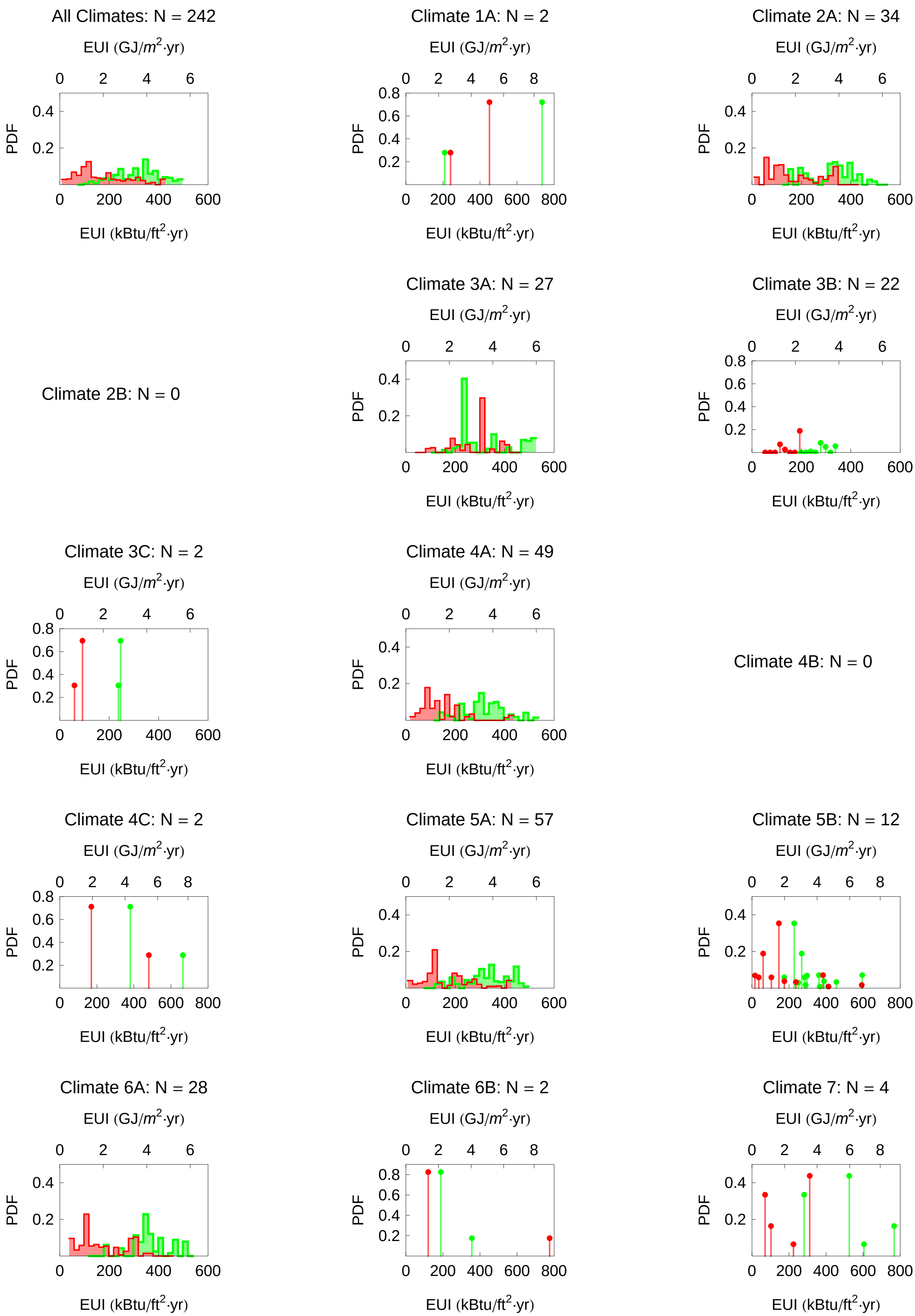


Figure A-11 PDFs for Food Services Buildings in Various Climates: Survey Results in Red, Model Results in Green

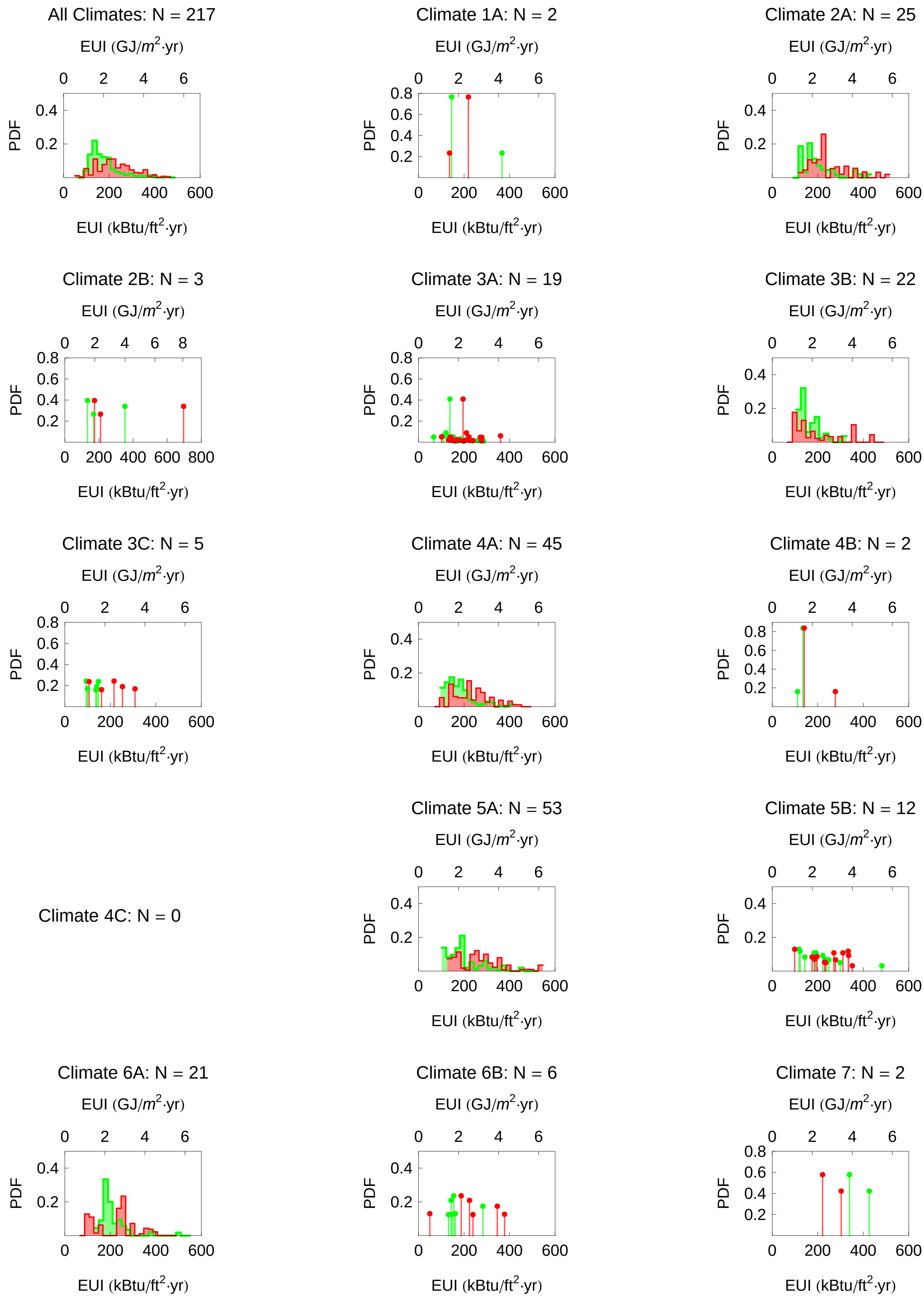


Figure A-12 PDFs for Inpatient Health Care Buildings in Various Climates: Survey Results in Red, Model Results in Green

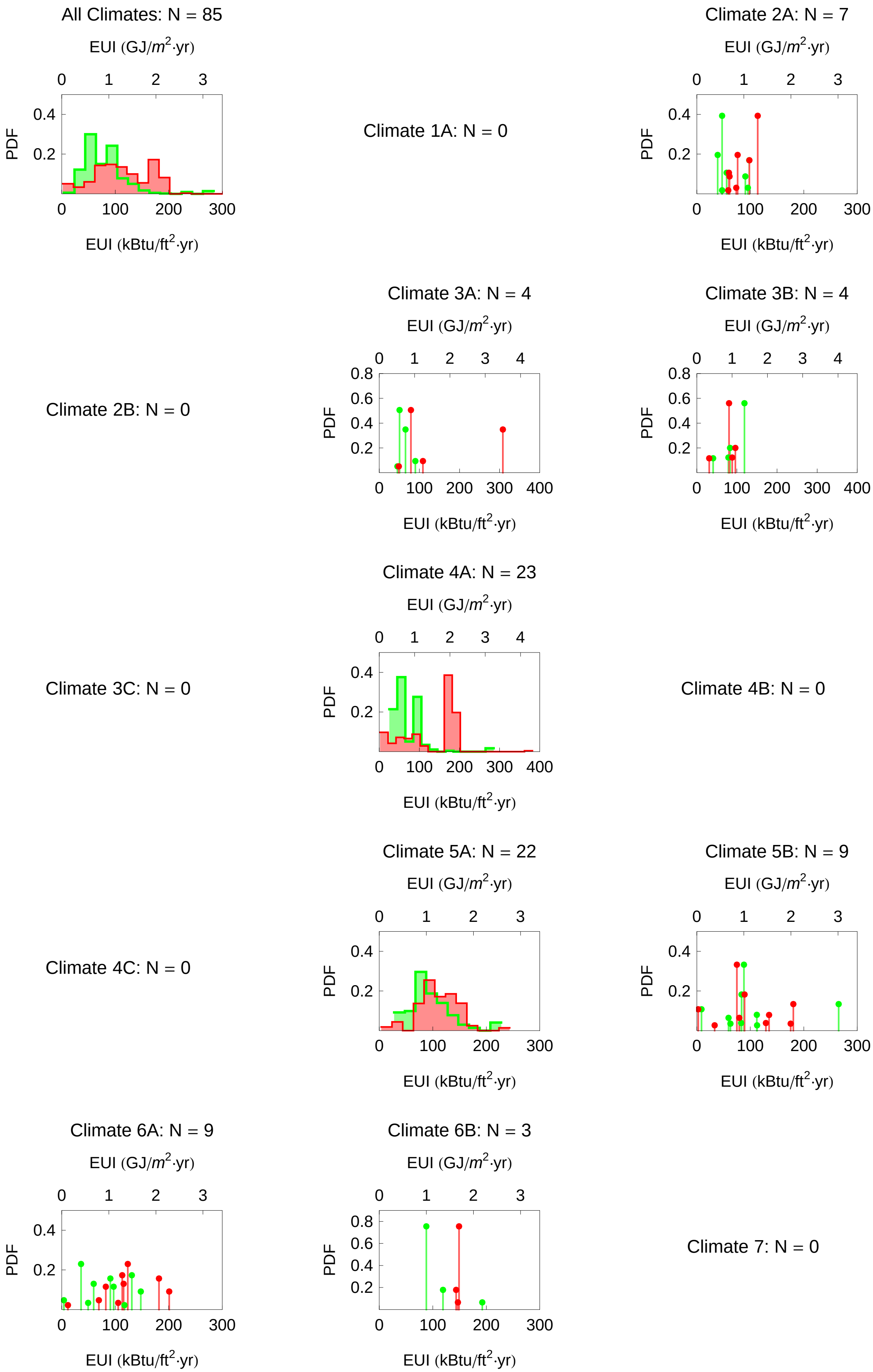


Figure A-13 PDFs for Public Order and Safety Buildings in Various Climates: Survey Results in Red, Model Results in Green

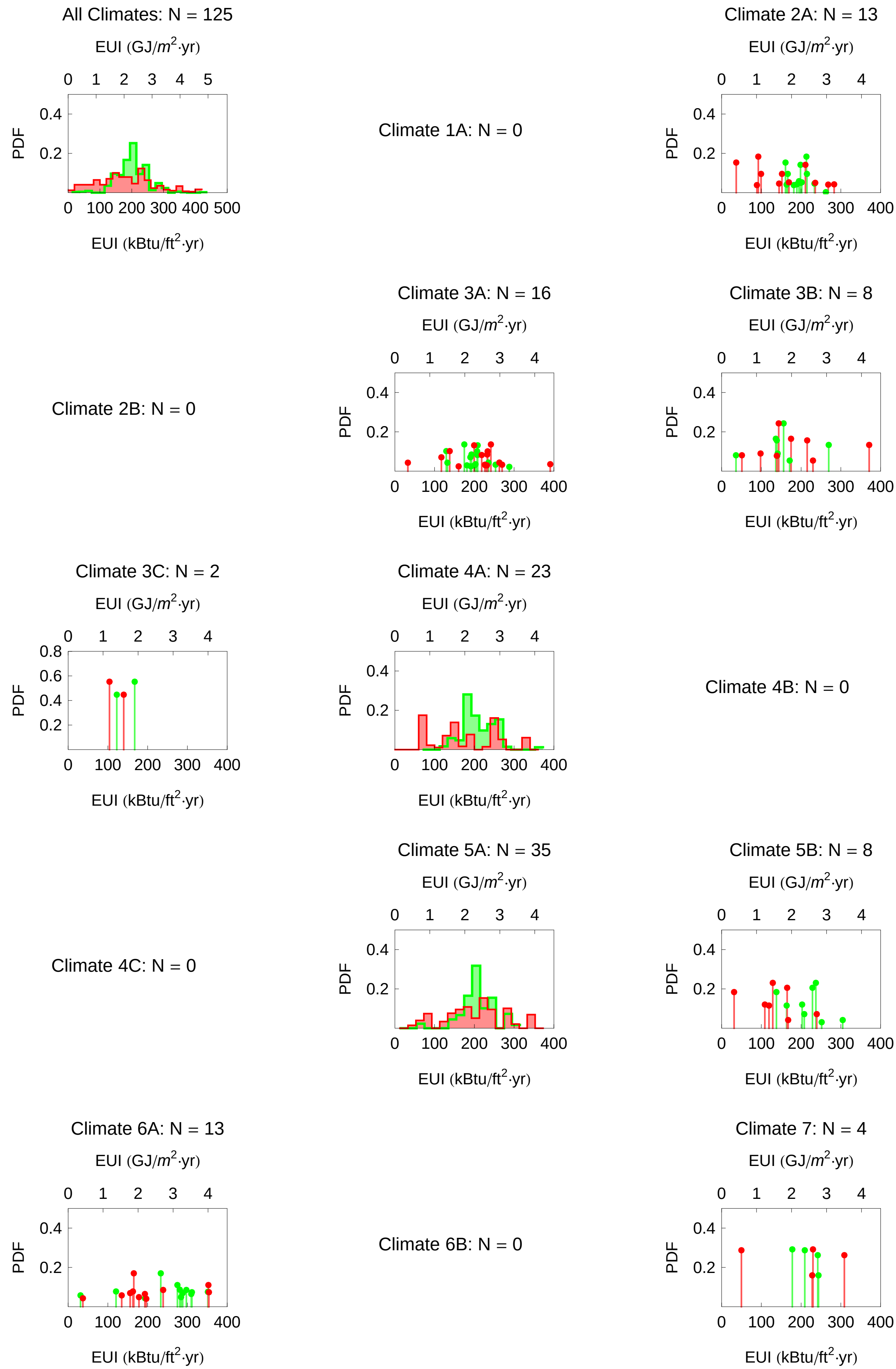


Figure A-14 PDFs for Food Sales Buildings in Various Climates: Survey Results in Red, Model Results in Green

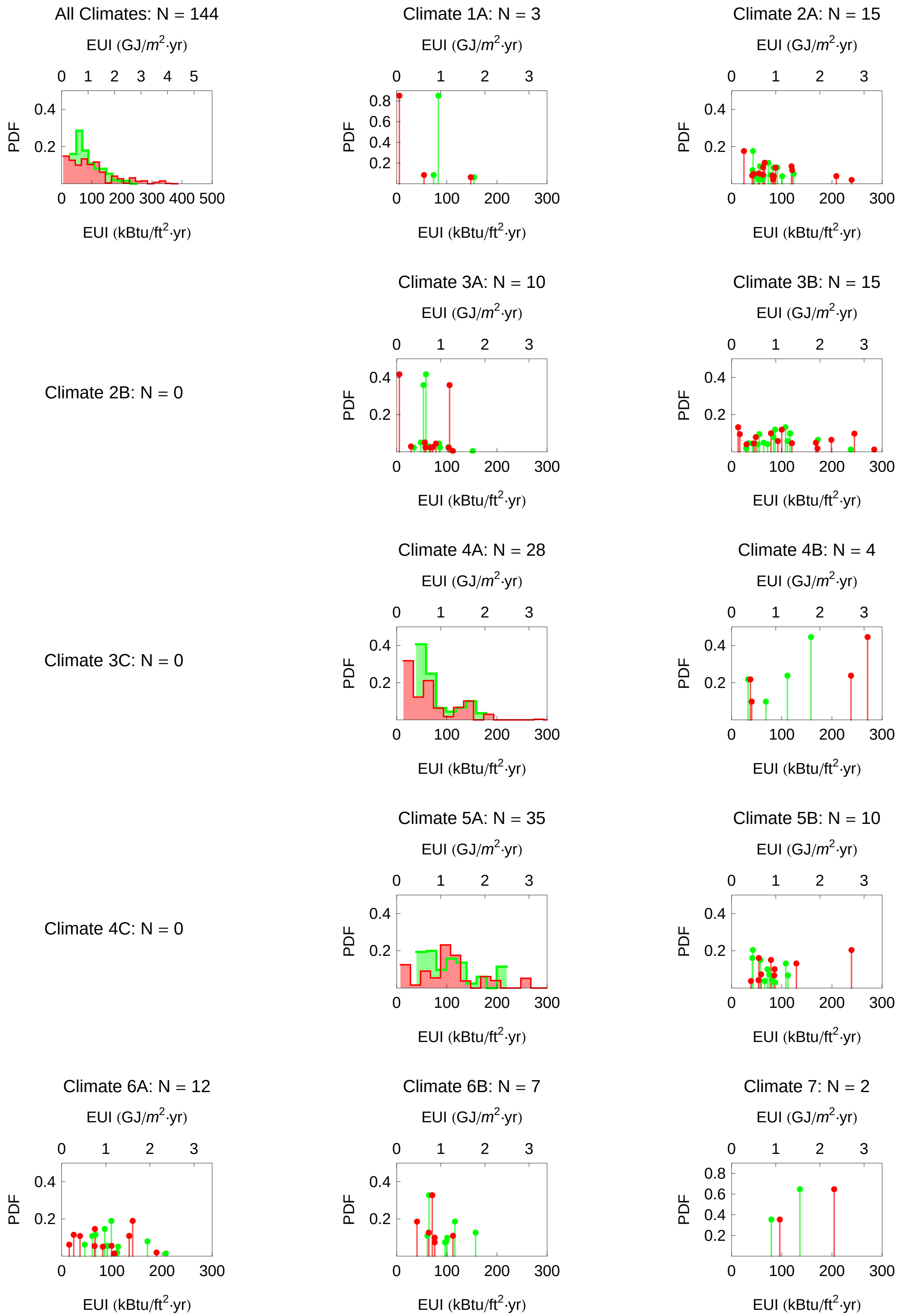


Figure A-15 PDFs for Outpatient Health Care Buildings in Various Climates: Survey Results in Red, Model Results in Green

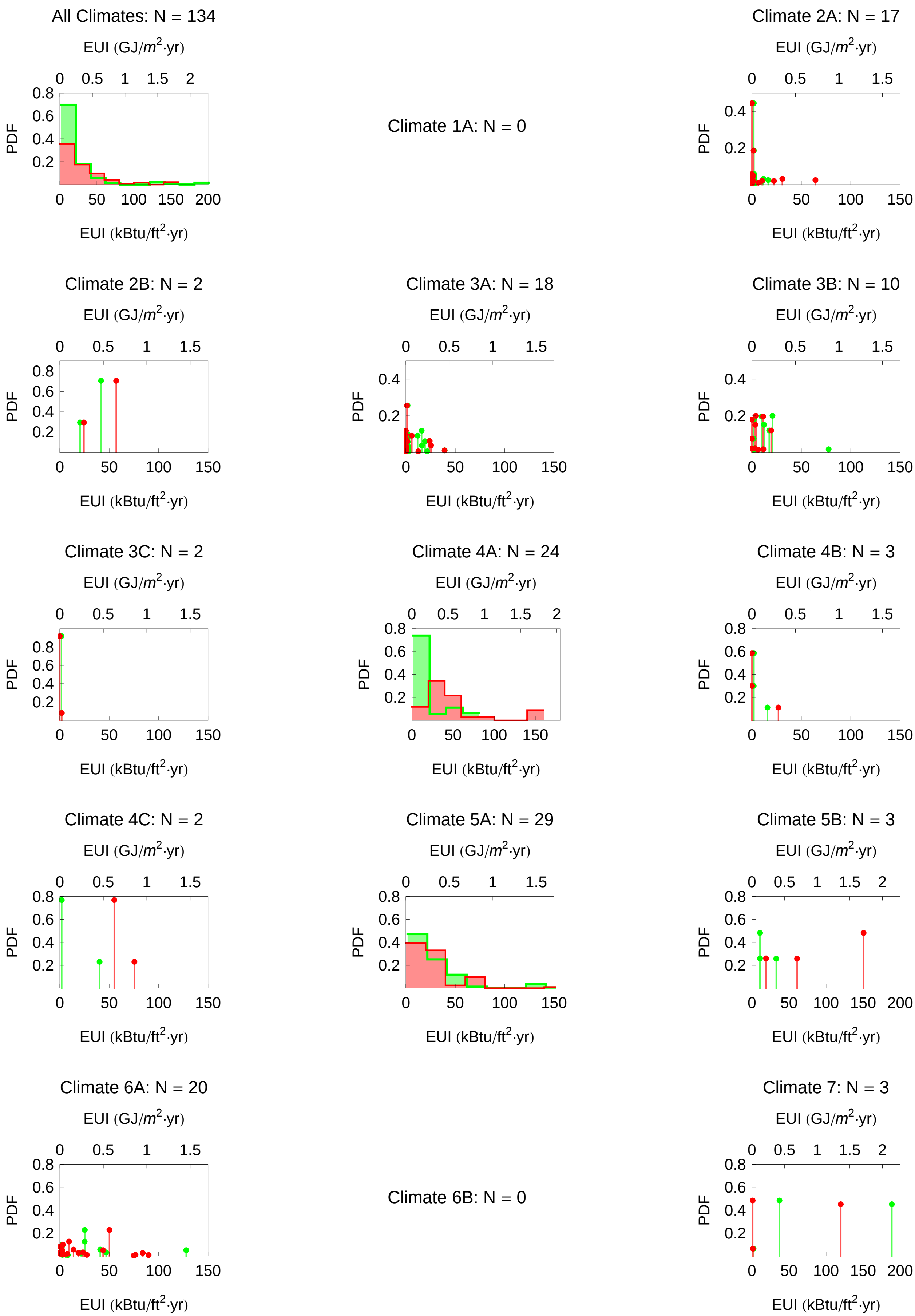


Figure A-16 PDFs for Vacant Buildings in Various Climates:
Survey Results in Red, Model Results in Green

