CHAPTER 6. BUILDING ENERGY USE AND END-USE LOAD CHARACTERIZATION

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CHAPTER 6. BUILDING ENERGY USE AND END-USE LOAD CHARACTERIZATION

6.1 INTRODUCTION

The building energy use and end-use load characterization analysis produced energy use estimates and end-use load shapes for commercial unitary air-cooled air conditioners. The energy use estimates enabled evaluation of energy savings from the operation of commercial unitary air-conditioning equipment at various efficiency levels, while the end-use load shapes allowed evaluation of the impact on electricity demand from the operation of commercial unitary air-conditioning equipment. The analysis produced results from a variety of building types in multiple climate locations in order to capture some of the diversity of use, and performance, of commercial unitary air conditioning equipment.

6.1.1 Background

Previous analytic work focused on evaluating cost-effective levels of efficiency for commercial unitary air-cooled air conditioning equipment. The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) Standing Standards Project Committee 90.1 (SSPC 90.1) performed the initial analysis in 1994 that led to the establishment of equipment efficiency levels in ASHRAE Standard 90.1-1999. This analysis focused on two building types (office and retail) situated in 11 climate locations to represent the diversity of climate parameters influencing commercial building energy use. Building simulation results for each of the building types provided the data to calculate full load equivalent operating hours (FLEOHs). Then the SSPC 90.1 members weighted the FLEOH results by construction volume estimates derived from DOE's Commercial Building Energy Consumption Survey (CBECS) data set.

In 1996, the Pacific Northwest National Laboratory (PNNL) performed an independent analysis of efficiency levels of commercial unitary air-conditioning equipment, using an expanded set of seven building types, but retaining the 11 climate locations used by ASHRAE. This work is documented in *Preliminary Findings: Analysis of Commercial Space-Conditioning and Storage Water-Heating Equipment Efficiencies*.[1] In addition to the expanded building types, the analysis used different fundamental assumptions for the building simulations, including the assumptions on the use of economizers and the method of sizing equipment, as well as the scaling of the thermal loads in the simulated buildings to building sizes more representative of the actual building population. Compared to the ASHRAE work, PNNL used different building sizes and weights for each building type. The PNNL used a separate unitary air conditioning system simulator based on a heat pump simulation model developed at Oak Ridge National Laboratory (ORNL) for DOE. This simulator allowed the determination of energy use for the air-conditioning equipment based on various design options that improved air conditioning system efficiency.

A subsequent independent analysis by PNNL in 2000 provided a further evaluation of efficiency levels of commercial unitary air conditioning equipment using the same seven

building types and 11 climate locations, with the exception that Tampa, Florida, replaced Orlando, Florida, in the new climate set. The replacement of Orlando became necessary since Typical Meteorological Year version 2 (TMY2) weather files were used in this analysis and the Orlando weather station is no longer represented in the TMY2 files. The 2000 analysis is documented in *Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment*.[2] Pacific Northwest National Laboratory updated the input assumptions for the building simulations from the 1996 analysis based on projected changes to internal lighting densities resulting from the greater use of electronic ballasts in the marketplace. Pacific Northwest National Laboratory based the lighting densities on projected densities in 2015, and updated its data sources from those used in the 1996 analysis (1992 CBECS) to the 1995 version of the CBECS data set. It used separate simulations to reflect differences in air-conditioning schedules for setback/setup and economizer/no economizer, and weighted the results based on the reported use of setback and economizer systems in the CBECS data set. Finally, it developed commercial unitary air-conditioning equipment energy usage directly from the building simulations, using FLEOHs that were weighted by construction volume and building type.

In each of the three analyses described above, FLEOHs were used to estimate energy use of cooling equipment, using the following equation:

$$AnnualEnergyUse = \frac{FLEOH \times EquipmentCapacity}{Efficiency}$$

The FLEOH is expressed in each of the analyses as the number of annual operating hours at full capacity that a properly-sized particular air-conditioning unit would need to operate to satisfy the annual cooling load of the building.