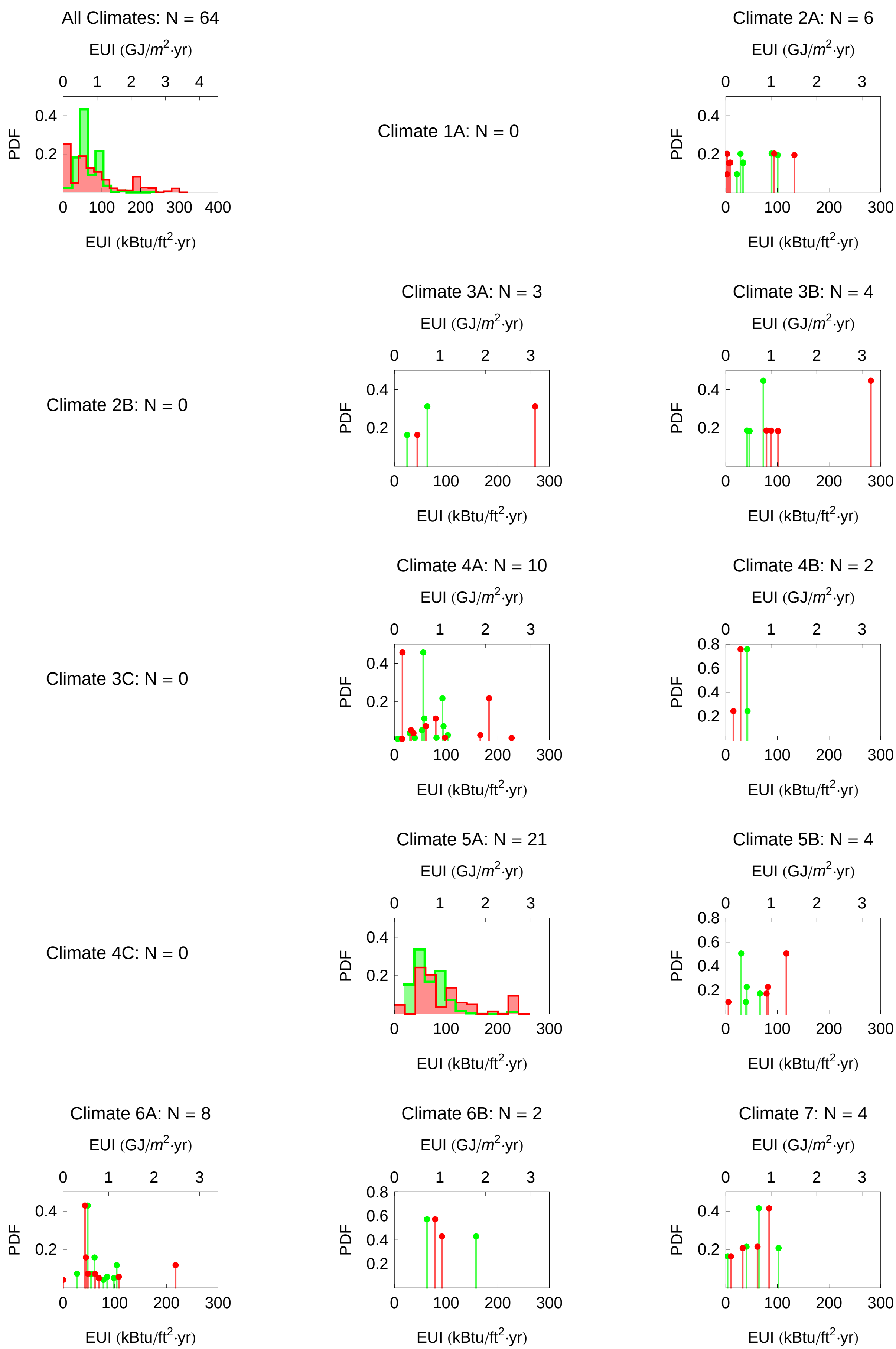


Figure A-17 PDFs for Other Buildings in Various Climates:
Survey Results in Red, Model Results in Green

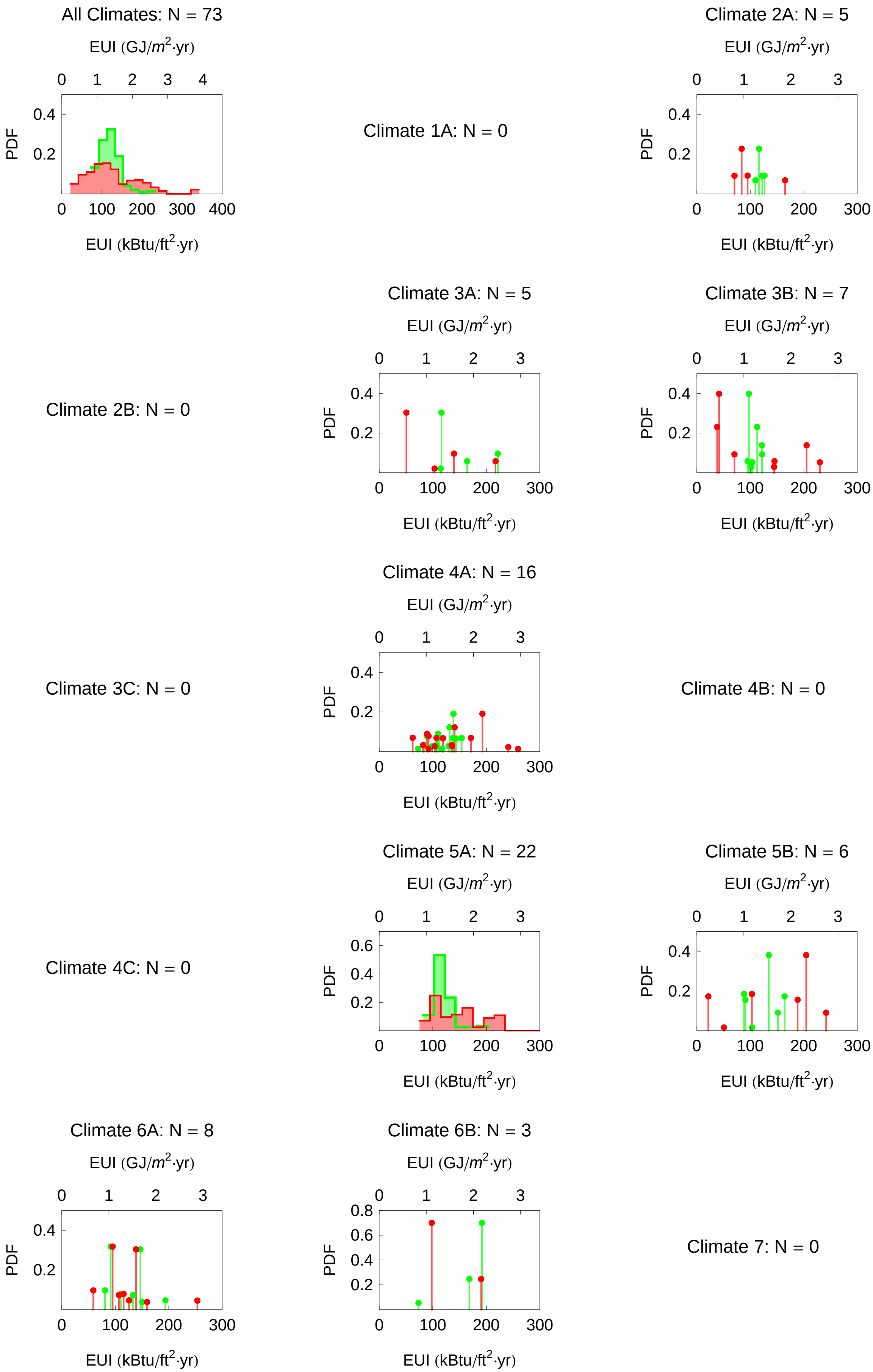


Figure A-18 PDFs for Skilled Nursing Buildings in Various Climates: Survey Results in Red, Model Results in Green

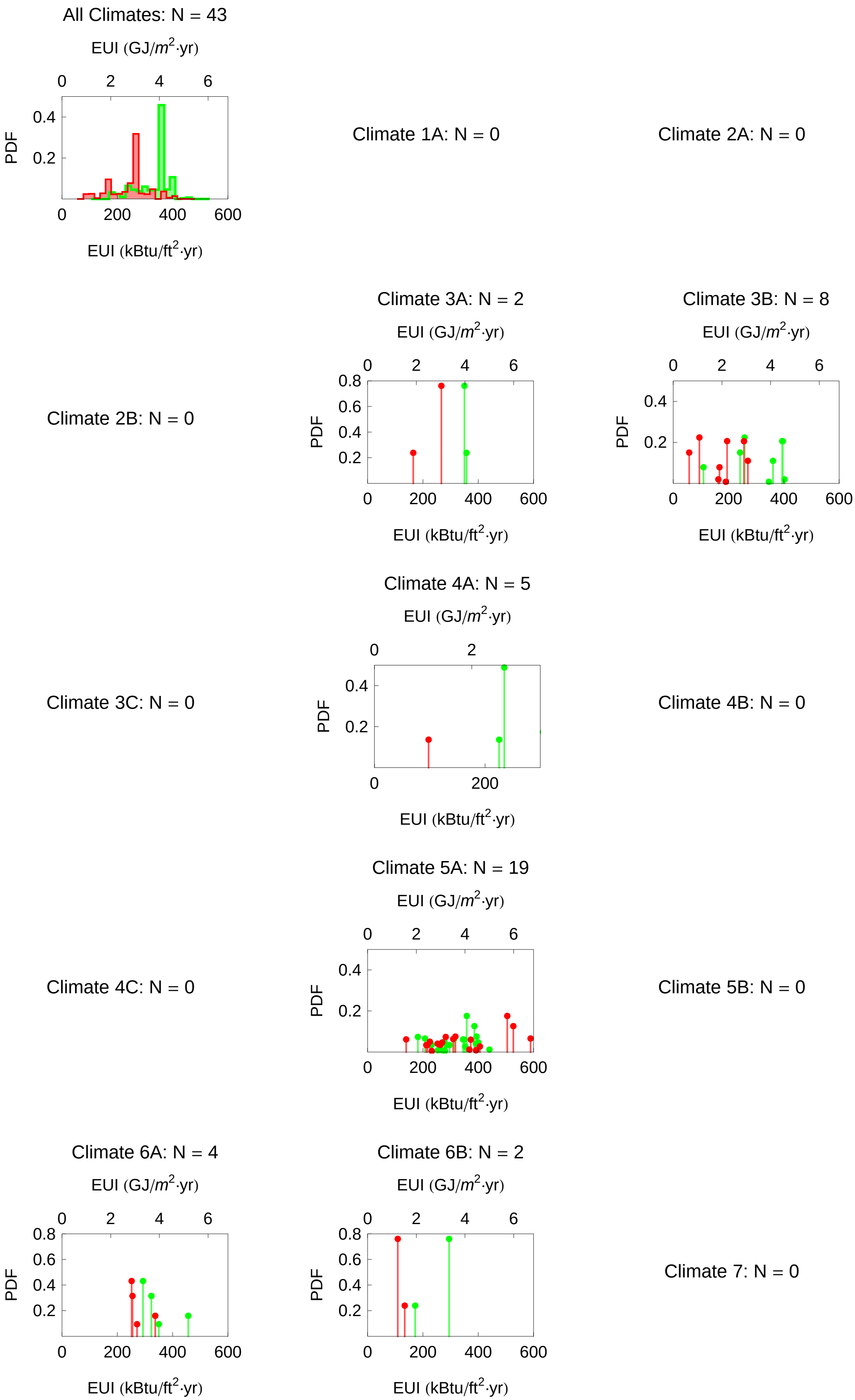
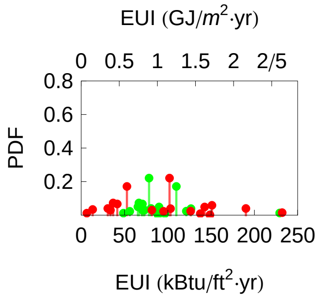


Figure A-19 PDFs for Laboratory Buildings in Various Climates: Survey Results in Red, Model Results in Green

All Climates: N = 20



Climate 1A: N = 0

Climate 2A: N = 0

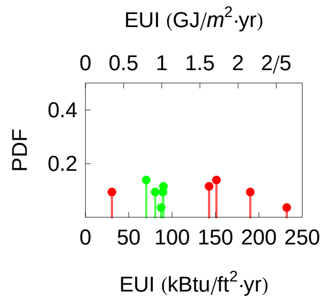
Climate 2B: N = 0

Climate 3A: N = 0

Climate 3B: N = 0

Climate 3C: N = 0

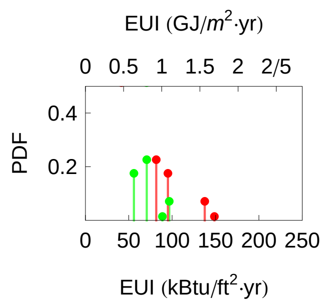
Climate 4A: N = 6



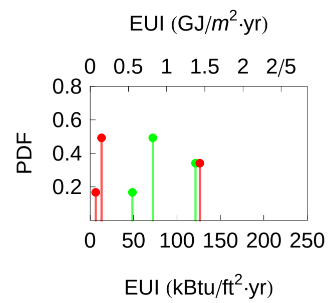
Climate 4B: N = 0

Climate 4C: N = 0

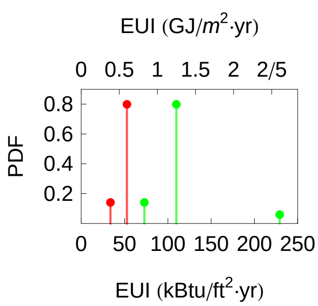
Climate 5A: N = 5



Climate 5B: N = 3



Climate 6A: N = 3



Climate 6B: N = 0

Climate 7: N = 0

Figure A-20 PDFs for Refrigerated Warehouse Buildings in Various Climates: Survey Results in Red, Model Results in Green

A.4 Scatter Plots

The results for individual sample buildings can also be compared. The models are generated from random assignments for many parameters that will affect energy performance. Therefore, compared to aggregations of large numbers, there is little reason to expect that the models and survey results *should* agree well. There is also concern that the rounding of floor areas in CBECS data for anonymity will introduce errors in metrics that are normalized by floor area. Nevertheless, the trends on a one-for-one basis are interesting to see, so this section presents a long series of X-Y scatter plots that compare total EUI with individual points for each sample. The 2003 CBECS survey results are on the X-axis; the modeling results are on the Y-axis. Figure A-21 through Figure A-39 present scatter plots by subsector. Figure A-40 through Figure A-53 present them by climate zone classification.

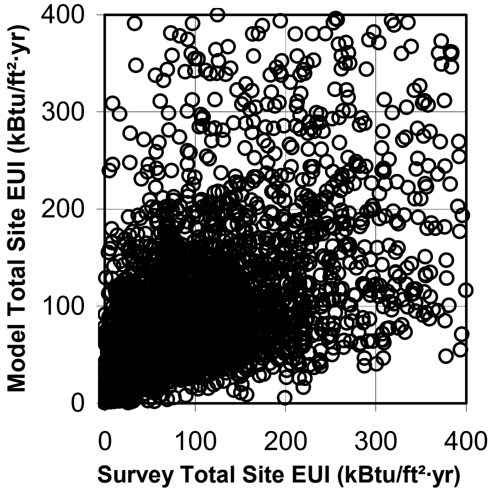


Figure A-21 Scatter Plot of Total EUI: All Buildings

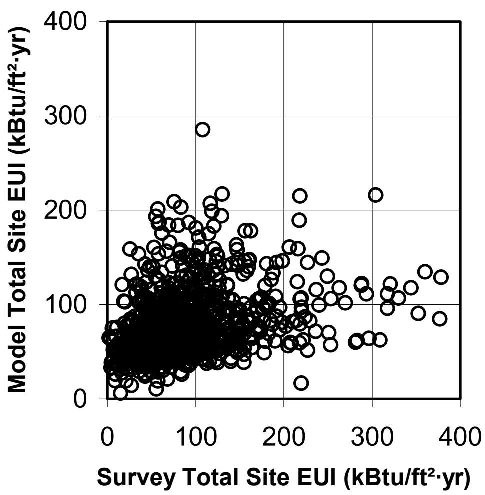


Figure A-22 Scatter Plot of Total EUI: Offices

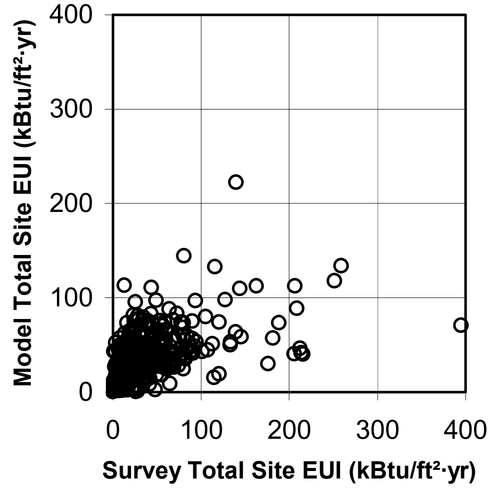


Figure A-23 Scatter Plot of Total EUI: Nonrefrigerated Warehouse

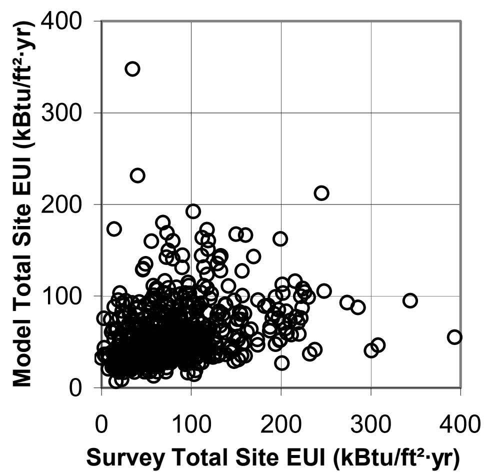


Figure A-24 Scatter Plot of Total EUI: Education

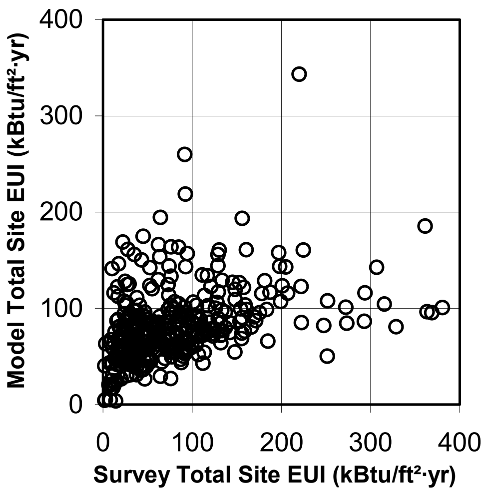


Figure A-25 Scatter Plot of Total EUI: Retail (except Malls)

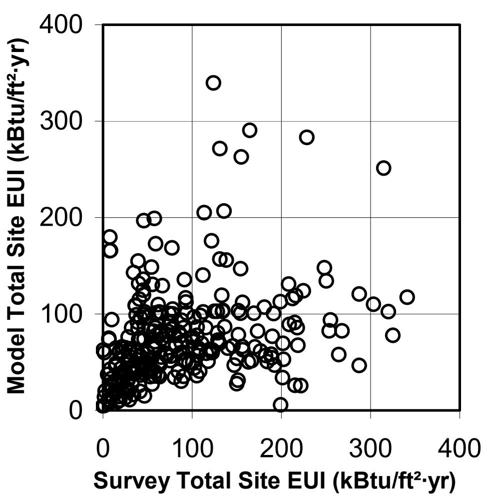


Figure A-26 Scatter Plot of Total EUI: Public Assembly

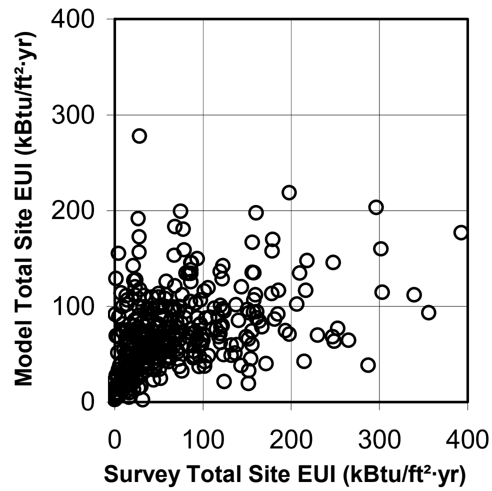


Figure A-27 Scatter Plot of Total EUI: Service

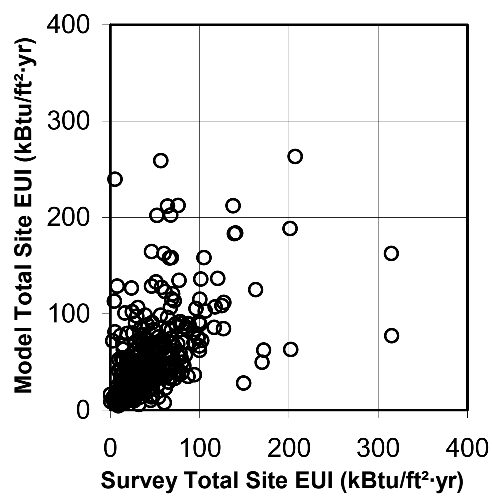


Figure A-28 Scatter Plot of Total EUI: Religious Worship

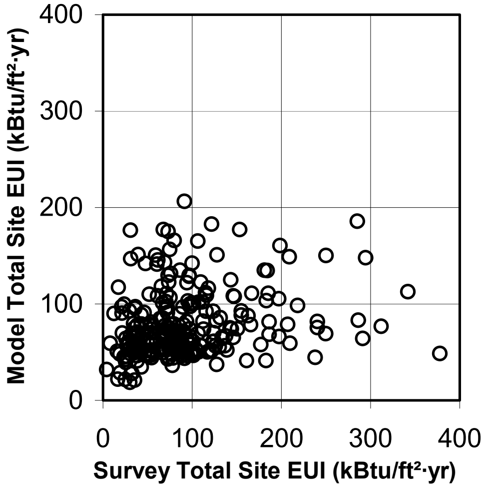


Figure A-29 Scatter Plot of Total EUI: Lodging

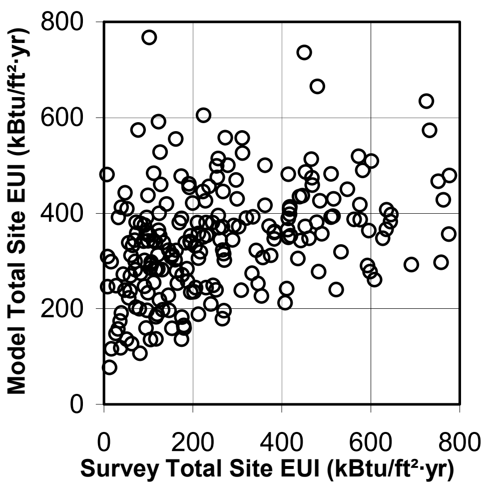


Figure A-30 Scatter Plot of Total EUI: Food Service

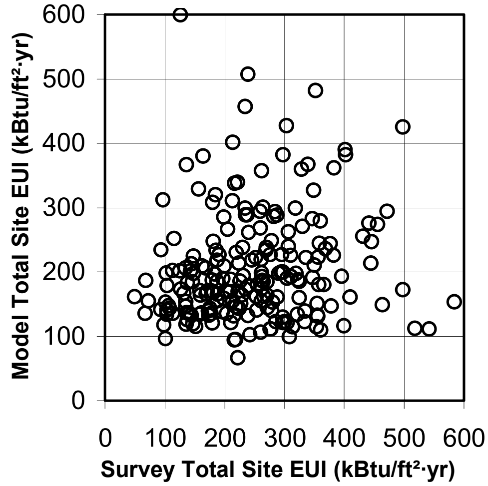


Figure A-31 Scatter Plot of Total EUI: Health Care (Inpatient)

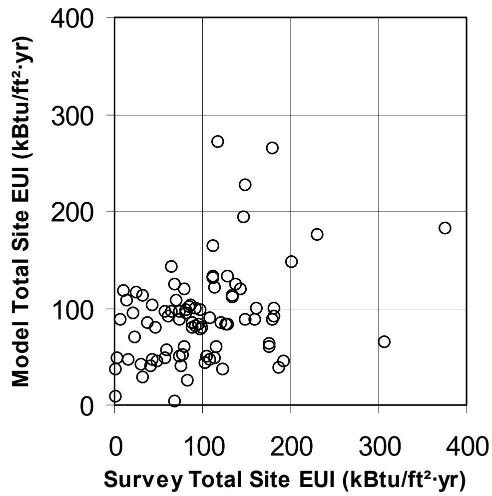


Figure A-32 Scatter Plot of Total EUI: Public Order and Safety

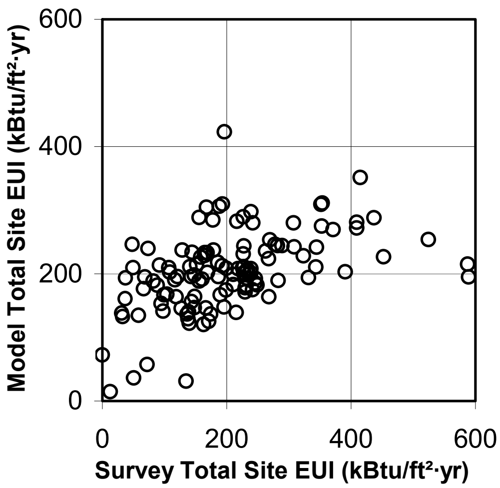


Figure A-33 Scatter Plot of Total EUI: Food Sales

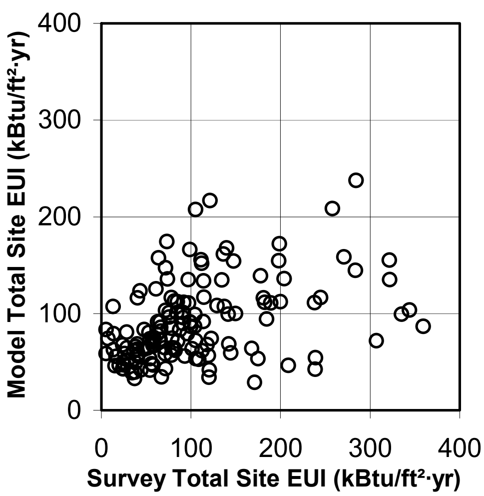


Figure A-34 Scatter Plot of Total EUI: Health Care (Outpatient)

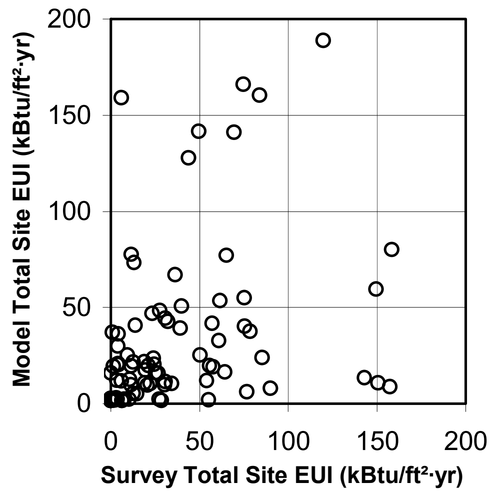


Figure A-35 Scatter Plot of Total EUI: Vacant

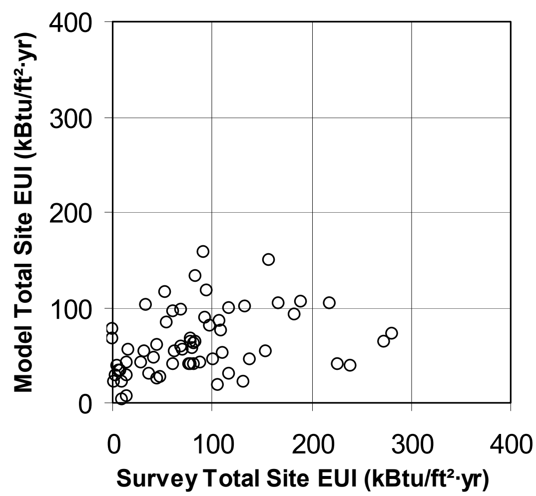


Figure A-36 Scatter Plot of Total EUI: Other

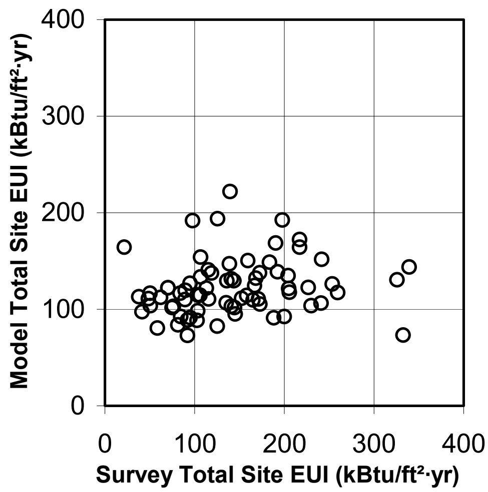


Figure A-37 Scatter Plot of Total EUI: Skilled Nursing

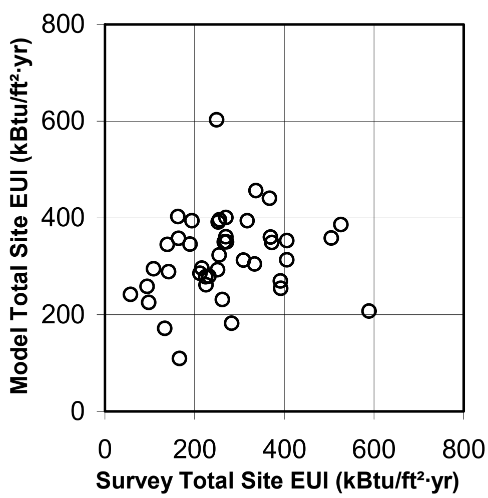


Figure A-38 Scatter Plot of Total EUI: Laboratory

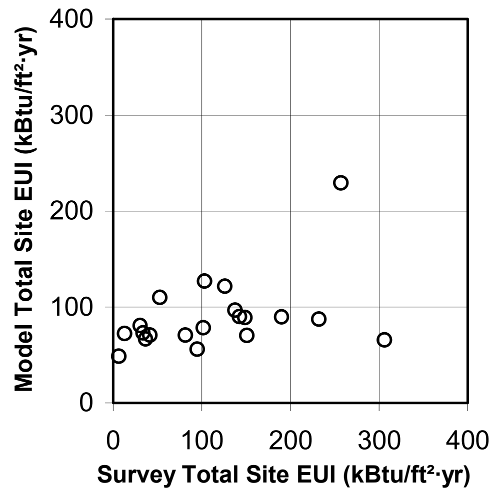


Figure A-39 Scatter Plot of Total EUI: Refrigerated Warehouse

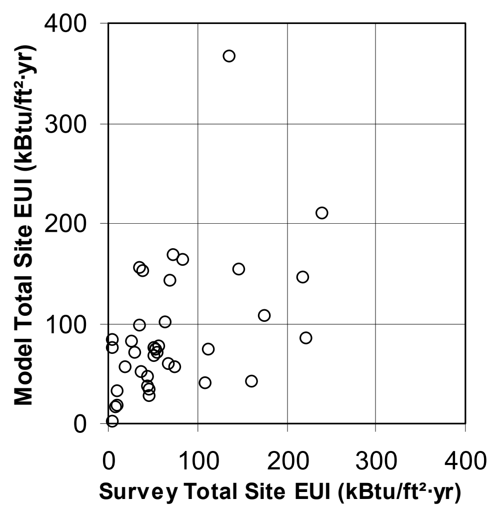


Figure A-40 Scatter Plot of Total EUI: Climate Zone 1A

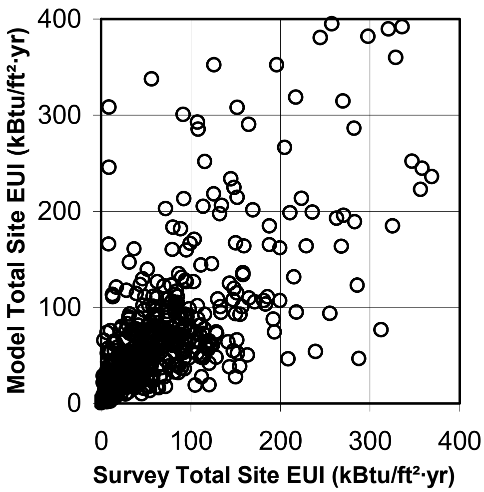


Figure A-41 Scatter Plot of Total EUI: Climate Zone 2A

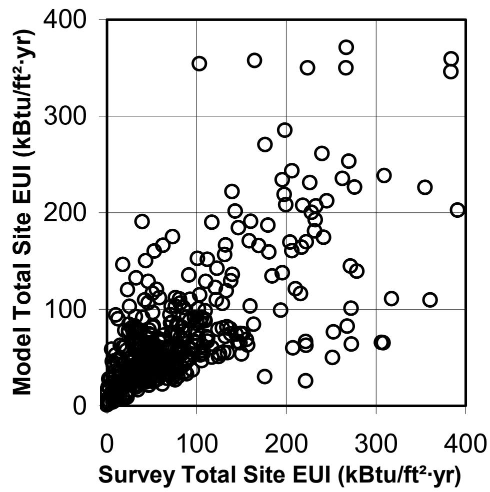


Figure A-43 Scatter Plot of Total EUI: Climate Zone 3A

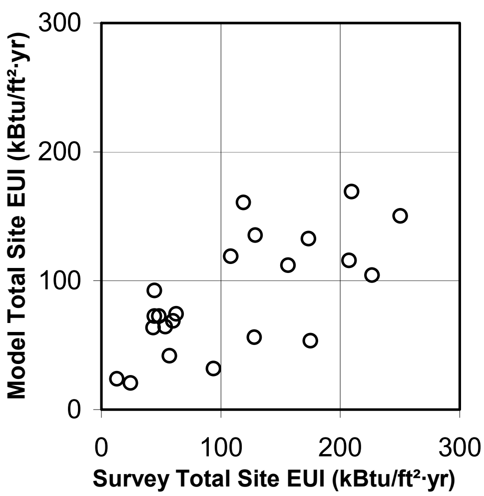


Figure A-42 Scatter Plot of Total EUI: Climate Zone 2B

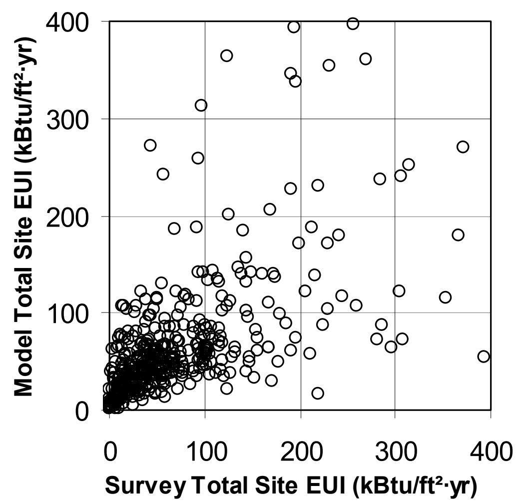


Figure A-44 Scatter Plot of Total EUI: Climate Zone 3B

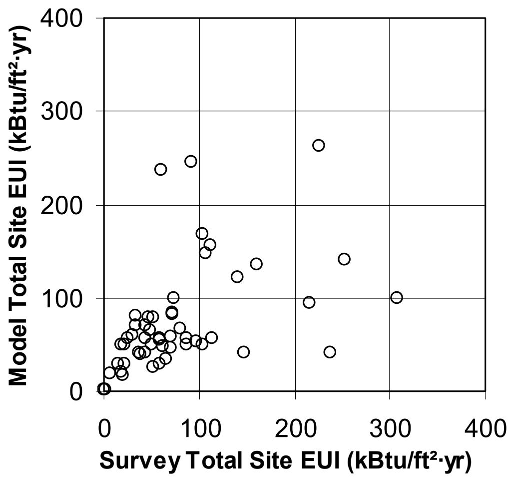


Figure A-45 Scatter Plot of Total EUI: Climate Zone 3C

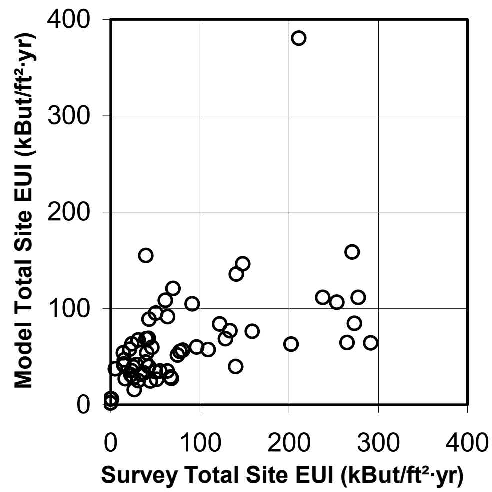


Figure A-47 Scatter Plot of Total EUI: Climate Zone 4B

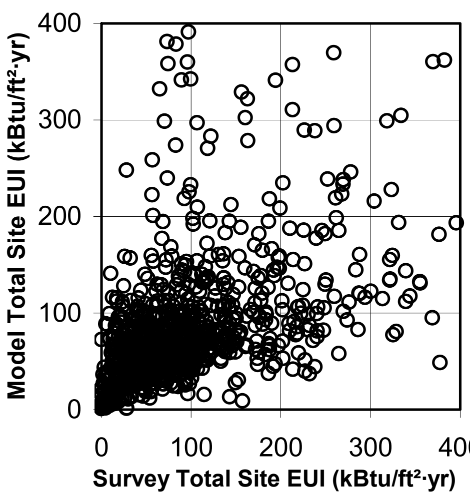


Figure A-46 Scatter Plot of Total EUI: Climate Zone 4A

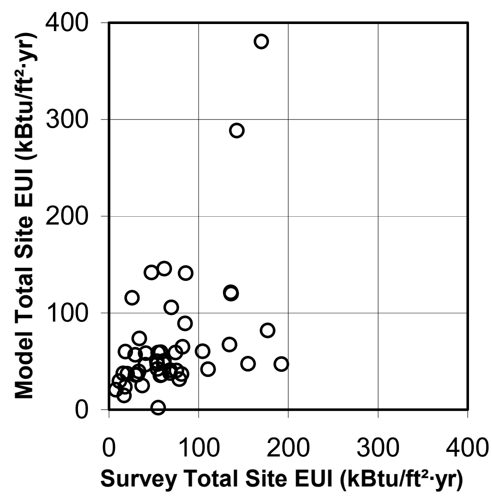


Figure A-48 Scatter Plot of Total EUI: Climate Zone 4C

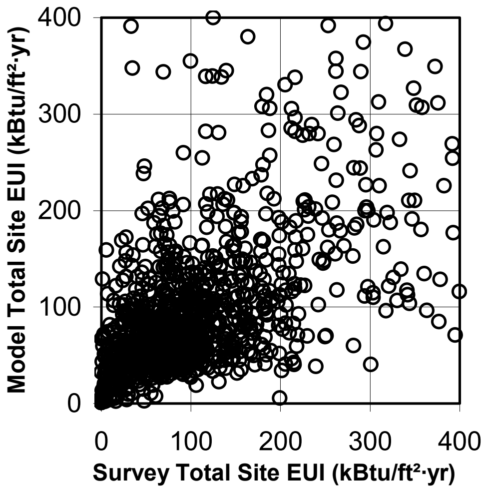


Figure A-49 Scatter Plot of Total EUI: Climate Zone 5A

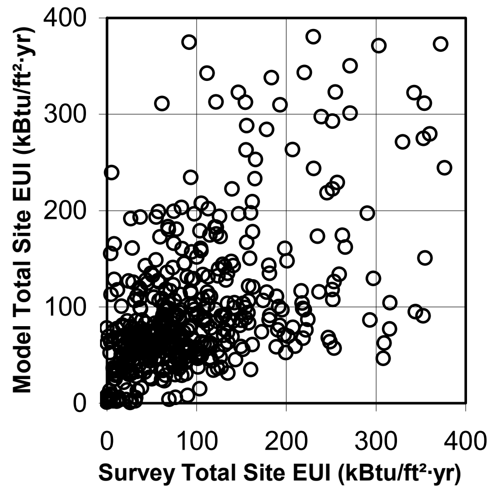


Figure A-51 Scatter Plot of Total EUI: Climate Zone 6A

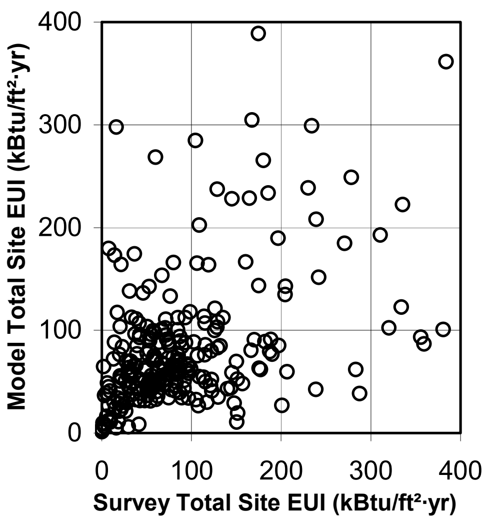


Figure A-50 Scatter Plot of Total EUI: Climate Zone 5B

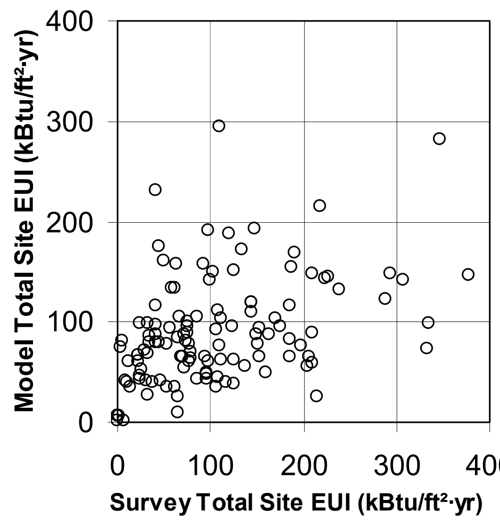


Figure A-52 Scatter Plot of Total EUI: Climate Zone 6B

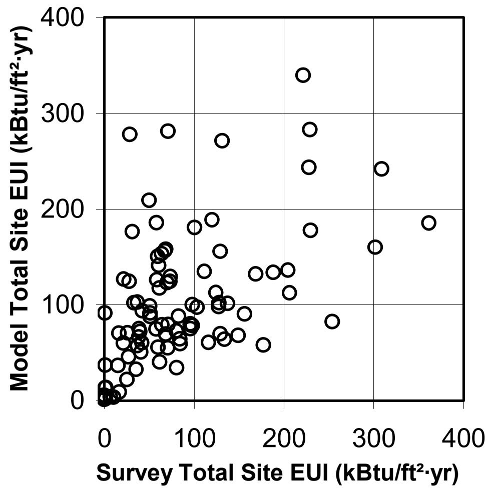


Figure A-53 Scatter Plot of Total EUI: Climate Zone 7

Appendix B. Energy Simulation Tools

This appendix contains additional details about the computer tools NREL used for the modeling.

B.1 EnergyPlus

Modeling is all about selecting an appropriate level of detail. The spectrum of opportunity in commercial buildings is enormous, as indicated by the 75.6 billion ft^2 (6.2 billion m^2) of floor area in 2006 and the 53 billion ft^2 (1.8 billion m^2) forecast for new construction through 2030 (EIA 2007). Design has an impact on individual buildings, not on the aggregated sector. Because buildings are complex, sophisticated models must be used to conduct research. Considering that the EnergyPlus program (Crawley et al. 2001; www.energyplus.gov) is already in use, justifying new calculation routines would be difficult. EnergyPlus is a detailed, forward model that predicts energy and other performance characteristics of buildings. This section outlines some of the reasons why we selected EnergyPlus as the analysis tool.

EnergyPlus yields a high level of modeling detail, but it comes at the expense of having to prepare large and complex input files and to allow for long execution times. These issues were resolved by implementing a simple preprocessor and using distributed computing. The preprocessor automatically prepares EnergyPlus input files from a small eXtensible Markup Language (XML) file that contains input parameters that use various automatic file building routines and macro templates. One advantage of the software architecture behind EnergyPlus is that it runs well on remote machines. NREL researchers used distributed computing to run numerous simulations in parallel on multiple processors and remote machines to model some 40 buildings at a time. NREL compiled 64-bit versions of EnergyPlus version 2.0 to run on a Linux-based cluster and Windows XP x64.

Even though there are drawbacks to using a detailed program such as EnergyPlus, only such a program can fully account for the complicated interactions between climate, internal gains, building form and fabric, HVAC systems, and renewable energy systems. EnergyPlus is also a heavily tested program; formal BESTEST validation (Judkoff 1995; Neymark 2002; GARD 2004a; GARD 2004b) efforts were repeated for every release. EnergyPlus source code is well organized and available to collaborative developers. This makes customizing the program with models for building technologies straightforward.

Many simplified engineering models can predict energy performance. Some are inverse models that need to be calibrated with performance data, but such data are not available for buildings that have not yet been built or monitored. Simple models may have been formulated as steady state, or to neglect (nonintuitive) system interactions, but high-performance buildings tend to rely on system interactions and time-dependent behaviors, which the simulations need to model explicitly.

EnergyPlus is a detailed energy simulation engine that requires all inputs to be explicitly defined. Although this is a large quantity of information, the definitions require that all inputs be defined, either by actual data or by defaults or assumptions. This necessitates a robust definition of the buildings, their operation, and specific operating performances of technologies.

B.2 Modeling Framework and Input Parameters

We conducted the current modeling study using an analysis framework currently called “OptEPlus” that is based on EnergyPlus. The high number of models prohibited the use of manual methods. The basic architecture of the framework is diagrammed in Figure B-1. The framework is separated into two domains: simulation management and building modeling. These domains are introduced later in this section. The interfaces between these domains are handled with text data files in XML and tabular data files produced by EnergyPlus.