6.1.2 Methodology Overview

The purpose of the building energy use and load shape characterization analysis is to assess the energy and peak demand savings potential of different equipment efficiencies across the range of commercial building types and climate zones. The 1995 CBECS (CBECS95) data set was the primary source used to develop the assumptions for building characteristics. The Department used six building types: assembly, education, food service, office, retail, and warehouse. The Department chose to analyze buildings that cooled 70 percent or more of the total floor space with air-cooled unitary air-conditioning equipment. Each CBECS building was modeled using the Building Loads and System Thermodynamics (BLAST) program. The Department computed each building's loads by simulating the same prototype three-story, 48,000-square foot (sf) building with five thermal zones per floor. The Department "scaled" the results of that prototype's simulation to match the specific geometry of the CBECS building represented—e.g., conditioned floor area, aspect ratio, number of floors, number of thermal zones per floor. The Department simulated the same buildings at 10 different energy efficiency ratio (EER) levels. The end result was an hourly end-use energy profile of the following:

- air-cooled unitary air conditioning equipment;
- heating;
- lights;
- plug and miscellaneous loads;
- package equipment fan;
- other cooling; and
- other fan.

Figure 6.1.1 is a simplified flow diagram of this process.

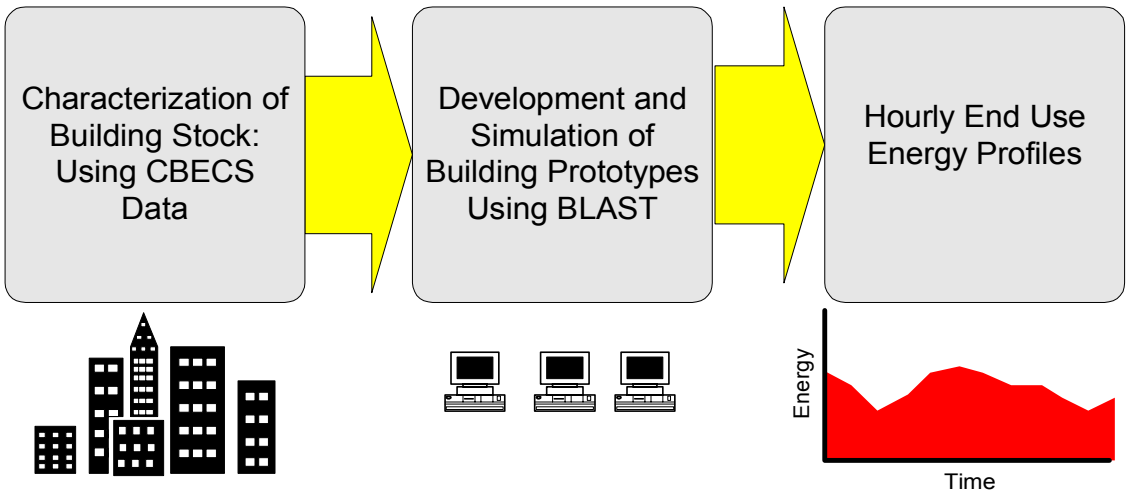

Figure 6.1.1 Flow Diagram of the Load Shape Characterization Process

6.2 ENGINEERING APPROACH

This section describes the engineering approach and assumptions used in the Advanced Notice of Proposed Rulemaking (ANOPR) analysis. It includes discussion of how DOE generated the air-conditioning loads, and descriptions of building types and characteristics, load densities, and operating schedules. There is a presentation of the methodology for assigning TMY2 stations to each of the 1033 buildings used in the analysis. Last, there is discussion of issues related to ventilation, equipment sizing, and economizer use.