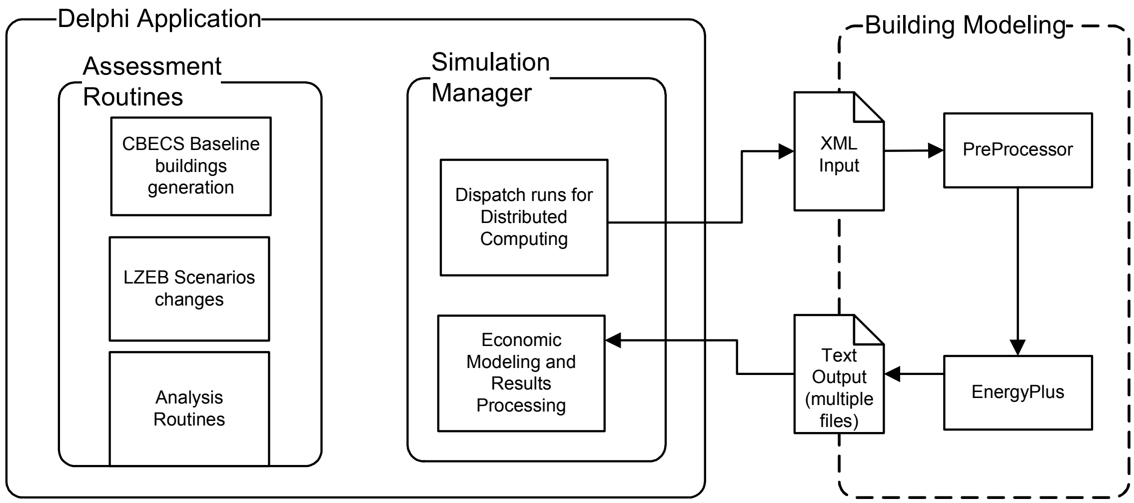


Figure B-1 Analysis framework overview

B.2.1 OptEplus

We use the term *OptEPlus* to refer to the entire collection of EnergyPlus input and output files, file system directories, and computer routines that are used to conduct and manage the analyses. Automated methods are needed to enable their creation, execution, and postprocessing to be managed. The simulation files and directories need structure. OptEPlus is also the name given to a computer program that collects routines and scripts that are needed to work with the simulations. The OptEPlus routines are programmed in Delphi, a powerful rapid application development environment from the Pascal family of languages. OptEPlus includes capabilities for:

- Managing and storing about 100,000 EnergyPlus simulations
- Managing the creation of XML input files
- Submitting and monitoring jobs for distributed computing on Windows machines and Linux clusters
- Postprocessing results to make them available for subsequent analyses
- Relational database for input and output
- Search routines for evaluating cost and performance of design options (single building optimization)
- CBECS Public Use Data import, filter, analysis, export, and translation to XML input files for EnergyPlus modeling
- Sector-wide scenario analysis
- Creating and running example files for EnergyPlus users via a Web site form
- Applying minimum-Standard prescriptive measures for 90.1-1999, 90.1-2004, 90.1-2007, and 189P.

A full set of simulation input and output files from the modeling are stored in individual directories on a 1-terabyte hard drive; a second hard drive mirrors the contents of the first for backup. EnergyPlus models that are similar to those used in this study are publicly available from the EnergyPlus Example File Generator at www.energyplus.gov. (This service is a direct by-product of the analysis routines originally implemented for the current study.)

B.2.2 Building Modeling

EnergyPlus is a detailed calculation engine described elsewhere (Crawley et al. 2001; www.energyplus.gov). The input for EnergyPlus is a detailed text file that describes the form and operation of the building. We use an in-house preprocessor to create the EnergyPlus input files. The preprocessor program takes a specially formatted (XML) text file to generate the EnergyPlus input file. This text file is an instance of a high-level data model that constitutes the interface for input to the building modeling. (This data model is cast as an XML schema called HPBxml.xsd.) We distinguish high-level parameters as those that do not, or cannot, appear directly in the simulation input file. These parameters often imply a one-to-many relationship, and imply that rules are needed to translate the parameter into multiple model input values. The main task of the preprocessor is to translate the high-level parameters into a description of the building geometry and HVAC systems and combine that with all the other data needed to run a simulation. High-level parameters can directly represent the energy design measure separately from how that measure needs to be represented to the simulation program. An XML-based data model was selected because XML is becoming a very popular format for text-based data. In addition, parsers are available for most programming languages, and the XML schema provides methods for validating that the input matches the expectation. The model includes a complete set of parameters that, when combined with defaults and assumptions contained in the preprocessor, can produce entire input files for EnergyPlus. Table B-1 lists the main parameters that are included in the data model. The HPBxml schema also differs from building data models (IFC or gbxml) in that it includes attributes that provide a high-level rather than a fine-grained description of all the data. The data model includes lengthy enumerations of allowable locations, weather files, materials, constructions, schedule sets, and HVAC system options that are closely coordinated with what is available in the preprocessor and input data libraries. Table B-1 also includes a column that indicates the relationship between the high-level data element and the EnergyPlus simulation file where “1-to-1” indicates a parameter that is easy to vary directly in an input file and “1-to-many” indicates a parameter that requires preprocessing.

Table B-1 High-Level Data Model Parameters

Element Name	Description	Relationship to E+ Input File
WeatherFile	Name of weather file for simulation	1-to-1
DesignDays	Key for location information, including latitude, longitude, elevation, design day weather, and ground temperatures	1-to-1
UtilityCosts	Key for selecting energy tariff data sets	1-to-1
SetsofConstructions	Key for selecting groups of materials and construction	1-to-many
FloorArea	Total floor area	1-to-many
NumFloors	Number of floors (stories) in building	1-to-many
AspectRatio	East–west length divided by north–south length	1-to-many
PerimDepth	Depth of perimeter thermal zones	1-to-many
FloortoFloorHeight	Distance from top of slab to top of slab on next floor	1-to-many
PlenumHeight	Height of suspended ceiling	1-to-many
Rotation	Angle of building with respect to north	1-to-1
GlazingSillHeight	Distance from floor to bottom of glazing	1-to-many
GlazingFraction	Ratio of total glazed area to above-grade exterior wall area for an orientation	1-to-many
GlazingEdgeOffset	Thickness of vertical band at edge of glazings	1-to-many
OverhangDepth	Distance fixed shading overhang extends from wall	1-to-many
OverhangBase	Distance from glazing head to fixed shading overhang	1-to-many
DaylightingSetpoint	Nonzero value triggers daylighting model with specified lighting level	1-to-many
TubularDaylightDevices	Nonzero value triggers distributing TDDs throughout core zone in topmost floor at specified density	1-to-many
PeopleDensity	Value for design level for people per area	1-to-many
PlugDensity	Value for design level for watts per unit area for plug and process loads	1-to-many
LightIntensity	Value for design level for watts per unit area for lighting loads	1-to-many
InfiltrationRate	Value for design level for ACH	1-to-many
ScheduleSet	Key for selecting groups of schedules	1-to-many
HVACSystem	Key for selecting the type of HVAC system	1-to-many
OAVentPerPerson	Value for minimum outdoor air rate	1-to-1
FanPressureDrop	Value for static pressure experienced by one or more fans in the HVAC system	1-to-1
ChillerCOP	Value for nominal COP for mechanical cooling equipment	1-to-1
GasCoilEff	Value for theoretical efficiency for gas heating equipment	1-to-1
PV-Simple	Select mode for how to apply PV power systems	1-to-many
PVAreaFraction	Value for fraction of available surface area that is covered with PV modules	1-to-1
PVEfficiency	Value for solar-to-electric conversion efficiency	1-to-1
PVInverterEff	Value for DC-to-AC conversion efficiency	1-to-1
MacroControl	File system path for include files and key for selecting sets of report variables	1-to-many

Appendix C. Input Data and Translation Rules from 2003 CBECS to Building Models

This appendix documents how EnergyPlus input data were developed from 2003 CBECS. Fully defining a building model for the EnergyPlus simulation program requires defining a large number of details—many more than are available in the CBECS data. Therefore, the focus is on helping the reader understand how the detailed input data were obtained or generated to enable modeling with EnergyPlus.

We have categorized the plethora of details about the building into four groups: program, form, fabric, and equipment:

- *Program* refers to the *architectural program*, which describes how the building will be used and the services it will provide the occupants. From an energy point of view, program decisions influence many important drivers such as climate, internal gains, ventilation requirements, operating schedules, and comfort tolerances that will ultimately determine the energy performance.
- *Form* refers to the geometry of the building and its elements. Form has important energy implications that stem from how the building interacts with the sun and ambient conditions.
- *Fabric* refers the materials used to construct the building and involves decisions about insulation levels, glazing systems, and thermal mass.
- *Equipment* includes HVAC equipment as well as lighting systems and controls. This includes all the energy-consuming equipment that is part of the building except for plug and process load equipment selected by the occupants.

Table C-1 lists examples of various input parameters for the four categories.

Table C-1 Input Parameter Categories with Sample Parameters

Program	Form	Fabric	Equipment
Facility location Total floor area Schedules Plug and process loads Lighting quality Ventilation needs Occupancy Site constraints	Number of floors Aspect ratio Window fraction Window locations Shading Floor height Orientation	Exterior walls Roof Windows Interior partitions Internal mass	HVAC system types Component efficiency Control settings Lighting fixtures Lamp types Daylighting controls

An obvious problem in simulating buildings from the scant data in CBECS is determining and generating geometric form. "Autobuilding" refers to the practice of automatically generating a building geometry for energy simulation. It involves developing routines that use simple rules to translate from a small set of program and form parameters to a full set of surface and zone objects that describe a building to the simulation program. The autobuilding routines used here build orthogonal, "shoebox" shaped buildings with five thermal zones per floor and bands of windows.

The first step in developing a building model is to define the architectural program for the building that is being evaluated. The remainder of this appendix focuses on the technical details for how we map various CBECS data to parameters for energy models.

The CBECS data need to be transformed into simulation files through the assignment algorithms documented in this appendix. The main elements in the data model listed in Table B-1, and the methods used to determine values for them, are revisited in the following subsections.

C.1 CBECS Variables

The CBECS data contain information for several building types in the commercial sector. Table C-2 lists the PBAs and codes from 2003 CBECS. In this study we used the "A" data set, which does not include strip malls or enclosed malls. This is because the "B" public use data set was not yet available at the time of this study. The numbering of the PBA codes is intentionally discontinuous.

Table C-2 List of Subsectors by PBA in CBECS Data

PBA Code	Definition
1	Vacant
2	Office/professional
4	Laboratory
5	Nonrefrigerated warehouse
6	Food sales
7	Public order and safety
8	Outpatient health care
11	Refrigerated warehouse
12	Religious worship
13	Public assembly
14	Education
15	Food service
16	Inpatient health care
17	Skilled nursing
18	Lodging
25	Retail (except malls)
26	Service
91	Other

Table C-3 contains a list of select CBECS variables that are used to determine specific instances for input parameters during the CBECS translations. Many more CBECS variables are used in the assignment algorithms and are described in later sections of this appendix.

Table C-3 List of Important Variables in CBECS Data

CBECS Variable	Definition
CDD658	CDDs for 65°F
CENDIV8	Census division
HDD658	HDDs for 65°F
NFLOOR8	Number of floors in building
NWKER8	Number of workers
PBA8	PBA
SQFT8	Square footage of building
PBAPLUS8	Extra information on building activity
EDSEAT8	Total seats in classrooms
RWSEAT8	Religious worship seating capacity
PBSEAT8	Public assembly seating capacity
FDSEAT8	Food service seating capacity
HCBED8	Inpatient licensed bed capacity
RENOV8	Renovations since 1980

C.2 Location and Weather File

This assignment selects a location to assign to each building in the 2003 CBECS data set. EIA masks the actual location of the samples for anonymity, so some method of assigning a location is needed. The location of the building determines several aspects, including simulation weather file, utility tariffs, emissions factors, site-to-source conversion factor, latitude, longitude, and elevation, that are important to the modeling. CBECS masks the actual locations of sample buildings for anonymity, but does provide data for the census division (CENDIV8) and values for HDDs (HDD658) and CDDs (CDD658). Table C-4 lists the number of buildings in 2003 CBECS by census division.

Comparing 1999 CBECS to 2003 CBECS reveals significantly more spread in the variation in values for HDD and CDD across the sample for 2003 CBECS. Whether this represents an actual large increase in the real number of locations, or a different method was used to develop degree day values for reporting is unclear.

An assignment algorithm is used to select the location in the following manner. An initial set of candidate locations was assembled that was formed by a set of 232 EnergyPlus weather files that are based on TMY2 or TMY weather data locations. However, the TMY data were not used. Instead we used data from the National Solar Resource Database (NSRDB) that were reformulated into the EnergyPlus weather file format. These historical weather data files for 2003 were used in this study. HDD and CDD data (base 65°F) from the 2003 weather data were also used in the location assignments. For each CBECS building, we then selected a subset of these candidate locations that lie within the appropriate census division. (Table C-4 lists the number of candidate locations by census division.) This subset of candidate locations is subsequently searched to find the location that most closely matches the reported HDDs and CDDs. A "brute force" search algorithm was used, where for each possible assignment we calculated the root mean square of the combined deviations for HDDs and CDDs. The resulting array of root mean square error values was then searched for the minimum and the location with the lowest error selected for the assignment.

Table C-4 Summary of Location Assignments for All Buildings in 2003 CBECS

Census Division	Number of Buildings in 2003 CBECS	Number of Candidate Weather Data Locations	Number of Locations Assigned
1 New England	195	9	8
2 Middle Atlantic	641	18	15
3 East North Central	860	30	29
4 West North Central	452	30	27
5 South Atlantic	912	32	28
6 East South Central	279	14	13
7 West South Central	579	26	23
8 Mountain	305	41	20
9 Pacific	597	32	19
All	4,820	232	181

The results of applying the location assignment algorithm are summarized in Table C-4. Figure C-1 and Figure C-2 compare the HDD and CDD values from the assignments and show the level of agreement between the locations that were selected for modeling and the data that were available from the 2003 CBECS (based on these weather criteria). The selection algorithm chose 181 unique locations, which represented 78% of the candidate locations with weather data.

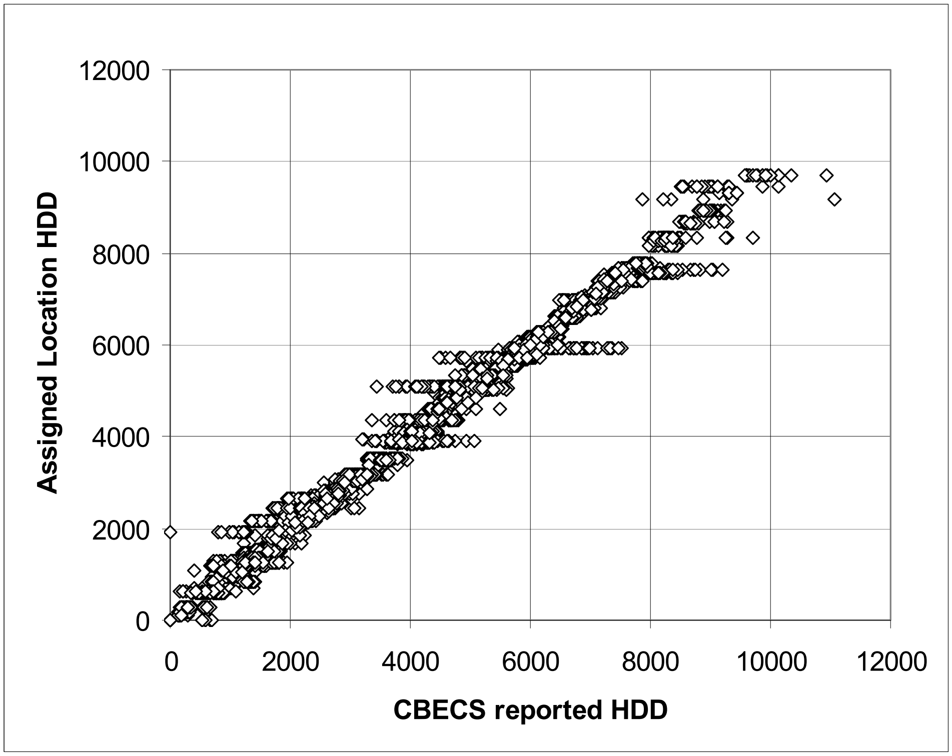


Figure C-1 Comparison of HDDs between assigned locations and 2003 CBECS

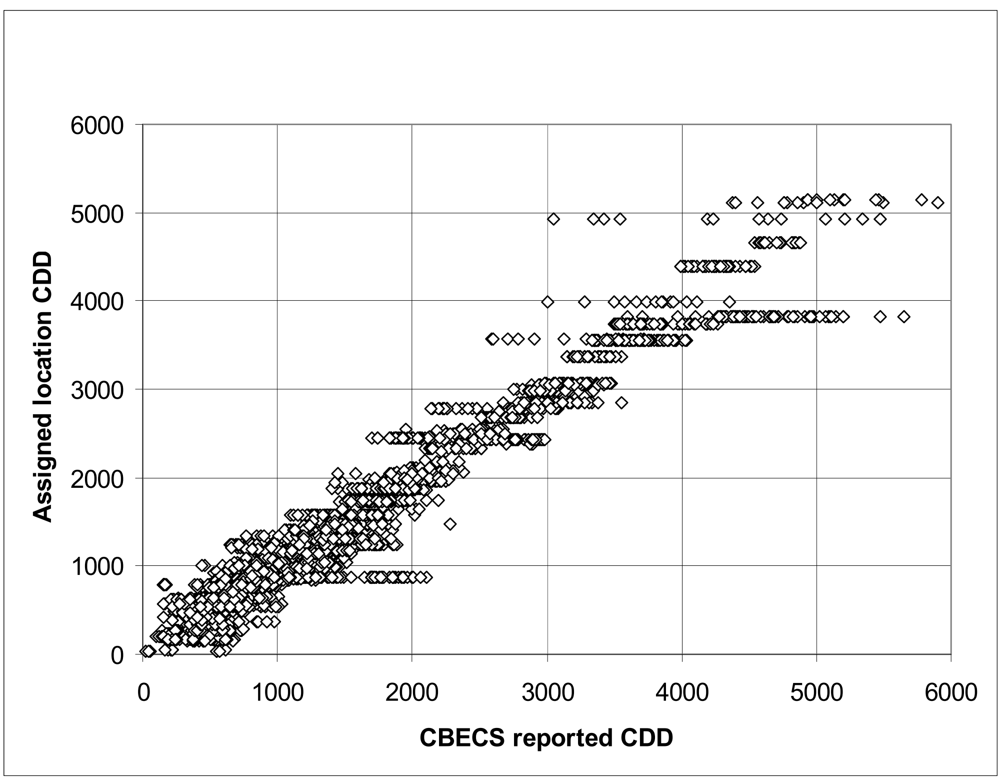


Figure C-2 Comparison of CDDs between assigned locations and 2003 CBECS

C.3 Utility Costs

Utility rate schedules, or tariffs, are needed to calculate energy costs. This section describes how rates are assigned to each building. As discussed in Section C.2, the building location is assigned with census division and degree-day data. This location is then used to determine utility tariffs for the building. Electricity and natural gas are the only two types of energy with costs modeled in the study. The methods for selecting tariffs are described in the following two subsections.

C.3.1 Electricity

The models include the energy and demand charges and geographic variations. In many commercial buildings, demand charges can account for 50% of the total electricity bill. As buildings strive for lower energy, anecdotal experience shows that the demand savings are lower than the energy savings and become a larger portion of the bill. Using virtual or average rates does not account for this and can inflate the appeal of technologies such as PV power systems, solar hot water systems, and daylighting. Other techniques, such as increasing thermal envelope, overhangs, and glazing selection can realize demand savings if the HVAC systems are sized appropriately. Technologies such as improved lighting efficiency can affect both demand and energy. To fully realize the savings and interactions, demand and energy charges must be computed.

Tariffs for electricity pricing are complex. Averaged pricing data are readily available from EIA, but do not provide the necessary detail for calculating realistic rate structures. For the study, a set of realistic rate structures was developed in three steps:

- Determine specific utility companies for each location.
- Access and understand the electricity rate schedules published by those utilities.
- Translate those rates into the input form needed for calculating the energy costs in EnergyPlus.

Table C-5 lists the utility companies used in the study. (Documenting the actual tariffs would be complex and lengthy, so the details of each are left to the EnergyPlus input data.) Forty utility companies were identified through the following process:

1. For each location assignment, we identified the largest utilities in the state from EIA data. These data show the total annual sales to commercial customers for the five largest utilities (EIA State Electricity Profiles for 2002 [www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html]; accessed January 13, 2005).
2. We examined the tariffs (available from a Web-based central repository run by the Tariff Analysis Project (TAP) [http://tariffs.lbl.gov/; accessed February 2005]) to determine whether data for one of the largest utilities were available. Largest utilities were determined from EIA State Electricity Profiles for 2002 (www.eia.doe.gov/cneaf/electricity/st_profiles/e_profiles_sum.html; accessed January 13, 2005).
3. If TAP did not have data for a large and dominant utility, we went directly to the electric utility company Web sites to verify that the tariff data were available. Additional resolution in rates is required for different sizes of utility customers with up to five tariffs for each location, depending on how each utility organizes its schedules.
4. Tax rates on energy costs were assumed to correlate with state sales tax using state sales tax plus 2%. State tax rates were developed from http://thestc.com/Strates.stm (accessed January 19, 2005).
5. We used the tariff calculations from EnergyPlus to apply the lowest cost tariff when more than one rate structure might qualify. The total number of electricity tariffs is 110 for 40 utilities.
6. We selected the assignments by choosing the largest utilities that serve commercial customers based on the EIA data and what was available in TAP. New York and California were divided

into two regions. The electrical rate modeling is all based on secondary power (no customer ownership of transformer).

Table C-5 Electric Utility Company Tariff Summary

Electric Utility Company	Utility Tax Rate (%)	Number of Electricity Rates	Effective Date for Tariff
Connecticut Light & Power	8	4	2004/06/23 2005/01/01
Energy Atlantic LLC	7	3	2004/07/01
Boston Edison Co.	9	5	2004/01/01
Consolidated Edison Co.-NY	8	2	2004/11/01
Niagara Mohawk Power Co.	8	3	2005/01/05
PECO Energy Co.	8	1	2004/11/01
Public Service Electric & Gas Co.	8	3	2004/06/01
PSI Energy, Inc.	8	2	2004/05/24
Ohio Edison Co.	8	1	2003/01/23
Wisconsin Public Service Corp.	7	4	2004/01/01
Consumers Energy Co.	8	2	2005/01/03
Union Electric Co.	6.25	2	2004/04/01
MidAmerican Energy Co.	7	2	2003/01/01
Northern States Power Co.	6	2	2003/05/26
Lincoln Electric System	7.5	3	2004/10/15
Florida Power & Light Co.	8	3	2005/01/04
Georgia Power Co.	6	4	2002/03/01
Virginia Electric & Power Co.	6	3	2004/01/01
Duke Energy Corp.	9	1	2004/07/01
Allegheny Power Co.	8	3	2000/07/01
Delmarva Power & Light Co.	2	3	2002/10/01
Alabama Power Co.	6	3	2004/07/01
Entergy Mississippi, Inc.	7	2	2002/12/31
City of Memphis	9	3	2003/12/30
Reliant Energy HL&P	8.25	2	2004/12/21
Entergy Louisiana	6	5	2003/01/01
Entergy Arkansas	10	2	2004/01/01
Arizona Public Service Co.	7.6	1	2003/07/01
Public Service Co. of N.M.	7	3	2003/09/01
Idaho Power Co.	8	3	2004/07/28
Nevada Power Co.	6.5	4	2004/06/01
Public Service Co. of Colorado	4.9	2	2004/04/02
NorthWestern Energy	2	2	2005/02/01
Hawaiian Electric Co. Inc.	6	3	2003/01/01
Southern Cal Edison	8	3	2004/07/16
Pacific Gas & Electric	8	3	2004/12/01
PacifiCorp	2	8	2004/01/01
Puget Sound Energy	8.5	3	2004/07/01
Chugach Electric Association, Inc.	2	2	2004/10/01

Utility customers also pay taxes. Tax rates on utilities vary at the city and county government levels, so developing a broad set of specific tax rates is difficult. TAP neglected taxes. Most utility companies do not publish tax rates with their tariffs because they vary within the service territory. Collecting sufficient data about tax rates to formulate appropriate averages for use in the study would require a major research effort. However, taxes form an important part of energy costs in the commercial sector, and therefore need to be included in the modeling. These data were filled by assuming that energy taxes are equal to the state sales tax rate plus 2%. For example, if a state has a 5% sales tax, we model the utility tax rate as 7%. All the locations in a state are assigned the same tax rate. Table C-5 also lists these tax rate assignments for each location in the study. Although many institutions do not have to pay taxes, the current modeling does not distinguish between the owners of the buildings, so all are assumed to pay taxes.

Many commercial buildings have multiple owners or tenants, so there are many more utility customers than buildings in the United States. In some cases, a customer has multiple buildings in a single utility district. However, we could not identify good methods or supporting data to handle these real-world complexities, and assumed that each building has only one electricity customer. This will tend to make for fewer and larger electrical customers and can be expected to affect our modeling results by decreasing the significance of monthly service charges and shifting tariff schedules upward to those of larger customers (which tends to increase demand charges relative to energy charges).

C.3.2 Natural Gas

Table C-6 lists the averages of the monthly natural gas rates that are assigned to the models. The actual values are monthly and were taken from the last 12 months of recent EIA data at the state level. The gas tariff data set uses the same locations and tax rates as the electricity. Most natural gas rates are either fixed price or have some limited price tiers. Very few rates are based on demand charges in the same way electricity is. Metering and billing charges can be significant; however, with an analysis that looks at differences, these charges are not important when cost savings are calculated. Also, our understanding is that these EIA data are for revenues and already include monthly service charges. Retail gas companies tend to have small service areas; many small companies provide natural gas.

Table C-6 Utility Rate Assignments for Natural Gas Average Retail Prices for Commercial Customers Assigned to Electric Utility Territory*

Electric Utility Company Assignment	Utility Tax Rate (%)	Average Annual Gas Rate ($/MCF)
Connecticut Light & Power	8	10.94
Energy Atlantic LLC	7	11.53
Boston Edison Co.	9	11.20
Consolidated Edison Co.-NY	8	9.22
Niagara Mohawk Power Co.	8	9.22
PECO Energy Co.	8	10.57
Public Service Electric & Gas Co.	8	9.99
PSI Energy, Inc.	8	8.88
Ohio Edison Co.	8	8.89
Wisconsin Public Service Corp.	7	8.40
Consumers Energy Co.	8	8.31
Union Electric Co.	6.25	10.19
MidAmerican Energy Co.	7	8.98
Northern States Power Co.	6	7.98
Lincoln Electric System	7.5	7.31
Florida Power & Light Co.	8	11.21
Georgia Power Co.	6	10.98
Virginia Electric & Power Co.	6	10.15
Duke Energy Corp.	9	10.26
Allegheny Power Co.	8	10.34
Delmarva Power & Light Co.	2	10.15
Alabama Power Co.	6	11.15
Entergy Mississippi, Inc.	7	7.99
City of Memphis	9	9.20
Reliant Energy HL&P	8.25	8.01

Electric Utility Company Assignment	Utility Tax Rate (%)	Average Annual Gas Rate ($/MCF)
Entergy Louisiana	6	9.43
Entergy Arkansas	10	9.18
Arizona Public Service Co.	7.6	8.47
Public Service Co. of N.M.	7	7.75
Idaho Power Co.	8	8.39
Nevada Power Co.	6.5	8.17
Public Service Co. of Colorado	4.9	7.31
NorthWestern Energy	2	9.28
Hawaiian Electric Co. Inc.	6	20.74
Southern Cal Edison	8	8.19
Pacific Gas & Electric	8	8.19
PacifiCorp	2	8.70
Puget Sound Energy	8.5	8.04
Chugach Electric Association, Inc.	2	4.38

*Source: Energy Information Agency:
http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_m.htm (accessed January 12, 2005)

C.4 Fuel Factors for Electricity to Source Energy

The factors used to convert from site energy use to source energy are listed in Table C-7. These data were compiled for 2004 by Deru and Torcellini (2007). This data set was selected because it provides the latest data for source energy factors that are specially tailored for building energy analyses and offers a regional breakdown by state. These factors are the "total with precombustion" from Table B-9 in Deru and Torcellini (2007) and include the source energy consequences of nuclear generation. Source energy results are not included in this report, but are available for subsequent studies.

Table C-7 Site-to-Source Conversion Factors for Electricity

Census Division	State	Electric Utility Company Assignment	Site-to-Source Factor for Electricity
New England	CT	Connecticut Light & Power	3.310
	ME	Energy Atlantic LLC	2.904
	RI	Connecticut Light & Power	2.779
	MA	Boston Edison Co.	3.309
Middle Atlantic	NY	Consolidated Edison Co.-NY	3.229
	NY	Niagara Mohawk Power Co.	3.229
	NY	Niagara Mohawk Power Co.	3.229
	PA	PECO Energy Co.	3.453
	NJ	Public Service Electric & Gas Co.	3.500
East North Central	IN	PSI Energy, Inc	3.611
	OH	Ohio Edison Co.	3.448
	WI	Wisconsin Public Service Corp.	3.635
	MI	Consumers Energy Co.	3.485
West North Central	MO	Union Electric Co.	3.551
	IA	MidAmerican Energy Co.	3.694
	SD	Northern States Power Co.	2.484
	NE	Lincoln Electric System	3.524
South Atlantic	FL	Florida Power & Light Co.	3.374
	GA	Georgia Power Co.	3.397
	VA	Virginia Electric & Power Co.	3.613
	NC	Duke Energy Corp.	3.307
	WV	Allegheny Power Co.	3.391
	DE	Delmarva Power & Light Co.	3.941
East South Central	AL	Alabama Power Co.	3.332
	MS	Entergy Mississippi, Inc.	3.540
	TN	City of Memphis	3.194
West South Central	TX	Reliant Energy HL&P	3.712
	LA	Entergy Louisiana	3.411
	AR	Entergy Arkansas	3.264
Mountain	AZ	Arizona Public Service Co.	3.202
	NM	Public Service Co. of N.M.	3.620
	ID	Idaho Power Co.	1.597
	NV	Nevada Power Co.	3.327
	CO	Public Service Co. of Colorado	3.380
	MT	NorthWestern Energy	3.009
Pacific	HI	Hawaiian Electric Co. Inc.	4.022
	CA	Southern Cal Edison	3.135
	CA	Pacific Gas & Electric	3.135
	OR	PacifiCorp	1.690
	WA	Puget Sound Energy	1.753
	AK	Chugach Electric Association, Inc.	3.650

Source: Deru and Torcellini 2007 (Table B-9)

C.5 Schedules

This section documents how various CBECS variables were used to generate a unique set of input schedules for each building. In EnergyPlus, schedules are important model inputs that describe time-dependent operation of building systems and occupant behaviors. Table C-8 lists schedules that were created for the modeling.

Table C-8 Schedules Generated for Each Building

Schedule Purpose	Description	Type (Units)	Name in Input File	Notes
HVAC operation	HVAC operation – is HVAC available	Fraction	HVACOperationSchd	
Lighting system operation	Lighting – Same for all zones	Fraction	BLDG_LIGHT_SCH	
Plug and process loads	Equipment – Same for all zones	Fraction	BLDG_EQUIP_SCH	
People	Occupancy – Same for all zones	Fraction	BLDG_OCC_SCH	
Hot water use	Service Hot Water	Fraction	BLDG_SWH_SCH	
People activity	Activity level schedule	Number (W/Person)	ACTIVITY_SCH	Pg 283 IORef
People activity	Work efficiency, 0 signifies that all energy is heat gain	Fraction	WORK_EFF_SCH	Always 0
People clothing	Clothing schedule	Number (Clo)	CLOTHING_SCH	
Comfort air velocity	Amount of air movement	Number (m/s)	AIR_VELO_SCH	Always 0.2
Infiltration	Infiltration – inverse of HVAC operation schedule	On/Off	INFIL_SCH	
Plant availability	Plant availability schedule – for VAV systems	On/Off	PlantOnSched	Always 1
Fan availability	Fan availability schedule – for VAV systems	On/Off	FAN_SCH	Always 1
Reheat availability	Reheat coil availability – for VAV systems	On/Off	ReheatCoilAvailSched	Always 1
Cooling availability	Cooling coil availability – for VAV systems	On/Off	CoolingCoilAvailSched	Always 1
Thermostat	Heating set point	Number (ºC)	HTGSETP_SCH	
Thermostat	Cooling set point	Number (ºC)	CLGSETP_SCH	
Humidistat	Humidity Setpoint	Number (RH)	Humidity Setpoint Schedule	Always 50
Ventilation requirements	Minimum outside air	On/Off	MinOA_Sched	Outside Air Controller
Thermostat	Type of zone control (4 = dual set point)	Number (0-4)	Dual Zone Control Type Sched	Always 4
Air system cold deck temperature	Schedule to determine set points	Number (ºC)	Seasonal-Reset-Supply-Air-Temp-Sch	
Chilled water supply temperature	Cooling water temperature	Number (ºC)	CW-Loop-Temp-Schedule	Always 6.7
Hot water supply temperature	Hot water temperature	Number (ºC)	HW-Loop-Temp-Schedule	Always 60
Air system hot deck temperature	Heating supply air temperature	Number (ºC)	Heating-Supply-Air-Temp-Sch	

For many schedules, the building's hours of operation drive the underlying time dependence. Therefore, the first step for each building is to apply the CBECS variables listed in Table C-9 to model the hours of operation.

Table C-9 CBECS Variables Used To Determine Hours of Operation

CBECS Variable	Description	Notes
OPEN24	Open 24 hours 1 – Yes 2 – No	
DAYSOPN	Days open (Mon-Fri) 1 – Open all five days 2 – Open some of these days 3 – Not open at all	
OPENWE	Open on weekends 1 – Yes 2 – No	
WKHRS8	Total weekly operating hours XX – Value	If ≥ 997 then unknown (DNE in dataset)
PBAPLUS	More specific building activity	See Table C-10
MONCON	Month ready for occupancy in 2003 0 – N/A 1:12 – Month	
PORVAC	Space vacant 3 consecutive months 1 – Yes 2 – No	If 0 then not used (variable not used because of inconsistencies)
MONUSE	Months in use past 12 months	

The variables defined in Table C-9 were used to determine the typical operating schedules of the building. If the building was defined to be open 24 hours, the schedules were set to always open. If the building was not open 24 hours, other logic had to be used. The idea was to generate a typical week by applying the CBECS variables. First, if the building was open only on the weekends, we had to determine if it was open on both Saturday and Sunday, or just one of the days. If the total weekly hours were more than 20 (assumed value), the building was open both Saturday and Sunday. However, if it was open 20 hours or fewer, the building was open only one day. If the building was open both days of the weekend, another assumed variable weighted either Saturday or Sunday, based on the more specific building activities. These are defined in Table C-10.

If the building was open during the week and during the weekend, another set of logic was needed to interpolate the hours of operation. First, the favored day of the weekend was assigned a couple of hours (to be targeted later to match the total weekly hours). The hours were assigned to the middle of the day, again defined in Table C-10. If the total weekly hours were fewer than 10 (assumed value), the middle of the day may be different because of the limited hours. Finally, if the total weekly hours were more than 70 (assumed value), the building was assumed to be open the other day of the weekend.

The next step was to assign the correct number of hours to the week by first assigning the average daily hours to the opened days. Sometimes a building was open only some weekdays. In this case the days open were randomly chosen based on the number of days needed to be open 10 hours per day.

Sometimes the total number of hours open could not be distributed evenly across the days open. In this case, the missing hours were randomly assigned to the days. First a random day was chosen, and yet another random process determined whether to assign the hour to the beginning of the day or to the end of the day. If the building was open during the weekend, the weekends were weighted slightly higher (25%) to accommodate different schedules on the weekend.

Table C-10 Hours of Operation Modeling Data by PBAPLUS

Code	PBAPLUS Name More Specific Building Activity	Weekday Center Hour	Saturday Center Hour	Sunday Center Hour	Small Weekend Center Hour	Saturday Favored
1	Vacant	13	13	13	10	Yes
2	Administrative/professional office	16	14	14	12	Yes
3	Bank/other financial	13	10	10	12	Yes
4	Government office	13	13	15	12	Yes
5	Medical office (nondiagnostic)	16	14	14	11	Yes
6	Mixed-use office	16	14	14	11	Yes
7	Other office	16	14	14	11	Yes
8	Laboratory	13	11	13	11	Yes
9	Distribution/shipping center	12	12	12	12	Yes
10	Nonrefrigerated warehouse	12	12	12	12	Yes
11	Self-storage	12	12	12	12	Yes
12	Convenience store	13	14	12	12	Yes
13	Convenience store with gas station	14	14	14	12	Yes
14	Grocery store/food market	13	14	12	12	Yes
15	Other food sales	13	14	12	12	Yes
16	Fire station/police station	13	14	12	12	Yes
17	Other public order and safety	13	14	12	12	Yes
18	Medical office (diagnostic)	13	14	12	12	Yes
19	Clinic/other outpatient health	13	14	12	12	Yes
20	Refrigerated warehouse	13	14	12	12	Yes
21	Religious worship	13	13	12	9	No
22	Entertainment/culture	14	14	14	18	Yes
23	Library	13	13	13	13	Yes
24	Recreation	12	13	14	13	Yes
25	Social/meeting	14	14	14	18	Yes
26	Other public assembly	13	13	13	13	Yes
27	College/university	14	10	14	10	Yes
28	Elementary/middle school	14	14	14	10	Yes
29	High school	14	14	14	10	Yes
30	Preschool/daycare	14	14	14	10	Yes
31	Other classroom education	14	14	14	10	Yes
32	Fast food	18	18	18	16	Yes
33	Restaurant/cafeteria	16	16	18	16	Yes
34	Other food service	18	18	18	16	Yes
35	Hospital/inpatient health	13	14	12	14	Yes
36	Nursing home/assisted living	13	14	12	14	Yes
37	Dormitory/fraternity/sorority	13	13	13	13	Yes
38	Hotel	13	13	13	13	Yes
39	Motel or inn	13	13	13	13	Yes
40	Other lodging	13	13	13	13	Yes

Code	PBAPLUS Name More Specific Building Activity	Weekday Center Hour	Saturday Center Hour	Sunday Center Hour	Small Weekend Center Hour	Saturday Favored
41	Vehicle dealership/showroom	14	14	14	12	Yes
42	Retail store	14	14	14	12	Yes
43	Other retail	14	14	14	12	Yes
44	Post office/postal center	14	14	14	12	Yes
45	Repair shop	14	14	14	12	Yes
46	Vehicle service/repair shop	14	14	14	12	Yes
47	Vehicle storage/maintenance	14	14	14	12	Yes
48	Other service	14	14	14	12	Yes
49	Other	13	13	13	13	Yes

Holidays also affect schedules. Holiday schedules are usually set to match the day that has the fewest open hours (typically Sunday). The holidays are listed in Table C-11. If the holiday falls on a day that the business is closed, the holiday is not moved to the following business day, but rather observed on the closed day.

Table C-11 Observed Holidays

Holiday	Day of Year
New Years Day	January 1
Veterans Day	November 11
Christmas	December 25
Independence Day	July 4
Martin Luther King Day	Third Monday in January
Presidents Day	Third Monday in February
Memorial Day	Last Monday in May
Labor Day	First Monday in September
Columbus Day	Second Monday in October
Thanksgiving	Fourth Thursday in November

Each building's lighting schedule uses the hours of operation schedule to determine the timing of lights. The lighting schedule was modeled from the hours of operation schedule with maximum and minimum fractions determined from CBECS variables (see Table C-12). The schedule values area also scaled by an additional factor for diversity (see Table C-27).

Table C-12 Lighting Schedule Modeling

CBECS Variable	Description	Notes
RDLTNF	Lighting reduced during off hours 1 – Yes 2 – No	If 0 then defaults to other schedule
LTNHRP	Percent lit when closed	Used for minimum fraction for schedule
LTOHRP	Percent lit when open	Used for maximum fraction for schedule

The building equipment schedule used to model plug and process electricity use is based on the operation schedule created first. When occupied, the equipment fraction is assumed to be at a maximum of 0.95.

When unoccupied, the equipment fraction is assumed to be at one of the minimum fractions (see Table C-14). Using the variable RDPFEQ in Table C-13, the fractions were applied (see Table C-14), by assumption.

Table C-13 Plug and Process Load Schedule Modeling

CBECS Variable	Description (Weight of Occurrence)	Notes
RDOFEQ	Equipment turned off during off hours 0 – Not reported (40%) 1 – Always (32%) 2 – Sometimes (16%) 3 – Never (10%) 4 – Computers are powered down (2%)	If 0 then assumed to be 1 – always turned off (because 1 is the most common response)

Table C-14 Plug and Process Load Fractions

RDOFEQ Variable	Plug and Process Load Minimum Fraction
Not reported	0.10
Always	0.10
Sometimes	0.40
Never	0.95
Computers are powered down	0.80

Heating and cooling thermostatic set points were set based on the CBECS variables listed in Table C-15.

Table C-15 Variables for Heating and Cooling Set Points

CBECS Variable	Description	Notes
RDCLNF	Cooling reduced in 24 hours 1 – Yes 2 – No	If 0 then assumed to be no (because 2 is the most common response)
RDHTNF	Heating reduced in 24 hours 1 – Yes 2 – No	If 0 then assumed to be no (because 2 is the most common response)
HWRDCL	How reduce cooling 1 – Time-clock thermostat 2 – Manually reset 3 – Part of EMCS	If 0 then not reduced (not used)
HWRDHT	How reduce heating 1 – Time-clock thermostat 2 – Manually reset 3 – Part of EMCS	If 0 then not reduced
HTLS50	Heated to lower than 50ºF 1 – Yes 2 – No	If yes then set to 50ºF and nonrefrigerated warehouse

The maximum heating and cooling set points were assigned based on the PBA during operating hours. Setback is used only if stated in CBECS. The heating and cooling set points were always assumed to be the same, except in vacant buildings. They were defined as in Table C-16. However, if the building was heated to lower than 50ºF (10ºC), the maximum heating set point and setback were set to 50ºF (10ºC).

Table C-16 Thermostat Set Point Schedule Modeling

PBAPLUS Name	Heating Set Point (ºC)	Heating Setback (ºC)	Cooling Set Point (ºC)	Cooling Setback (ºC)
Vacant	19	13	24	33
All others	21	13	24	33

The HVAC operation schedule was the same as the hours of operation schedule unless the building's heating or cooling was reduced during the night.

Metabolic activity level is used to model thermal comfort and requires scheduled values (Table C-17).

Table C-17 Activity Level Schedule Modeling

PBA Code	PBAPLUS Name	Activity Level (W)
1	Vacant	120
2	Administrative/professional office	120
3	Bank/other financial	120
4	Government office	120
5	Medical office (nondiagnostic)	120
6	Mixed-use office	120
7	Other office	120
8	Laboratory	140
9	Distribution/shipping center	140
10	Nonrefrigerated warehouse	140
11	Self-storage	140
12	Convenience store	120
13	Convenience store with gas station	120
14	Grocery store/food market	120
15	Other food sales	120
16	Fire station/police station	120
17	Other public order and safety	120
18	Medical office (diagnostic)	120
19	Clinic/other outpatient health	120
20	Refrigerated warehouse	120
21	Religious worship	120
22	Entertainment/culture	120
23	Library	80
24	Recreation	250
25	Social/meeting	100
26	Other public assembly	120
27	College/university	120
28	Elementary/middle school	120
29	High school	120
30	Preschool/daycare	120
31	Other classroom education	120
32	Fast food	120
33	Restaurant/cafeteria	120
34	Other food service	120
35	Hospital/inpatient health	100
36	Nursing home/assisted living	100
37	Dormitory/fraternity/sorority	120
38	Hotel	120
39	Motel or inn	120
40	Other lodging	120
41	Vehicle dealership/showroom	120
42	Retail store	120
43	Other retail	120

PBA Code	PBAPLUS Name	Activity Level (W)
44	Post office/postal center	120
45	Repair shop	140
46	Vehicle service/repair shop	140
47	Vehicle storage/maintenance	140
48	Other service	120
49	Other	120

C.6 Floor Area and Number of Floors

CBECS provides values for total floor area (SQFT8) and number of floors (NFLOOR8). Therefore, the mapping is often trivial and these are directly translated to FloorArea and NumFloors in the data model.

CBECS uses special values for NFLOOR8 to mask the identity of actual buildings with large numbers of floors. If NFLOOR8 has the value 991, we used a uniform probability distribution to select the number of floors at random from 15 to 25, inclusive. If NFLOOR8 has the value 992, we used a uniform probability distribution to select the number of floors at random from 26 to 50, inclusive.

CBECS value for number of floors includes basements, parking levels, and any other floors below grade level. However, in the EnergyPlus modeling, we do not model below grade levels and assume that all the floors are aboveground.

C.7 Aspect Ratio and Rotation

The aspect ratio is defined as the east−west length of the building divided by the north−south width of the building. Obviously, this definition is unique only before the building is rotated; that is, when Rotation = 0. The aspect ratio for each building was modeled from the 2003 CBECS variables:

- Building shape (BLDSHP8), which can take the following values (% sector floor area):
  - 00 not ascertained in survey (10.1%)
  - 01 square (8.5%)
  - 02 wide rectangle (48.8%)
  - 03 narrow rectangle (7.0%)
  - 04 rectangle square with courtyard (3.7%)
  - 05 “H” shaped (3.0%)
  - 06 “U” shaped (2.5%)
  - 07 “E” shaped (1.3%)
  - 08 “T” shaped (2.1%)
  - 09 “L” shaped (6.2%)
  - 10 “+” or cross shaped (1.8%)
  - 11 other shape (4.9%)
- Glass sides receive most sunlight (SUNGLS8).

To simplify the generation of full energy models, we use only rectangular forms and neglect the other general shapes of courtyards, “H”, “U”, “E”, “T”, “L”, or “+”. These forms are used in 20% of the buildings. Such forms are accounted for by shifting to higher aspect ratios to model increased perimeter area for a given floor area as listed in Table C-18.