6.2.1 Representative Building Types

Consistent with both the preliminary findings[1] and the screening analyses,[2] DOE used a subset of representative building types to characterize the energy use and loads for this analysis. Building types are characterized in CBECS using their reported principal building activity (PBA). The Department identified six building types, made up of a combination of CBECS PBA categories (see Table 6.2.1), based on their significance of energy use. These building types

typically use unitary air-cooled air-conditioning equipment, and the CBECS data set contained sufficient information to characterize the building for modeling purposes. The six building types selected included most of the top eight energy-using building types (with the exception of Health Care and Lodging), based on CBECS data. The Department did not include the inpatient segment of the Health Care building type because there were insufficient data to characterize the buildings for the purpose of energy simulations; however, DOE did include the outpatient segment of Health Care by adding these observations into the Office category, since these buildings could be modeled similar to office buildings. The Department deleted Lodging because the number of observations nationwide was small, and because these types of buildings do not typically use unitary air-conditioning equipment. From a practical standpoint, typical lodging units are usually air conditioned either with incremental units, such as packaged terminal air conditioners (PTACs), or by terminal units connected to a central chilled water system.

The building types selected for analysis were Assembly, Education, Food Services, Office, Retail, and Warehouses (non-refrigerated). The Department further screened the individual CBECS buildings so that only buildings with 70 percent or more of their total floor space air conditioned by unitary air conditioning equipment were included in the representative building set. The Department based its threshold of 70 percent air-conditioned floor space on a need to keep the sample size reasonable, yet representative of the building stock with unitary air-conditioning equipment. A higher threshold (i.e., 90 percent air-conditioned floor space) would have resulted in too small a sample; a lower threshold (i.e., less than 50 percent) would have included buildings with limited unitary air-conditioning equipment for uses that would be problematic in characterizing their loads accurately. The total number of observations in the six building types meeting the 70 percent threshold was 1033. These buildings accounted for over 73 percent of the annual air-conditioning energy use and 67 percent of the square footage of commercial buildings that air condition at least part of their floor space with unitary air-conditioning equipment. The Department built up the building types being used for the EPAct analysis from observations that are categorized in CBECS as PBAs. Table 6.2.1 provides a map of the CBECS PBA to the Energy Policy Act of 1992 (EPAct) Building Category, and accounts for the PBAs that DOE did not use.

Table 6.2.1 ANOPR Building Categories Versus CBECS PBA Categories

EPAct No.	EPAct Building Category	CBECS PBA Code	CBECS Principal Building Activity
1	Assembly (ASM)	13	Public Assembly
2	Education (EDU)	6	Education
3	Food Service (FDS)	15	Food Service (restaurant)
4	Office (OFF)	2 8	Office/Professional Healthcare (outpatient)
5	Retail (RET)	3 23 24 25 26	Mercantile/Services Strip Shopping Enclosed Shopping Center/Mall Retail (except Mall) Service (except Food)
6	Warehouse (WHS)	5	Warehouses (non-refrigerated)
NA	All Other PBAs	1 4 6 7 9 10 11 12 16 17 18 19 20 91	Vacant Laboratory Food Sales Public Order and Safety Industrial Processing/Manufacturing Agricultural Purposes Warehouses (refrigerated) Religious Worship Healthcare (inpatient) Nursing Home Lodging (hotel/motel/dorn) Residential Indoor Parking Garage Other

6.2.2 CBECS Data (1992 and 1995)

The Department used the CBECS95 data set as the primary data source to develop the assumptions for building characteristics for the purpose of modeling; DOE supplemented this with the CBECS92 data set (for window-to-wall ratio and aspect ratio) as well as other sources, when CBECS95 did not contain the needed data for the energy simulations. The CBECS data sets are publicly available and provide statistically valid results from a periodic national survey of commercial buildings and their energy suppliers performed by the U.S. Department of Energy, Energy Information Administration (EIA). The results of the surveys are available as downloadable reports and microdata files from the EIA website (www.eia.doe.gov). The Department did not use CBECS99 data, which are the latest data available, because: 1) the characteristics data were not initially available at the time of the analysis, and 2) there is potential bias in the data because the new survey lacks data for any new buildings smaller than 10,000 square feet—a size category that includes buildings likely to use unitary air-conditioning equipment. The previous CBECS data include characteristic and energy consumption information for buildings 1,000 square feet or more.