Table C-18 Aspect Ratio Assignments by Building Shape

BLDSHP8 Code	Shape	Probability Distribution for Aspect Ratio	Source
00	Not ascertained	Uniform on [1..4]	Assumption
01	Square	Uniform on [1..1.2]	Assumption
02	Wide rectangle	Uniform on [1.2..2]	Assumption
03	Narrow rectangle	Uniform on [2..6]	Assumption
04	Rectangle/square with courtyard	Uniform on [2.0.5.0]	Assumption
05	"H" shaped	Uniform on [3..6.0]	Assumption
06	"U" shaped	Uniform on [2..5]	Assumption
07	"E" shaped	Uniform on [2..5]	Assumption
08	"T" shaped	Uniform on [1.5..5]	Assumption
09	"L" shaped	Uniform on [1.5..4]	Assumption
10	"+" or cross shaped	Uniform on [2.0..6]	Assumption
11	other	Uniform on [1..4]	Assumption

Rotation is assigned on [0..360) randomly by using uniform probability distribution.

C.8 Perimeter Depth

The perimeter depth is defined as the distance from the outside wall to the interior core zone. This value was fixed at 15 ft (4.57 m) following customary energy modeling practice. This value is also selected, because with this we have more faith in the capability of the split-flux models for daylighting.

C.9 Floor-to-Floor Height

CBECS does not provide data about the floor-to-floor height, which is defined as the distance from the top of one floor to the top of the next higher floor (includes any plenum spaces). In our modeling, the building is assumed to have equal floor-to-floor heights on all levels. This value is therefore generated at random from assumed ranges. Table C-19 documents how these rules were organized by PBA.

Table C-19 Floor-to-Floor Height Assignments by Subsector

PBA Code	Subsector (PBA)	Probability Distribution	Source
1	Vacant	Uniform on [10..20] ft	Assumption
2	Office/professional	Uniform on [11..15] ft	Assumption
4	Laboratory	Uniform on [13..17] ft	Assumption
5	Nonrefrigerated warehouse	Uniform on [15..20] ft	Assumption
6	Food sales	Uniform on [15..20] ft	Assumption
7	Public order and safety	Uniform on [13..17] ft	Assumption
8	Outpatient health care	Uniform on [11..15] ft	Assumption
11	Refrigerated warehouse	Uniform on [15..20] ft	Assumption
12	Religious worship	Uniform on [15..25] ft	Assumption
13	Public assembly	Uniform on [15..25] ft	Assumption
14	Education	Uniform on [11..15] ft	Assumption
15	Food service	Uniform on [11..15] ft	Assumption
16	Inpatient health care	Uniform on [11..15] ft	Assumption
17	Skilled nursing	Uniform on [10..13] ft	Assumption
18	Lodging	Uniform on [10..13] ft	Assumption
23	Strip shopping mall	Uniform on [15..20] ft	Assumption
24	Enclosed mall	Uniform on [15..25] ft	Assumption
25	Retail (except malls)	Uniform on [15..20] ft	Assumption
26	Service	Uniform on [15..20] ft	Assumption
91	Other	Uniform on [15..20] ft	Assumption

C.10 Plenum Height

CBECS provides no information on the height of plenum spaces. This value is zero in building types that do not include suspended ceilings. The floor-to-floor height minus the plenum height results in the zone ceiling height for the occupied space. Earlier efforts to develop the current methodology included plenums in some of the model geometries. However, the final set of models had no plenums.

C.11 Glazing Geometry

The locations and sizes of windows in the building need to be known and are referred to here as *glazing geometry*. The most important glazing geometry parameter is the glazing fraction, which is defined as the total (above-grade) wall area divided by the total visible window area (for each orientation). The schema for window form used in this study is continuous bands of windows for each floor and each orientation. Although real buildings will often have individual windows, continuous horizontal bands are used to simplify the EnergyPlus models and avoid excessive simulation run times.

2003 CBECS provides the following data related to glazing geometry:

- Percent exterior glass (GLSSPC8)
    - 0 no data
    - 1 10% or less
    - 2 11% to 25%
    - 3 16% to 50%
    - 4 51% to 75%
    - 5 76% to 100%
- Equal glass on all sides (EQGLSS8)

- 0 no data
- 1 yes
- 2 no

- Glass sides receive most sunlight (SUNGLS8)
  - 0 no data
  - 1 "more glass area"
  - 2 "less glass area"
  - 3 "about the same"
- Skylights and atriums designed for lighting (SKYLT8).

If data are reported for percent exterior glass, glazing fractions are assigned to be within the reported category. A uniform probability distribution is used to select a specific glazing fraction within the range specified by each category according to Table C-20.

Table C-20 Glazing Fraction Assignments

GLSSPC8 Code	Category	Probability Distribution
00	Not ascertained	See Table C-21
01	10% or less	Uniform on [0.0..0.1]
02	11% to 25%	Uniform on [0.11..0.25]
03	16% to 50%	Uniform on [0.26..0.50]
04	51% to 75%	Uniform on [0.51..0.75]
05	76% to 100%	Uniform on [0.76..0.98]

For cases where the CBECS data about percent exterior glass are missing (GLSSPC8 = 0), we have no data to determine the glazing fraction. For these cases we used assignments developed from Huang and Franconi (1999) and assumptions as shown in Table C-21.

Table C-21 Glazing Fraction Assignments by PBA (Used When No Data Are Available for Percent Exterior Glass)

PBA Code	PBA Name	Rule	Source
1	Vacant	Post-1980: If floor area ≥ 25,000 ft^2 then 0.5 If floor area < 25,000 ft^2 then 0.15 Pre-1980: If floor area ≥ 25,000 ft^2 then 0.4 If floor area < 25,000 ft^2 then 0.2	Assumed to match office from Huang and Franconi 1999
2	Office/professional	Post-1980: If floor area ≥ 25,000 ft^2 then 0.5 If floor area < 25,000 ft^2 then 0.15 Pre-1980: If floor area ≥ 25,000 ft^2 then 0.4 If floor area < 25,000 ft^2 then 0.2	Huang and Franconi 1999
4	Laboratory	0.10	Assumption
5	Nonrefrigerated warehouse	If post-1980 then 0.03 If pre-1980 then 0.06	Huang and Franconi 1999
6	Food sales	0.15	Huang and Franconi 1999
7	Public order and safety	Post-1980: If floor area ≥ 25,000 ft^2 then 0.5	Assumed to match office

PBA Code	PBA Name	Rule	Source
		If floor area < 25,000 ft^2 then 0.15 Pre-1980: If floor area ≥ 25,000 ft^2 then 0.4 If floor area < 25,000 ft^2 then 0.2	from Huang and Franconi 1999
8	Outpatient health care	0.25	Huang and Franconi 1999 hospital
11	Refrigerated warehouse	0.0	Assumption
12	Religious worship	0.20	Assumption
13	Public assembly	Post-1980: If floor area ≥ 25,000 ft^2 then 0.5 If floor area < 25,000 ft^2 then 0.15 Pre-1980: If floor area ≥ 25,000 ft^2 then 0.4 If floor area < 25,000 ft^2 then 0.2	Assumed to match office from Huang and Franconi 1999
14	Education	If post-1980 then 0.18 If pre-1980 then 0.27	Huang and Franconi 1999
15	Food service	If post-1980 then 0.175 If pre-1980 then 0.25	Huang and Franconi 1999 (average of restaurants)
16	Inpatient health care	0.25	Huang and Franconi 1999 hospital
17	Skilled nursing	0.25	Huang and Franconi 1999 hospital
18	Lodging	Post-1980: If floor area ≥ 25,000 ft^2 then 0.35 If floor area < 25,000 ft^2 then 0.21 Pre-1980: If floor area ≥ 25,000 ft^2 then 0.29 If floor area < 25,000 ft^2 then 0.24	Huang and Franconi 1999
25	Retail (except malls)	0.15	Huang and Franconi 1999
26	Service	0.15	Assumption
91	Other	0.20	Assumption

Once the overall glazing fraction has been determined, the CBECS variable for "equal glass on all sides" (EQGLSS8) is used, if possible, to further refine the distribution of glazing on the cardinal directions. If the value of EQGLSS8 is "0" (not available) or "1" (yes), we used the same glazing fraction on all four cardinal directions. If the value of EQGLSS8 is "2" (no), we distributed the glazing fraction to be different in the different cardinal directions in the following manner. The CBECS variable "glass sides receive most sunlight" (SUNGLS8) was assumed to indicate a tendency for the relative glazing fractions along the south-facing facade. If the value of SUNGLS8 was "1" (more glass area), we increased the glazing fraction on the south facade using,

$$f_{gls,south} = MIN\left(f_{gls,south} + f_{gls,south}/2 , \quad f_{gls,south} + (1 - f_{gls,south})/2 \right).$$

If the value of SUNGLS8 was "2" (less glass area), we decreased the glazing fraction on the south facade using,

$$f_{gls,south} = f_{gls,south} - f_{gls,south}/2 .$$

If the value of SUNGLS8 was "0" or "3", the SUNGLS8 variable does not affect the glazing fraction allocations, and unequal glazing was modeled by picking a facade orientation at random and then increasing the glazing on that facade using,

$$f_{gls,south} = MIN\left(f_{gls,south} + {f_{gls,south}}/{4}, \quad f_{gls,south} + {(1 - f_{gls,south})}/{4} \right)$$

At this point in the assignments and geometry generation, we have not yet calculated the overall areas of the facade in the cardinal directions. This makes it difficult to use a scheme that would preserve glazed areas. The areas could be computed at this point, but these calculations are being done much later in the process. Given the vagaries of the glazing fraction value, it does not seem necessary to ensure that the overall value is totally preserved when redistributing.

The data model requires two additional parameters for glazing geometry: GlazingSillHeight and GlazingEdgeOffset. The sill height is the distance from each floor to where the window starts. This value is fixed by assumption at 3.6 ft (1.1 m), except for high glazing fractions where lower sills are required to provide enough area for higher glazing fractions. The next value is the edge offset, which is the length of clear wall along the window jambs (also required to ensure that windows are smaller than the walls in which they are located). This value is fixed by assumption at 0.16 ft (0.05 m).

C.12 Construction

This mapping selects sets of constructions in the data model. CBECS provides PBA and year of construction along with a number of variables that provide some information about the envelope, including:

- Insulation upgrade (RENINS8)
    - 00 not known
    - 01 yes
    - 02 no
- Wall construction material (WLCNS8)
    - 01 brick, stone or stucco (51%)
    - 02 precast concrete panels (10%)
    - 03 concrete block or poured concrete (17%)
    - 04 siding, shingles, tiles, or shakes (6%)
    - 05 sheet metal panels (12%)
    - 06 window or vision glass (1.6%)
    - 07 decorative or construction glass (0.8%)
    - 08 no one major type (0.6%)
    - 09 other (0.8%)
- Roof construction material (RFCNS8)
    - 01 built up (33%)
    - 02 slate or tile shingles (4%)
    - 03 wood shingles, shakes, or other wood (1.4%)
    - 04 asphalt, fiberglass, or other shingles (16%)

    - 05 metal surfacing (18%)
    - 06 plastic, rubber, or synthetic sheeting (23%)
    - 07 concrete (3.4%)
    - 08 no one major type (0.9%)
    - 09 other (0.9%)
- Tinted window glass (TINT8)
- Window glass type (WINTYP8)
- Window replacement (RENWIN8)
- Reflective window glass (REFL8)

With these data, and the activity and location (determined earlier), the construction types for the thermal envelope are assigned in the following manner.

The year of construction variable (YRCON8) is examined and sorted into vintages—pre-1980 and post-1980. This categorization was selected to align with Huang and Franconi (1999) to use their data in assignments. If the insulation was renovated (RENINS8 = yes), the vintage was set to post-1980 regardless of the year of construction.

The vintage is used with the CBECS variables for census division (CENDIV8) and PBA8 to assign construction R-values according to data from Huang and Franconi (1999). These data were presented in Table 2-6 and Table 2-7.

Locations were mapped based on CDDs and HDDs. In Huang and Franconi's document, they split Climate Zone 3 into two parts (north and south). This climate zone had 4,000 to 5,499 HDDs and fewer than 2,000 CDDs. To disaggregate this climate zone, the north was assumed to have more than 4,750 HDDs, and the south was assumed to have 4,750 or fewer HDDs.

The type of windows installed was based on the four CBECS variables listed in Table C-22.

Table C-22 Variables Used To Determine Window Constructions

Variable ID	Description
TINT8	Tinted window glass 1 – Yes 2 – No
WINTYP8	Window glass type 1 – Single layer glass 2 – Multi-layer glass 3 – Combination of both 4 – No windows
RENWIN8	Window replacement 1 – Yes 2 – No
REFL8	Reflective window glass 1 – Yes 2 – No

The values for RENWIN8 were not used because the variable WINTYP8 included the renovated window constructions. Based on the three variables, a 3 × 2 matrix was created to assign window constructions.

The six window types are either single or double pane and have clear, tinted, or reflective solar optical properties.

C.13 People Density

CBECS provides data about the number of workers (NWKER8), the total square feet (SQFT8), and various numbers for capacities (RWSEAT8, PBSEAT8, EDSEAT8, FDSEAT8, and HCBED8). The data model uses the PeopleDensity element, which is defined as the number of people in the space per every 100 m^2 (1076 ft^2). ASHRAE 90.1-1989 Section 13 provides recommendations for occupancy density. Table C-23 shows how the occupancy assignments are made for each subsector. We generally use the number of workers specified in CBECS, unless nonemployees as well as employees are expected to be in the buildings. The people density assignment for vacant buildings is used to size the HVAC systems, and schedules are used to zero out the number of occupants.

Table C-23 People Density Assignments

PBA Code	Subsector	Assignment Rules	Source
1	Vacant	200 ft^2/person	Assumption
2	Office/professional	NWKER8/SQFT8 * Conversion	2003 CBECS
4	Laboratory	NWKER8/SQFT8 * Conversion	2003 CBECS
5	Nonrefrigerated warehouse	NWKER8/SQFT8 * Conversion	2003 CBECS
6	Food sales	300 ft^2/person	ASHRAE 90.1-1989 (retail)
7	Public order and safety	NWKER8/SQFT8 * Conversion	2003 CBECS
8	Outpatient health care	200 ft^2/person	ASHRAE 90.1-1989 w/addendum (Health/Institutional)
11	Refrigerated warehouse	(NWKER8/SQFT8) * Conversion	2003 CBECS
12	Religious worship	(NWKER8 + 0.5*RWSEAT8)/SQFT8 * Conversion	Assumption
13	Public assembly	(NWKER8 +0.5*PBSEAT8)/SQFT8 * Conversion	2003 CBECS; Assumption
14	Education	(NWKER8 + 0.9*EDSEAT8)/SQFT8 * Conversion	2003 CBECS
15	Food service	(NWKER8 + 0.8*FDSEAT8)/SQFT8 * Conversion	1999 CBECS; Assumption
16	Inpatient health care	(NWKER8 + 0.8*HCBED8)/SQFT8 * Conversion	2003 CBECS; Assumption
17	Skilled nursing	200 ft^2/person	ASHRAE 90.1-1989 w/addendum (Health/Institutional)
18	Lodging	200 ft^2/person	ASHRAE 90.1-1989 w/addendum (Health/Institutional)
25	Retail (except malls)	300 ft^2/person	ASHRAE 90.1-1989 (Retail)
26	Service	NWKER8/SQFT8 * Conversion	2003 CBECS
91	Other	NWKER8/SQFT8 * Conversion	2003 CBECS

C.14 Plug and Process Electricity Intensity

Establishing levels for plug and process loads for whole building energy modeling is very difficult. These energy uses are not regulated as part of building design, and little information is available to help model these loads. The plug and process intensity is used in conjunction with schedules to determine energy use in the EnergyPlus models. For this study, we used modeling based on CBECS variables to determine plug and process where possible, and iterated assumed power densities and probabilistic assignments.

CBECS variables include the number of some types of plug and process electrical equipment.

- Number of computers (PCNUM8)
  - Flat screen monitors (FLAT8)
  - Computer area percent (PCRMP8)
  - Computers used (PCTERM8)
- Number of servers (SRVNUM8)
  - Dedicated servers used (SERVER8)
- Number of cash registers (RGSTRN8)
- Number of photocopiers (COPRN8)
- Number of printers (PRNTRN8)
  - Types of printers (PRNTYP8)
- Number of residential refrigerators (RFGRSN8)
- Number of vending machines (RFGVNN8)
- Number of elevators (NELVTR8)
- Number of escalators (NESLTR8)

The CBECS variables for number of devices can be combined with the electrical power draws of such devices when active to develop estimates for the intensity of plug and process loads. Roth et al. (2002) and others have developed estimates of the energy consumed by office and telecommunications equipment. The Roth study and others like it contain a bottom-up assessment of office equipment that uses data about the power draws and usage patterns. We selected data from Roth et al. (2002) for the nominal power of various pieces of office equipment, as listed in Table C-24.

Table C-24 Mean Nominal Peak Power Levels of Surveyed Devices

Listed Item	CBECS Variable	Data Source	Nominal Mean Power (W)
Personal computers	PCNUM8	Roth et al. 2002	55
Personal computer monitors (CRTs when FLAT8 = no or missing)	PCNUM8	Roth et al. 2002	90
Personal computer monitors (flat screens when FLAT8 = yes)	PCNUM8	Roth et al. 2002	25
Servers	SRVNUM8	Roth et al. 2002	650
Point of sale (cash registers)	RGSTRN8	Roth et al. 2002	50
Printers (laser)	PRNTRN8	Roth et al. 2002	263
Printers (inkjet)	PRNTRN8	Roth et al. 2002	42.5
Copy machines	COPRN8	Roth et al. 2002	660
Residential refrigerators	RFGRSN8	Assumption	350
Vending machines	RFGVNN8	Assumption; see ADL (1993)	450
Escalators	NESLTR8	TIAX (2006)	4,671
Elevators	NELVTR8	TIAX (2006)	10,000

The nominal mean power levels listed in Table C-24 are used in the first step of the method for assigning plug and process power densities. The power density of surveyed devices, PD_{sd} , is calculated using,

$$PD_{sd} = \frac{\begin{pmatrix} P_{PC}R_{PC}PCNUM8 + P_{mon}R_{mon}PCNUM8 + P_{server}R_{server}SRVNUM8 + P_{POS}R_{POS}RGSTRN8 \\ + P_{PRN}R_{PRN}PRNTRN8 + P_{copy}R_{copy}COPRN8 + P_{rf}R_{rf}RFGRSN8 + P_{vend}R_{vend}RFGVNN8 \\ + P_{Escl}R_{Escl}NESLTR8 + P_{Elev}R_{Elev}NELVTR8 \end{pmatrix}}{SQFT8}$$

where,

P is the nominal peak power for each of the surveyed devices listed in Table C-24,

R is a Gaussian random number about 1.0 with a standard deviation of 0.05 that is introduced to model variation in such power levels.

The modeled plug and process peak power density, *P*, is then modeled from the power density of surveyed devices using the linear formulation,

$$P = \left(c_{sd}PD_{sd} + PD_{misc}\right) * d$$

where,

$\boldsymbol{c_{sd}}$ is a coefficient used to scale power density from PD_{sd}

PD_{misc} is the power density of devices that are independent of the devices included in the survey. Values for PD_{misc} are organized to vary with the more detailed building activity (PBAPLUS8), and

d is a scheduling diversity factor that is used here as a simplified correction for some building types were a lack of detail on the shapes of load profiles appears to cause problems.

Specific values for the unknowns c_{sd}, PD_{misc}, and *d* were developed by using an iterative process and comparing them to EUI results from CEUS (CEC 2006) (see Table 2-1). The non-HVAC end use results from CEUS were selected to calibrate the plug and process peak loads, because that study appears to offer the best source of such data, and by reasoning that there is little reason the non-weather related, non-HVAC energy uses in California commercial buildings should differ from the rest of the U.S. commercial sector. The scheduling diversity factor was used for the religious worship subsectors when the square-wave load shapes were suspected to be especially inadequate.

The calibration process was carried out in five steps:

Step 1 involved assuming values for $\boldsymbol{c_{sd}}$ and PD_{misc} based on expert opinion.

Step 2 involved running the simulations using the power density model and the schedules for plug and process loads. The creation of these equipment schedules is described in section C.5 Schedules. Creating these schedules introduces Step 3.

Step 3 aggregates the results for plug and process loads by the building activities used in CEUS.

Step 4 involved comparing the results from the current modeling to those from CEUS.

Step 5 formulated new values for c_{sd} , PD_{misc}, and *d*.

Steps 2 through 5 were repeated eight times to obtain reasonable agreement during Step 4. Table C-25 lists the final values for c_{sd} and PD_{misc} used in the modeling. In general, we doubled the power density obtained from modeling the surveyed devices.

Table C-25 Plug and Process Peak Power Levels by PBAPLUS

PBAPLUS8 Code	PBAPLUS Name	C_{sd}	PD_{misc} (W/m^2)	Schedule Diversity Factor
1	Vacant	2.0	5.9	1.0
2	Administrative/professional office	2.0	8.3	1.0
3	Bank/other financial	2.0	8.3	1.0
4	Government office	2.0	8.3	1.0
5	Medical office (nondiagnostic)	2.0	8.3	1.0
6	Mixed-use office	2.0	8.3	1.0
7	Other office	2.0	8.3	1.0
8	Laboratory	2.0	30.0	1.0
9	Distribution/shipping center	2.0	2.0	1.0
10	Nonrefrigerated warehouse	2.0	2.0	1.0
11	Self-storage	2.0	2.0	1.0
12	Convenience store	2.0	5.1	1.0
13	Convenience store with gas station	2.0	5.1	1.0
14	Grocery store/food market	2.0	5.1	1.0
15	Other food sales	2.0	5.1	1.0
16	Fire station/police station	2.0	12.0	1.0
17	Other public order and safety	2.0	12.0	1.0
18	Medical office (diagnostic)	2.0	5.9	1.0
19	Clinic/other outpatient health	2.0	5.9	1.0
20	Refrigerated warehouse	2.0	1.0	1.0
21	Religious worship	2.0	5.9	0.4
22	Entertainment/culture	2.0	5.9	1.0
23	Library	2.0	5.9	1.0
24	Recreation	2.0	5.9	1.0
25	Social/meeting	2.0	5.9	1.0
26	Other public assembly	2.0	5.9	1.0
27	College/university	1.6	8.0	1.0
28	Elementary/middle school	2.0	1.6	1.0
29	High school	2.0	1.6	1.0
30	Preschool/daycare	2.0	1.6	1.0
31	Other classroom education	2.0	2.0	1.0
32	Fast food	2.0	10.0	1.0
33	Restaurant/cafeteria	2.0	10.0	1.0
34	Other food service	2.0	10.0	1.0
35	Hospital/inpatient health	2.0	8.2	1.0
36	Nursing home/assisted living	2.0	12.0	1.0
37	Dormitory/fraternity/sorority	2.0	3.2	1.0
38	Hotel	2.0	3.2	1.0
39	Motel or inn	2.0	3.2	1.0
40	Other lodging	2.0	3.2	1.0
41	Vehicle dealership/showroom	2.0	3.7	1.0
42	Retail store	2.0	3.7	1.0
43	Other retail	2.0	3.7	1.0
44	Post office/postal center	2.0	5.9	1.0

PBAPLUS8 Code	PBAPLUS Name	C_{sd}	PD_{misc} (W/m^2)	Schedule Diversity Factor
45	Repair shop	2.0	5.9	1.0
46	Vehicle service/repair shop	2.0	5.9	1.0
47	Vehicle storage/maintenance	2.0	5.9	1.0
48	Other service	2.0	5.9	1.0
49	Other	2.0	5.9	1.0

C.15 Lighting Intensity

DOE has studied the national lighting stock. Navigant (DOE 2002) used a variety of data sources, including 1999 CBECS and the XenCAP™ database, to produce national estimates for lighting stock and energy consumption. Because the goal of this study was to produce national estimates, the published data do not appear to be well-suited to producing estimates for individual CBECS buildings. The Navigant results for lighting power densities (LPDs) by PBA (from Table 5-11 in DOE 2002) are used as the mean values for a normal probability distribution and are listed in Table C-26. The standard deviations used for Gaussian assignments were arbitrarily assumed to be 1/15 the magnitude of the LPD. This is a simplification, as the distribution is likely to be multi-modal, reflecting different lighting technologies (e.g., incandescent versus fluorescent). The high value for vacant buildings is likely an error in the literature data (DOE 2002). Schedule diversity factors listed in Table C-27 were developed by iteration to obtain better agreement between the models and Navigant's data for lighting energy use by attempting to correct for differences in schedules.

Table C-26 Interior LPD Assignments

PBA Code	PBA Name	Mean LPD (W/ft^2)	Standard Deviation (W/ft^2)	Mean LPD (W/m^2)	Standard Deviation (W/m^2)
1	Vacant	2.1	0.14	22.6	1.51
2	Office/professional	1.8	0.12	19.4	1.29
4	Laboratory	1.7	0.11	18.3	1.22
5	Nonrefrigerated warehouse	1.4	0.09	15.1	1.01
6	Food sales	1.9	0.13	20.5	1.37
7	Public order and safety	1.3	0.09	14.0	0.93
8	Outpatient health care	1.7	0.11	18.3	1.22
11	Refrigerated warehouse	1.4	0.09	15.1	1.01
12	Religious worship	1.4	0.09	15.1	1.01
13	Public assembly	1.4	0.09	15.1	1.01
14	Education	1.8	0.12	19.4	1.29
15	Food service	1.6	0.11	17.2	1.15
16	Inpatient health care	1.7	0.11	18.3	1.22
17	Skilled nursing	1.3	0.09	14.0	0.93
18	Lodging	1.3	0.09	14.0	0.93
25	Retail (except malls)	1.9	0.13	20.5	1.37
26	Service (except food)	1.7	0.11	18.3	1.22
91	Other	1.7	0.11	18.3	1.22

Table C-27 Interior Lighting Schedule Diversity Factors

PBAPLUS8 Code	PBAPLUS Name	Schedule Diversity Factor
1	Vacant	1.0
2	Administrative/professional office	0.923
3	Bank/other financial	0.923
4	Government office	0.923
5	Medical office (nondiagnostic)	0.923
6	Mixed-use office	0.923
7	Other office	0.923
8	Laboratory	0.695
9	Distribution/shipping center	1.0
10	Nonrefrigerated warehouse	1.0
11	Self-storage	1.0
12	Convenience store	0.876
13	Convenience store with gas station	0.876
14	Grocery store/food market	0.876
15	Other food sales	0.876
16	Fire station/police station	0.627
17	Other public order and safety	0.627
18	Medical office (diagnostic)	0.962
19	Clinic/other outpatient health	0.962
20	Refrigerated warehouse	0.573
21	Religious worship	0.972
22	Entertainment/culture	0.779
23	Library	0.779
24	Recreation	0.779
25	Social/meeting	0.779
26	Other public assembly	0.779
27	College/university	0.773
28	Elementary/middle school	0.773
29	High school	0.773
30	Preschool/daycare	0.773
31	Other classroom education	0.773
32	Fast food	1.0
33	Restaurant/cafeteria	1.0
34	Other food service	1.0
35	Hospital/inpatient health	0.680
36	Nursing home/assisted living	0.529
37	Dormitory/fraternity/sorority	0.565
38	Hotel	0.565
39	Motel or inn	0.565
40	Other lodging	0.565
41	Vehicle dealership/showroom	0.963
42	Retail store	0.963
43	Other retail	0.963
44	Post office/postal center	0.963

PBAPLUS8 Code	PBAPLUS Name	Schedule Diversity Factor
45	Repair shop	0.943
46	Vehicle service/repair shop	0.943
47	Vehicle storage/maintenance	0.943
48	Other service	0.943
49	Other	0.839

C.16 Infiltration Rate

Very few data are available for determining appropriate infiltration rates to use in modeling. Persily (1998) reviewed literature with measured data about a combined total of 139 commercial buildings and concluded that commercial buildings are not tighter than residential buildings. Although the data set is minimal and not formulated from a suitable random sample, he also concluded that there is little evidence to support the notion that age and type of construction affect airtightness.

In this study, infiltration rates are modeled using a simple method based on constant air change rates over time. Annual average air change rates are modeled by combining a flow rate per exterior area with a whole-zone air change rate.

The bulk of the infiltration is attributed to leaks in the thermal envelope. However, infiltration rates for commercial buildings are characterized at relatively high pressure differences of 75 Pa. In this study, we generated flow rate per area values for annual average conditions by scaling values for 75 Pa to the flow for 4 Pa using the usual relationship $\frac{\dot{V}}{A} = C\,\Delta P^{n}$ using a flow exponent $n = 0.65$.

For the assignments in this study, we assumed a leakage rate of 0.4 (cfm/ft^2) at 75 Pa. This value is a factor of 4 lower than the mean value of 1.67 (cfm/ft^2) at 75 Pa reported by Persily (1998), but is used here as a continuous, annual average leakage rate for a constant infiltration model (rather than a flow that will actually vary over the course of the year). This value was scaled to a rate of 0.0002677 m^3/s/m^2 at 4 Pa. The preprocessor used to generate the individual EnergyPlus input files uses this value with a calculation of the exterior envelope area and produces an annual average air change rate for each zone.

The whole-zone air change is applied to all zones regardless of their proximity to the envelope. The magnitude of the whole zone component was assigned, by assumption, by taking 10% of a randomly assigned level determined using a lognormal probability distribution for infiltration found by Chan (2006). Chan's modeling study found infiltration rates in the commercial sector to have a lognormal distribution with geometric mean of 0.35 and a geometric standard deviation of 2.1 (see Figure 5-22 in Chan 2006).

Once the set of buildings has been simulated, we can compare the distribution of air change rates in the models to distribution obtained by Chan. This comparison is provided in Figure 4-14.

C.17 Exterior Lighting

An exterior lighting load is assigned for illuminating the building's facade based on Table 9.4.5 in ASHRAE 2004a. The entire perimeter of the building at ground level is illuminated at the minimum power density of 0.5 W per linear foot (1.64 W per linear meter). No parking lot or garage lighting is included in the analysis. This tends to yield relatively low values for exterior lighting loads because many existing buildings have much less efficient lighting than that specified in Standard 90.1-2004. These assignments need to be improved and the Navigant study (DOE 2002) may be useful.

C.18 HVAC Systems

The HVAC systems are modeled in EnergyPlus by using system types that are available for modeling in the EnergyPlus-based framework and attempting to follow as many of the CBECS variables as is practical. The first step is to determine if the building has heating and/or cooling using :

- Percent cooled (COOLP8)
- Percent heated (HEATP8).

Figure C-3 shows the distribution of CBECS data for percent cooled and heated. The most common response is 100% of the building cooled and heated. The next most common response is 0% of the building heated or cooled. For this study, we made the important simplification that buildings are either completely conditioned or not conditioned at all; the determination is made separately for heating and cooling. This simplification is very helpful for the following reasons:

- There is no way to determine which portion of a building is or is not conditioned.
- The preprocessor cannot yet generate EnergyPlus models where only some of the zones are conditioned.

We assumed that buildings that are more than 25% conditioned (COOLP8>25; HEATP8>25) were entirely conditioned, and those with 25% or less were not conditioned. The 25% level was chosen arbitrarily after inspecting the data in Figure C-3. The models can also be only cooled or only heated.

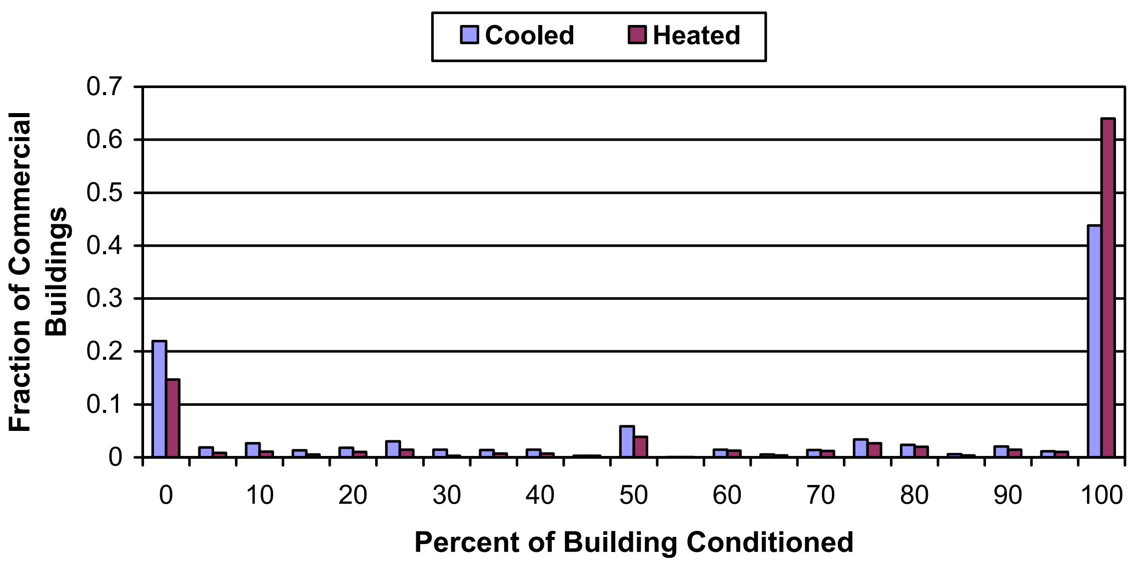


Figure C-3 Analysis of Percent Cooled and Heated Data (PDF for COOLP8 and HEATP8)

The next important variables used to assign a type of HVAC system to the model are the main cooling type (MAINCL8) and the main heating type (MAINHT8). Figure C-4 shows the joint probability distribution for these two variables. Table C-28 shows a matrix of the number of buildings in 2003 CBECS data set with the various combinations of values for MAINCL8 and MAINHT8. Table C-29 shows similar data but with the filtering applied that screens out if the percentage of conditioned floor is less than 25%.

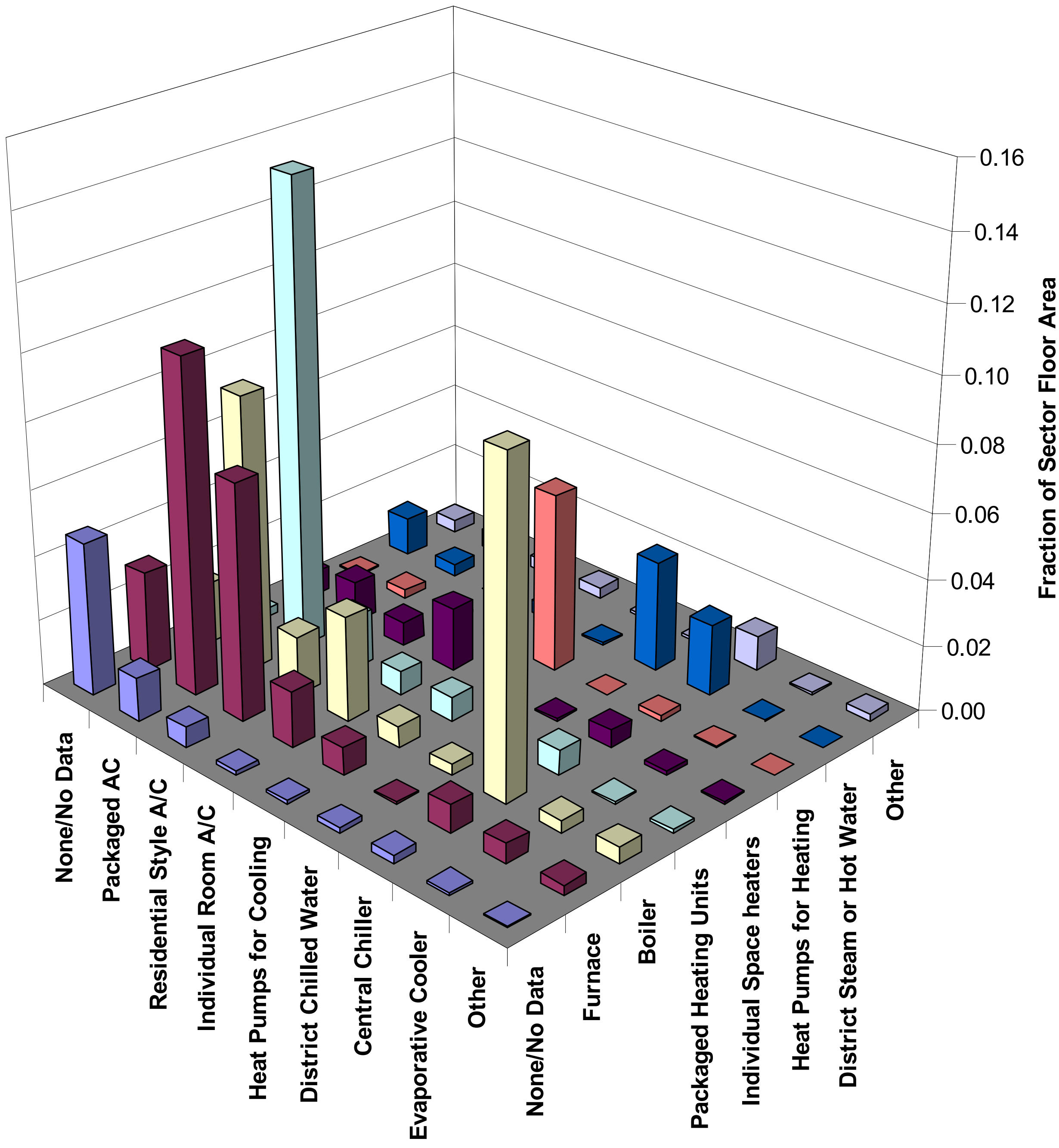


Figure C-4 Joint Discrete PDF for MAINCL8 and MAINHT8 (Raw; All Buildings Regardless of Percent Conditioned)

Table C-28 Number of Buildings for Each Combination of MAINCL8 and MAINHT8 (Raw Data, All)

	None	Furnace	Boiler	Packaged Heating Units	Individual Space Heaters	Heat Pumps for Heating	District Steam or Hot Water	Other
None	233	149	92	19	44	3	18	25
Packaged A/C	59	538	328	727	58	14	17	27
Residential style A/C	29	412	84	100	36	4	3	13
Individual room A/C	11	97	141	29	126	13	13	20
Heat pumps for cooling	7	35	22	20	4	317	2	6
District chilled water	4	4	14	7	2	0	145	3
Central chillers	13	23	434	26	14	6	85	36
Evaporative coolers	5	30	17	5	6	2	1	4
Other	1	7	13	4	2	0	1	11

Table C-29 Number of Buildings for Each Combination of MAINCL8 and MAINHT8 (Filtered for COOLP8 and HEATP8>25%)

	None (and HEATP8<25)	Furnace	Boiler	Packaged Heating Units	Individual Space Heaters	Heat Pumps for Heating	District Steam or Hot Water	Other
None (and COOLP8<25)	0	136	88	18	29	3	18	22
Packaged A/C	44	458	263	664	32	12	13	21
Residential style A/C	23	351	73	78	27	4	3	8
Individual room A/C	8	57	73	20	99	13	9	12
Heat pumps for cooling	7	26	20	15	1	300	1	3
District chilled water	12	4	13	7	2	0	145	3
Central chillers	4	22	431	23	14	5	83	36
Evaporative coolers	1	28	12	5	3	2	1	3
Other	0	6	12	3	0	0	1	9

Each combination of possible values for MAINCL8 and MAINHT8 are assigned a HVAC system type. Table C-30 shows the mappings from MAINCL8 and MAINHT8 to a HVAC system type identified by number. The numbers shown in Table C-30 correspond to the HVAC systems listed in Table C-31. Fifty-two system topologies were identified and implemented for analysis.

Table C-30 Mappings from MAINCL8 and MAINHT8 to Number of HVAC System as Modeled (Listed in Table C-31)

	None	Furnace	Boiler	Packaged Heating Units	Individual Space Heaters	Heat Pumps for Heating	District Steam or Hot Water	Other
None	0	19	29	30	31	32	37	21
Packaged A/C	24	3	5	3	22	4	38	6
Residential style A/C	21	9	16	9	23	10	17	9
Individual room A/C	15	11	12	13	14	4	18	14
Heat pumps for cooling	35	33	1*	33	34	2*	36	2*
District chilled water	34	20	40	41	42	0	43	39
Central chillers	45	25	7	26	27	28	44	8
Evaporative coolers	46	47	48	49	50	51	52	47
Other	24	3	7	3	14	2	43	7

* Modeled as air source heat pumps

Table C-31 Modeled HVAC System Configurations with Mappings to CBECS Variables

Sys No.	Name	Distribution	Main Components	Mech. Vent	CBECS Variable Sets (MAINHT8, MAINCL8)
1	PTAC air source	Multi-zone hydronic loop, zone PTAC	Boiler, air-to-air DX cooling, hot water coil	yes	(2,4)
2	PTHP air source	Single-zone air	Water to air or air to air coil heat/cool	yes	(5,4), (5,8)
3	PSZ-AC	Single-zone air	DX coil, gas coil, const fan	yes	(1,1), (3,1), (1,8), (3,8)
4	PSZ-HP	Single-zone air	DX coil cool/heat, const fan	yes	(5,1), (5,3)
5	Packaged VAV w/reheat	Multi-zone air	DX coil, VAV fan, boiler, hot water VAV boxes	yes	(2,1)
6	Packaged VAV w/PFP boxes	Multi-zone air	DX coil, VAV fan, fan-powered induction boxes, electric reheat	yes	(7,1)

Sys No.	Name	Distribution	Main Components	Mech. Vent	CBECS Variable Sets (MAINHT8, MAINCL8)
7	VAV w/Reheat	Multi-zone air	AHU, CW coil, hot water coil, VAV fan, chiller, boiler, hot water VAV boxes	yes	(2,6), (2,8), (7,8)
8	VAV w/PFP boxes	Multi-zone air	AHU, CW coil, hot water coil, VAV fan, chiller, fan-powered induction boxes, electric reheat	yes	(7, 6)
9	Residential forced air	Single-zone air	DX coil, gas coil, const fan	no	(1,2), (3,2), (7,2)
10	Residential heat pump	Single-zone air	DX coil heat/cool, const fan	no	(5,2)
11	Window A/C w/forced air furnace	Single-zone air, zone cool	Gas coil, const fan; zone window A/C	no	(1,3)
12	Window A/C w/hot water baseboards	Multi-zone hydronic heat; zone cool	Boiler, pump, hot water baseboards, window A/C	no	(2,3)
13	Window A/C; unit heater	Zone cool, zone heat	Window A/C, unit heater	no	(3,3)
14	Window A/C; electric baseboards	Zone cool, zone heat	Window A/C, electric baseboards	no	(4,3), (7,3), (4,8)
15	Window A/C	Zone cool	Window AC	no	(0,3)
16	Residential forced air cooling, hot water baseboards	Single-zone cool, multizone hydronic heat	DX coil, const fan, boiler, pump, hot water baseboards	no	(2,2)
17	Residential forced air w/district hot water	Single-zone air; multi-zone hydronic loop	DX coil, const fan; purchased hot water, hot water baseboards	no	(6,2)
18	Window A/C w/district hot water	Zone cool, multi-zone hydronic loop	Window A/C, purchased hot water, hot water baseboards	no	(6,3)
19	Forced air furnace	Single-zone air	Gas coil, const fan	yes	(1,0)
20	Forced air furnace, district chilled water fan coil	Single-zone air; mult-izone hydronic chilled water	Unit heater/ventilator with gas coil; 4-pipe fan coils; purchased chilled water	yes	(1,5)
21	Residential A/C (no heat)	Single-zone air	DX coil, const fan	no	(0,2)
22	PSZ-A/C w/electric baseboards	Single-zone air; zone heat	DX coil, const fan; zone electric baseboards	yes	(4,1)
23	Residential A/C w/electric baseboards	Single-zone air; zone heat	DX coil, const fan; zone electric baseboards	no	(4,2)

Sys No.	Name	Distribution	Main Components	Mech. Vent	CBECS Variable Sets (MAINHT8, MAINCL8)
24	PSZ-AC (no heat)	Single-zone air	DX coil, const fan	yes	(0,1), (1,8)
25	VAV w/gas reheat	Multi-zone air	AHU, cold water coil, gas coil, VAV fan, chiller,	yes	(1,6)
26	VAV w/zone unit heaters	Multi-zone air, zone heat	AHU, cold water coil, gas coil, VAV fan, chiller, single duct, zone unit heater	yes	(3,6)
27	VAV w/electric baseboards	Multi-zone air, zone heat	AHU, cold water coil, VAV fan, chiller, single duct, electric baseboards	yes	(4,6)
28	VAV cool with zone heat pump heating	Multi-zone air; zone heat	AHU, cold water coil, VAV fan, chiller, single duct, packaged hep	yes	(5,6)
29	Hot water baseboards	Multi-zone hydronic heat	Boiler pump, hot water baseboards	no	(2, 0)
30	Unit heaters	Zone heat	Unit heaters	no	(3, 0)
31	Electric baseboards	Zone heat	Electric baseboards	no	(4,0)
32	Heat pump heating	Single-zone air	DX coil heating, const fan	yes	(5,0)
33	PTAC with gas coil heat	Single-zone air	Air-to-air cool, gas coil heat	yes	(1,4), (3,4)
34	PTAC w/electric baseboards	Single-zone air, zone heat	Air-to-air cool, electric baseboards	yes	(4,4)
35	PTAC (no heat)	Single-zone air	Air-to-air cool	yes	(0,4)
36	PTAC w/district hot water	Multi-zone hydronic loop, single zone air, zone heat	Air-to-air cool, purchased hot water, hot water baseboard	yes	(6,4)
37	District hot water baseboards	Multizone hydronic loop	Purchased hot water, hot water baseboards	no	(6,0)
38	PSZ-AC w/district hot water	Single-zone air, multizone hydronic loop	DX coil, const fan, purchased hot water, hot water baseboards	yes	(6,1)
39	District chilled water fan coil	Multi-zone hydronic chilled water	4-pipe fan coil; purchased chilled water	no	(0,5)
40	Fan coil, district chilled water and boiler	Multi-zone hydronic chilled and hot water	4-pipe fan coil, boiler; purchased chilled water	no	(2,5)
41	Fan coil district chilled water, unit heaters	Multi-zone hydronic chilled water	4-pipe fan coil cooling, unit heater; purchased chilled water	no	(3,5)

Sys No.	Name	Distribution	Main Components	Mech. Vent	CBECS Variable Sets (MAINHT8, MAINCL8)
42	Fan coil district chilled water, electric baseboards	Multi-zone hydronic chilled water; zone heat	4-pipe fan coil cooling, electric baseboards; purchased chilled water	no	(4,5)
43	Fan coil, district hot and cold water	Multi-zone hydronic	4-pipe fan coil, purchased chilled water, purchased hot water	no	(6,5), (7,5)
44	Fan coil, District hot water and chiller	Multi-zone hydronic	4-pipe fan coil, chiller, purchased hot water	no	(6,6)
45	Fan coil chiller	Multi-zone hydronic	4-pipe fan coil, chiller	no	(0,6)
46	Direct evap cooler	Single-zone cool	Direct evap cooler	yes	(0,7)
47	Forced air furnace, direct evap cooler	Single-zone air	Gas coil, direct evap cooler	yes	(1,7), (7,7)
48	Hot water baseboards, direct evap cooler	Single-zone air, zone heat, multi-zone hydronic	Boiler, direct evap cooler, hot water baseboards	yes	(2,7)
49	Direct evap cooler, unit heaters	Zone heat, single-zone air	Direct evap cooler, gas unit heater	yes	(3,7)
50	Electric baseboards, direct evap cooler	Zone heat, single-zone air	Direct evap cooler, electric baseboards	yes	(4, 7)
51	Heat pump heating, direct evap cooler	Single-zone air	DX coil heating, const fan, direct evap cooler	yes	(5, 7)
52	District hot water baseboards, direct evap cooler	Multi-zone hydronic loop, single-zone air	Purchased hot water, hot water baseboards; direct evap cooler	yes	(6,7)

Once the basic topology of the HVAC system has been determined, the next step is to determine certain details for performance levels and optional features. The CBECS variable for economizer cycle (ECN8) is available to determine whether the system has an economizer. We assume that no economizer cycle is possible if the value of ECN8 is 0. If the building has an economizer cycle but the system type mappings do not call for mechanical ventilation, an outside air system was added to the system topology. Economizer cycle (ECN8):

- 0 no data—assumed no economizer, or not operating
- 1 yes
- 2 no

For these buildings, we assumed outside air systems have gravity dampers that would open when the equipment ran by setting the minimum outdoor air fraction to 1.0 during unoccupied hours via EnergyPlus schedules.