6.2.2.1 CBECS Data Used

In the CBECS95 survey, 5,766 buildings were surveyed and the sampled buildings were given base weights (CBECS variable *ADJWT6*) that relate the sampled buildings to the entire stock of commercial buildings in the United States. The DOE analysis used a subset of 1,033 buildings from the 5,766 buildings available. Included in the CBECS data are variables that indicate the percentage of each building that is air conditioned (CBECS variable *COOLP6*), and the percentage of the air-conditioned floor space in each building that is air conditioned by unitary air-conditioning equipment (CBECS variable *PKGCP6*). The buildings chosen for analysis were buildings that air conditioned 70percent or more of their floor space by unitary air-conditioning equipment:

$$(COOLP6*PKGCP6)/100>=70.$$

The Department eliminated from the query a building with a CBECS weight of zero and buildings with PBAs of "Lodging" and "Other." Table 6.2.2 presents a list of the variables used in the characterization process.

Table 6.2.2 CBECS Variables Used in the Characterization Process

Field Identifier	**Description**
BLDGID6	CBECS building identifier
SQFT6	Square footage
ADJWT6	Adjusted weight
YRCON6	Year construction was completed

YRCONC6	Year of construction category
NFLOOR6	Number of floors
PBA6	Principal building activity
VACBA16	First previous/intended activity, used as PBA for vacant buildings
VACP6	Percent vacant
PORVAC6	Space vacant for at least 3 months
REGION6	Census region
CENDIV6	Census division
ZONE11	Expanded census division
CLIMATE6	Climate zone
TEMPAVG6	Average 1995 temperature (F)
TEMPSTD6	Standard deviation of 1995 temperature (F)
CDD656	Cooling degree-days (Base 65 F)
HDD656	Heating degree-days (Base 65 F)
MSA6	Metropolitan statistical area
NWKER6	Number of workers during main shift
WKHRS6	Total weekly hours open
WKHRSC6	Total weekly hours open category
OPNMF6	Typically open Mon. thru Fri.
OPNSAT6	Typically open on Saturdays
OPNSUN6	Typically open on Sundays
LTOHRP6	Percent lit during operating hours
LOHRPC6	Percent lit during operating hours categorical variable (e.g., 0-10%)
LNHRPC6	Percent lit during off-hours category

WKHRS6	Total weekly hours open
MAINCL6	Main equipment used for cooling
COOLP6	Percent cooled in 1995
COOLPC6	Percent cooled in 1995 category
PKGCL6	Packaged cooling [unitary air conditioning] units used
PKGCP6	Percent packaged cooling [unitary air conditioning] units
PCTBLDGPKGD	*Calculated field (COOLP6*PKGCL6)/100*
HTPCP6	Percent cooled by heat pump
HTPMPC6	Heat pump used for cooling
ECN6	Economizer cycle
RFCNS6	Roof construction material
WLCNS6	Wall construction material
RIN6	Roof or ceiling insulation
WIN6	Exterior wall insulation
ELCLBTU6	Electric cooling use (mBtu)
LOADFAC6	Annual load factor
PEAK6	Peak annual load
PEAKS6	Peak summer load
PEAKW6	Peak winter load
SEASON6	Season of peak load

6.2.2.2 Building Characteristics in the 1033 Data Set

For this analysis, it is important that the buildings selected are representative of the entire building stock with unitary air-cooled air-conditioning equipment, and that there are no biases in the building distributions.

Table 6.2.3 shows the number of buildings, total floor area, and total package [unitary air-conditioning] equipment cooling energy reported by CBECS for various building disaggregations. The second number in each cell in rows 3 and 4 (in parentheses) is the percentage relative to the buildings reporting package cooling equipment (row 2).

Table 6.2.3 Characteristics of CBECS Buildings Used in the ANOPR Analysis

	Number of CBECS Observations	Total Floor Space Represented (million sf)	Total Floor Space Cooled with Package Equipment (million sf)	Total Package Cooling Energy (Million Btu)
All CBECS Observations	5,766	58,772	14,171	125,644,225
Buildings reporting package cooling equipment*	2,584	26,516	14,171	125,644,225
Buildings with at least 70% floor space cooled by package equipment*	1,206 (47%)	11,543 (44%)	10,967 (77%)	104,442,780 (83%)
Our six building types meeting 70% threshold	1,033 (40%)	9,914 (37%)	9,441 (67%)	91,426,091 (73%)
* Excluding buildings with no reported energy use				

The total number of observations in DOE's six representative building types meeting the 70percent criteria is 1033. Approximately 70 percent of the 1033 buildings reported 100 percent of the floor space air conditioned by unitary air-conditioning equipment. The six representative building types selected account for over 73 percent of the annual cooling energy use and 67 percent of the square footage of commercial buildings that reported unitary air-conditioning equipment.

Table 6.2.4 shows the relative percentages of the six representative building types in the final sample by number of buildings, floor area, and unitary air conditioner cooling energy consumption. In all three characterizations, retail and office building types are the most prevalent building type.

Table 6.2.5 shows the distribution of building floor area for each of the six building types for the 1033 building set. The buildings were binned by reported building floor area ranges, as shown.

Table 6.2.6 shows the percentage distribution of the CBECS observations by the nine Census divisions. The top number in each cell is the number of buildings from the 1033

building set in that cell. The bottom number is the total number of buildings represented by CBECS in that cell. The region populated with the most buildings is the Pacific (157,511 buildings), followed closely by the South Atlantic region (120,693 buildings) and the West South Central region (120,465 buildings). The two least populated regions are the West North Central region (33,398 buildings) and the New England region (33,480 buildings).

Table 6.2.4 Building Type Distributions in the 1033 Building Set

Building Type	Percentage by Number of Buildings	Percentage by Floor Area	Percentage by Unitary Air Conditioning Energy Use
Assembly	10	8	5
Education	9	10	8
Food Service	14	7	16
Office	35	30	32
Retail	30	42	38
Warehouse	2	3	1
Total	100	100	100

Table 6.2.5 Percentage of Represented Buildings by Floor Area for the 1033 Building Set

Floor Area (sf)	Assembly	Education	Food Service	Office	Retail	Warehouse
≤ 10,000	37%	27	82	27	20	11
10,001 - 20,000	29	15	9	16	15	11
20,001 - 30,000	11	13	2	15	10	8
30,001 - 40,000	8	6	0	8	7	11
40,001 - 50,000	4	5	5	7	4	8
50,001 - 100,000	8	24	2	13	15	24
100,001 - 200,000	3	8	0	6	12	14
200,001- 300,000	0	0	0	2	5	5
300,000 - 400,000	0	1	0	2	2	0
400,001 - 500,000	0	0	0	2	1	3
500,001 - 1,000,000	0	0	0	2	4	6
> 1,000,000	0	0	0	0	4	0
Total	100	100	100	100	100	100

Table 6.2.6 Building Distribution (Percentage) by Building Type and Census Division for the 1033 Building Set (Top Number in Each Cell) and the Total Number of Buildings Represented (Bottom Number).

Census Division	Assembly	Education	Food Service	Office	Retail	Warehouse	Total
East North Central	16 15,329	6 1,458	10 18,189	55 25,599	55 41,563	3 318	145 102,455
East South Central	10 17,638	8 7,651	5 9,586	20 40,070	37 27,012	3 113	83 102,069
Middle Atlantic	9 11,187	8 7,760	5 13,311	36 18,765	36 22,107	4 673	98 73,803
Mountain	7 7,440	7 2,956	2 3,115	23 12,277	12 14,095	0 0	51 39,883
New England	3 6,550	2 298	3 6,440	23 16,003	16 3,775	3 415	50 33,480
Pacific	10 9,552	19 28,765	10 21,685	90 53,792	74 42,070	7 1,647	210 157,511
South Atlantic	10 6,434	18 12,029	7 15,237	62 58,435	89 21,471	11 7,087	197 120,693
West North Central	4 755	3 849	2 3,636	18 9,452	28 18,706	0 0	55 33,398
West South Central	6 2,321	28 9,832	13 20,276	30 39,522	61 42,135	6 6,379	144 120,465
Total	75 77,206	99 71,597	57 111,473	357 273,916	408 232,933	37 16,633	1033 783,758