The components performance levels used within each system are discussed in the next section.

C.19 HVAC Components

This section discusses the performance parameters that need to be defined for each component in the HVAC system, including efficiency, coefficient of performance (COP), static pressure, and ventilation rates. In general, we would expect these to be complicated functions of the type of system and component, capacity, age, and maintenance history of the equipment. The age and maintenance situation are modeled from the results of the 2003 CBECS variables:

- HVAC equipment upgrade (RENHVC8). We assume this is already represented in the type of equipment present.
- Main cooling equipment replaced since 1990 (NWMNCL8).
- Main heating equipment replaced since 1990 (NWMNHT8).
- Regular HVAC maintenance (MAINT8).

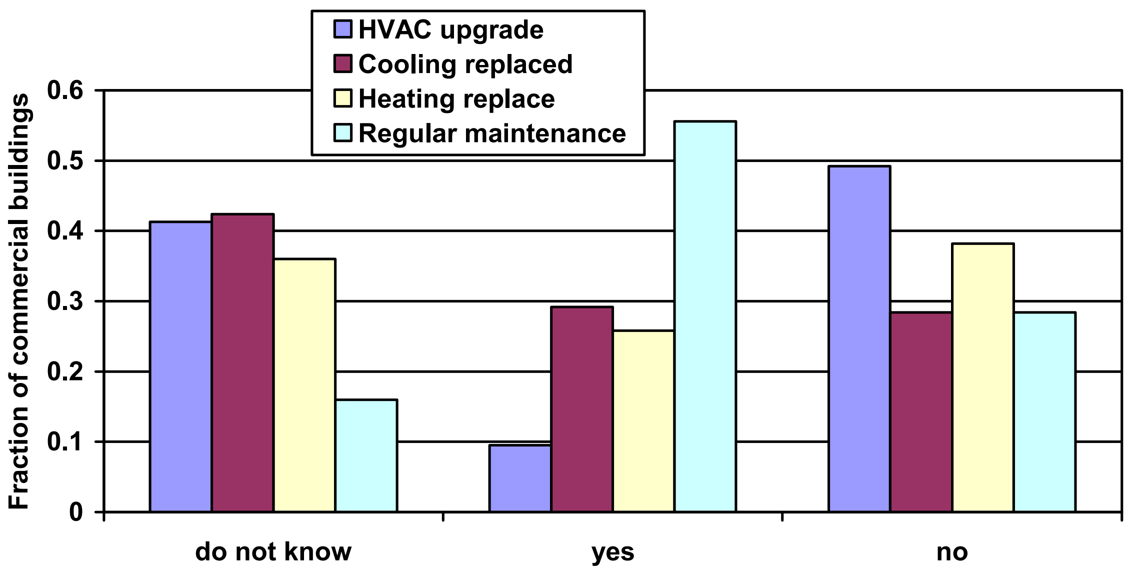


Figure C-5 Discrete PDFs for 2003 CBECS Variables: HVAC Upgraded, Cooling Replaced, Heating Replaced, Maintenance (Raw; All Building Regardless of Percent Conditioned)

The rest of this section documents details for how the performance parameters were modeled for various HVAC components.

COP values from Table C-32 and a simple degradation model based on age are used to model DX coil performance. These values are estimated by approximating the trends observed across historical versions of Standard 90.1.

Table C-32 DX Coil COP Values at Time of Initial Installation for Different Size Ranges

Cooling Capacity	Year of Installation			
	pre-1980	1980 to 1990	1990 to 1998	1998 to 2003
Small (< 65 kBtu/h)	2.64	2.72	3.22	3.72
Medium (> 65 kBtu; < 135 kBtu/h)	2.52	2.61	2.72	2.84
Large (> 135 kBtu; < 240 kBtu/h)	2.05	2.40	2.53	2.67
Very large (> 240 kBtu/h)	1.99	2.34	2.48	2.61

The elapsed time and degradation rate, which vary with the value of MAINT8, are used to model the performance degradation in DX coils. If MAINT8 = "no" or "don't know," the performance degrades at a simple rate of 1% per year. If MAINT8 = "yes," the performance degrades at a simple rate of 0.25% per year. These rates are assumptions, and further research is needed to better understand how to model this phenomenon. So, for example, if a medium-size DX coil were installed in 1984 (and not replaced) and not maintained, it would have an initial COP of 2.61 and a modeled COP of 2.61 × (1 - (2003-1984) × 0.01) or a COP of 2.11.

Central Chiller

The initial COP values in Table C-33 and a simple model for performance degradation are used to model the COP of central water-to-water chillers. These values do not include energy consumed by separate heat rejection towers. All central chillers are modeled as water cooled however many, if not most, buildings actually have air-cooled chillers with lower COPs. There is considerable room to improve the modeling of chilled water systems.

Table C-33 Chiller COP Values at Time of Initial Installation for Different Size Ranges

Cooling Capacity	Year of Installation			
	pre-1980	1980 to 1990	1990 to 1998	1998 to 2003
Small (< 150 tons)	3.9	4.1	4.2	4.45
Medium (> 150 tons; < 300 tons)	4.1	4.4	4.6	4.9
Large (> 300 tons)	4.5	4.8	5.0	5.5

The elapsed time and degradation rate, which vary with the value of MAINT8, are used to model the performance degradation in chillers. If MAINT8 = "no" or "don't know," the performance degrades at a simple rate of 1% per year. If MAINT8 = "yes," the performance degrades at a simple rate of 0.25% per year. These rates are assumptions, and further research is needed to better understand how to model this phenomenon.

Boiler

The initial efficiency values in Table C-34 and a simple model for degradation over time are used to model boiler performance in central hot water plant systems.

Table C-34 Boiler Efficiency Values at Time of Initial Installation

	Year of Installation			
	pre-1980	1980 to 1990	1990 to 1998	1998 to 2003
Boiler efficiency	0.7	0.75	0.8	0.83

The elapsed time and degradation rate, which vary with the value of MAINT8, are used to model the performance degradation of boiler efficiency. If MAINT8 = "no" or "don't know," the performance degrades at a simple rate of 0.5% per year. If MAINT8 = "yes," the performance degrades at a simple rate of 0.2% per year. These rates are assumptions, and further research is needed to better understand how to model this phenomenon.

Heat Pump Heating

COP values from Table C-35 and a simple degradation model based on age are used to model air-to-air heat pump heating performance.

Table C-35 Heat Pump COP Values at Time of Initial Installation for Different Size Ranges

Heating Capacity	Year of Installation			
	pre-1980	1980 to 1990	1990 to 1998	1998 to 2003
Small (< 65 kBtu)	2.8	3.0	3.2	3.4
Medium (> 65kBtu; < 135 kBtu)	2.6	2.8	3.0	3.2
Large (> 135 kBtu; < 240 kBtu)	2.5	2.7	2.9	3.1
Very large (> 240 kBtu)	2.4	2.6	2.8	3.0

The elapsed time and degradation rate, which vary with the value of MAINT8, are used to model the performance degradation in heat pump coils. If MAINT8 = "no" or "don't know," the performance degrades at a simple rate of 1% per year. If MAINT8 = "yes," the performance degrades at a simple rate of 0.25% per year. These rates are assumptions, and further research is needed to better understand how to model this phenomenon.

Constant Volume Fan

The initial efficiency values in Table C-36 and a simple model for degradation over time are used to model fan performance in packaged constant volume systems. After reviewing the methodology, we determined that the fan efficiencies are not understood very well and are likely too high.

Table C-36 Constant Volume Fan Efficiency Values at Time of Initial Installation

	Year of Installation			
	pre-1980	1980 to 1990	1990 to 1998	1998 to 2003
Fan total efficiency	0.48	0.52	0.56	0.6

The elapsed time and degradation rate, which vary with the value of MAINT8, are used to model the performance degradation of fan total efficiency. If MAINT8 = "no" or "don't know," the performance degrades at a simple rate of 0.5% per year. If MAINT8 = "yes," the performance degrades at a simple rate of 0.2% per year. These rates are assumptions, and further research is needed to better understand how to model this phenomenon. So, for example, if a fan was installed in 1984 (and not replaced) and not maintained, it would have an initial efficiency of 0.52 and a modeled efficiency of $0.52 \times (1 - (2003-1984) \times 0.005)$ or a total fan efficiency of 0.47.

Variable-Volume Fan

The initial efficiency values in Table C-37 and a simple model for degradation over time are used to model fan performance for variable-speed fans. After reviewing the methodology, we determined that the fan efficiencies were likely too high and lower estimates should be made for future work; these are listed in the "future revision" row.

Table C-37 Variable-Volume Fan Efficiency Values at Time of Initial Installation

	Year of Installation			
	pre-1980	1980 to 1990	1990 to 1998	1998 to 2003
Fan total efficiency	0.55	0.60	0.65	0.7
Future revision	0.20	0.25	0.30	0.35

The elapsed time and degradation rate, which vary with the value of MAINT8, are used to model the performance degradation of fan total efficiency. If MAINT8 = "no" or "don't know," the performance degrades at a simple rate of 0.5% per year. If MAINT8 = "yes," the performance degrades at a simple rate of 0.2% per year. These rates are assumptions, and further research is needed to better understand how to model this phenomenon.

Gas Heating Coil

The efficiency values in Table C-38 and a simple model for degradation over time are used to model gas heating coil performance in packaged constant-volume systems.

Table C-38 Natural Gas Heating Coil Efficiency Values at Time of Initial Installation

	Year of Installation			
	pre-1980	1980 to 1990	1990 to 1998	1998 to 2003
Gas heating coil efficiency	0.7	0.75	0.78	0.8

The elapsed time and degradation rate, which vary with the value of MAINT8, are used to model the performance degradation of gas heating coils. If MAINT8 = "no" or "don't know," the performance degrades at a simple rate of 0.2% per year. If MAINT8 = "yes," the performance degrades at a simple rate of 0.1% per year. These rates are assumptions, and further research is needed to better understand how to model this phenomenon.

C.20 Outside Air Mechanical Ventilation

For the modeling, a rate for outside air ventilation must be determined. This is a minimum rate, and more outside air may be introduced if there is an air-side economizer cycle. The rate is used during sizing routines to account for conditioning outside air when sizing equipment. Additional outside air will be introduced by separate infiltration modeling. If a building's system does not include mechanical ventilation, infiltration will be the only source of ventilation air. When the type of HVAC system selected for the modeling tends to include the components for mechanically ventilating the building, the models include components that bring in outside air. This air is introduced through air systems and generally involves air handling units (AHUs) or rooftop packaged units. The purpose of the outside air is to provide healthy indoor air by gradually purging stale indoor air with outdoor air.

Additional research is needed to fully characterize the ventilation rates for outdoor air; however, efforts to do so have been recorded in the literature. Most such efforts combine mechanical ventilation and infiltration. The modeling in the current study uses a separate method of modeling infiltration (see Section C.16).

Turk et al. (1989) used tracer gas techniques to measure ventilation rates in 38 commercial buildings in the Pacific Northwest. They found mean ventilation rates of 1.5 ACH or 28 l/s·person and provided a breakdown for educational, libraries, small and large offices, and multi-use. We used these results (see Table 2-8) to model ventilation by assuming that the infiltration portion is equivalent to 9.3 l/s·person. We then subtracted this rate for uncontrolled ventilation from the whole-building ventilation rates reported by Turk et al. to assemble the default rates for mechanical ventilation listed in Table C-39. For activity types not covered, we used the mean rate of 28 – 9.3 or 18.8 l/s·person. These rates are generally in excess of the minimum levels specified in ASHRAE Standard 62-2004, except for education, which is close but slightly low. We used the rates listed in Table C-39 as the minimum outside air rates for each type of HVAC system that includes an outdoor air mixer. This method of separating infiltration was developed prior to, and independent of, the infiltration input modeling (see Section C.16). Future efforts to separate out infiltration rates from measured overall rates should use results from the infiltration modeling rather than the crude method here based on l/s·person. Future efforts to measure outside air rates should seek to separate the portion attributed to infiltration or provide form and fabric data sufficient to model infiltration rates in the measured buildings.

Table C-39 Default Outside Air Mechanical Ventilation Rates by PBA

PBA Code	PBA Name	Default Outside Air Rate (cfm/person)	Default Outside Air Rate (l/s·person)	Data Source
1	Vacant	0.0	0.0	assumption
2	Office/professional < 9300 m^2	55.3	26.1	Turk et al. 1989
2	Office/professional > 9300 m^2	45.3	21.4	Turk et al. 1989
4	Laboratory	39.6	18.7	Turk et al. 1989
5	Nonrefrigerated warehouse	10.6	5.0	assumption
6	Food sales	39.6	18.7	Turk et al. 1989
7	Public order and safety	39.6	18.7	Turk et al. 1989
8	Outpatient health care	39.6	18.7	Turk et al. 1989
11	Refrigerated warehouse	4.2	2.0	assumption
12	Religious worship	39.6	18.7	Turk et al. 1989
13	Public assembly	39.6	18.7	Turk et al. 1989
14	Education	13.4	6.3	Turk et al. 1989
15	Food service	39.6	18.7	Turk et al. 1989
16	Inpatient health care	39.6	18.7	Turk et al. 1989
17	Skilled nursing	39.6	18.7	Turk et al. 1989
18	Lodging	39.6	18.7	Turk et al. 1989
25	Retail	39.6	18.7	Turk et al. 1989
26	Service	39.6	18.7	Turk et al. 1989
91	Other	39.6	18.7	Turk et al. 1989

C.21 Service Water Heating

This section describes how service water heating systems were modeled in the study. Hot water is used in commercial buildings for hand washing, cooking, cleaning, showers, etc. 2003 CBECS provides the following qualitative variables related to service water heating (sometimes referred to as domestic hot water):

- Water heating equipment present (WTHTEQ8)
- Large amounts of hot water used (HWTRM8)
- Laundry onsite (LAUNDR8)

- Type of fuel used for water heating
    - Electricity (ELWATR8)
    - Natural Gas (NGWATR8)
    - Fuel Oil (FKWATR8)
    - Propane (PRWATR8)
    - District Hot Water (DHWATR8)
    - District Steam (STWATR8).

Chapter 49 of ASHRAE's 2003 *HVAC Applications Handbook* (ASHRAE 2003) provides limited guidance about service water heating in commercial buildings. This reference is fairly limited, but is the best source of input data identified to date. We used this chapter's recommendations for the quantity of hot water used in commercial buildings, as well as the storage volume and recovery rates. Table C-40 lists the input data based on per-person-per-day. Table C-41 lists the input data for lodging on a per-room basis.

Table C-40 SHW Inputs per Person per Day by PBA: SI Units

PBA Code	PBA Name	Use Rate Value (l/Person·Day)	Storage Value (l/Person)	Water Heating Recovery Rate (ml/s·Person)	Data Source
1	Vacant	0.0	6.0	0.2	Assumption
2	Office/professional	3.8	6.0	0.2	ASHRAE 2003 HVAC Applications
4	Laboratory	38.0	30.0	2.0	Assumption
5	Nonrefrigerated warehouse	2.3	6.0	0.2	Assumption
6	Food sales	19.0	30.0	1.0	Assumption
7	Public order and safety	3.8	6.0	0.2	Assumption
8	Outpatient health care	11.4	18.0	0.6	Assumption
11	Refrigerated warehouse	2.3	5.0	0.2	Assumption
12	Religious worship	1.0	2.0	0.1	Assumption
13	Public assembly	1.0	2.0	0.1	Assumption
14	Education: college	2.3	6.0	0.2	Assumption
14	Education: elementary school	2.3	6.0	0.2	ASHRAE 2003 HVAC Applications
14	Education: high school	6.8	12.0	0.4	ASHRAE 2003 HVAC Applications
14	Education: preschool	2.3	6.0	0.2	Assumption
15	Food service	38.0	60.0	2.0	Assumption
16	Inpatient health care	11.4	18.0	0.6	Assumption
17	Skilled nursing	11.4	18.0	0.6	Assumption
25	Retail	2.3	4.0	0.2	Assumption
26	Service	3.8	6.0	0.2	Assumption
91	Other	3.8	6.0	0.2	Assumption

Table C-41 SHW Inputs per Room per Day for Lodging by PBA: SI Units

PBA Code	PBA Name	Use Rate Value (l/ Room·Day)	Storage Value (l/Room)	Water Heating Recovery Rate (ml/s·Room)	Data Source
18	Lodging: 20 or fewer rooms	75.8	50.0	3.0	ASHRAE 2003 HVAC Applications
18	Lodging: 60 rooms	53.1	50.0	3.0	ASHRAE 2003 HVAC Applications
18	Lodging: 100 or more rooms	37.9	50.0	3.0	ASHRAE 2003 HVAC Applications

C.22 Refrigeration

This energy use category is for commercial refrigeration used for cold storage and display, and does not include residential style refrigerators.

CBECS variables of interest include:

- Refrigeration equipment used (RFGEQP8)
- Number of closed refrigerated cases (RFGCLN8)
- Number of open refrigerated cases (RFGOPN8)
- Number of walk-in refrigeration units (RFGWIN8)

The number of cases and walk-in units is interesting, but we found that developing quantitative descriptions of the refrigeration systems from the data available in CBECS was difficult. We therefore adopted a simple modeling approach and used CEUS data (CEC 2006) listed in Table 2-1 to define refrigeration loads for all buildings that responded that refrigeration equipment was being used (RFGEQP8 = 1). The CEUS data for refrigeration EUI were processed to derive power densities by assuming constant operation year round. The modeling inputs are listed in Table C-42. The refrigeration systems were modeled as an external equipment load rather than the more complex refrigeration component models that are also available in EnergyPlus. This simplification ignores the interactions between refrigeration systems and thermal loads where cooling loads decrease and spaces may be controlled to lower humidity levels to avoid condensation.

Table C-42 Refrigeration Power Densities

PBA Code	PBA	Refrigeration Power Density (W/ft^2)	Refrigeration Power Density (W/m^2)
1	Vacant	0.00	0.0
2	Office/professional < 30,000 ft^2	0.07	0.8
2	Office/professional > 30,000 ft^2	0.06	0.6
4	Laboratory	0.28	3.0
5	Nonrefrigerated warehouse	0.05	0.5
6	Food sales	2.60	28.0
7	Public order and safety	0.06	0.6
8	Outpatient health care	0.08	0.9
11	Refrigerated warehouse	1.53	16.5
12	Religious worship	0.03	0.3
13	Public assembly	0.03	0.3
14	Education	0.06	0.6
15	Food service	1.12	12.1
16	Inpatient health care	0.08	0.9
17	Skilled nursing	0.08	0.9
18	Lodging	0.14	1.5
25	Retail	0.15	1.6
26	Service	0.12	1.3
91	Other	0.10	1.1

C.23 Gas Appliance Intensity

For internal loads powered by natural gas, we adopted a simple modeling approach and used CEUS data (CEC 2006) listed in Table 2-3 to define gas appliance loads for all buildings. The CEUS data for gas appliance EUI were processed to derive mean power densities by assuming constant, year-round operation. The modeling inputs were developed using a Gaussian distribution with the mean and standard deviations varying by PBA as listed in Table C-43. The standard deviations were developed by assuming them to be 1/15 of the mean and may be rather low.

Table C-43 Interior Gas Appliance Intensity Assignments

PBA Code	PBA Name	Mean Power Density (W/ft^2)	Standard Deviation (W/ft^2)	Mean Power Density (W/m^2)	Standard Deviation (W/m^2)
1	Vacant	0.00	0.000	0.05	0.003
2	Office/professional	0.04	0.002	0.40	0.027
4	Laboratory	3.72	0.248	40.00	2.667
5	Nonrefrigerated warehouse	0.00	0.000	0.00	0.000
6	Food sales	0.35	0.023	3.74	0.249
7	Public order/safety	0.09	0.006	1.00	0.067
8	Outpatient health care	0.33	0.022	3.56	0.237
11	Refrigerated warehouse	0.13	0.009	1.44	0.096
12	Religious worship	0.04	0.002	0.40	0.027
13	Public assembly	0.04	0.002	0.40	0.027
14	Education	0.04	0.003	0.43	0.029
15	Food service	5.14	0.342	55.30	3.687
16	Inpatient health care	0.33	0.022	3.56	0.237
17	Skilled nursing	0.33	0.022	3.56	0.237
18	Lodging	0.20	0.014	2.19	0.146
25	Retail (except malls)	0.03	0.002	0.28	0.019
26	Service (except food)	0.22	0.015	2.37	0.158
91	Other	0.09	0.006	1.00	0.067

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14. ABSTRACT *(Maximum 200 Words)*
This report uses EnergyPlus simulations of each building in the 2003 Commercial Buildings Energy Consumption Survey (CBECS) to document and demonstrate bottom-up methods of modeling the entire U.S. commercial buildings sector (EIA 2006). The ability to use a whole-building simulation tool to model the entire sector is of interest because the energy models enable us to answer subsequent “what-if” questions that involve technologies and practices related to energy. This report documents how the whole-building models were generated from the building characteristics in 2003 CBECS and compares the simulation results to the survey data for energy use.

15. SUBJECT TERMS
commercial building; building technology; cbecs; whole-building simulation tool

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