6.2.2.3 Engineering Database

Modeling commercial buildings and equipment using BLAST required assumptions about the buildings' envelope characteristics, internal loads, occupancy characteristics, and activity schedules. The Department created a database to store the primary set of 1033 buildings and associated characteristics from CBECS95 data, and to integrate this information with other engineering parameters developed for the analysis. The engineering assumptions are discussed in detail in section 7.2.6.

From the database, the Department generated a parameter file (Parm file) of inputs for BLAST. The Parm file consisted of input variables for simulation of each of the 1033 buildings with 10 different EER values, for a total of 10,330 records. Table 6.2.7 shows the parameter values for one of the sample buildings. A unique run identifier traces each record to the CBECS

building identifier, the location of the building, and the EER case being analyzed. Appendix D contains the full set of Parm file values for all of the 1033 buildings for one EER value.

Table 6.2.7 Listing of Parameter File Variables and Sample Values from One Building

Parm File Variable	Sample Value
run_ID	11_ILG_1
wban_number	13781
city	WILMINGTON_DE
bldg_type	ret
sqft_scale	25000
floors_scale	2
WWR	0.04
aspect_ratio_scale	3
wall_const_fyi	Sheet metal panels
roof_R_fyi	19
roof_U	0.051
wall_R_fyi	0
wall_U	1.18
fens_SC	0.94
fens_U	1.13
schedule_name	RET_MFS
months_oper	12
light_power	1.88
equip_power	0.4
people_dens	2.222
vent_peak	0.25
infiltration	0.038
activity_level	0.425
econ	Yes (only when indicated by CBECS dataset)
econ_type	Enth

heat_SPT	70
cool_SPT	75
setback_T	60
setup_T	85
econ_hi_limit	65
base_fan_esp	0.75
fan_power_ratio	0.11
run_type	design
roof_type	builtup
wall_type	metal
EER	8.5
over_sizing_factor	1.182225
pct_cooled_scale	100
pct_pkgd_cooling_scale	100

6.2.3 Overview of Modeling Methodology

Assessing the building energy use at specific equipment efficiency levels requires a sequence of modeling exercises. Figure 6.1.1 shows the process used in this study to estimate the annual energy consumption of the covered equipment at various efficiency levels. This section provides the reader with an overall understanding of the hourly load simulation analysis flow. Each of the process blocks in Figure 6.1.1 is described in more detail elsewhere in this document. This section should help put the more detailed discussions in proper context.

6.2.3.1 Space Air-Conditioning Load Modeling

Assessment of the annual energy use of space air-conditioning equipment at various efficiencies requires knowledge of the building loads of typical building types in various climates. The Department used the following approach, illustrated in Figure 6.2.1, to generate estimates of such loads:

- *Identify a set of cities that adequately represents the diversity of climates in the United States.* The Department based this analysis on simulations of space air-conditioning loads in 157 locations.

- *Evaluate data on existing and new buildings to identify appropriate assumptions regarding building construction (e.g., building type, size, number of floors, insulation levels, window-to-wall ratios [WWRs]).* The Department analyzed data from CBECS92 and CBECS95 to establish these assumptions.[3,4] The Department based the important input assumptions—internal load profiles, occupancy/activity schedules, equipment control schedules, ventilation strategies, and envelope characteristics—on the review of CBECS92 or CBECS95 data and other studies of real buildings. The analysis used a generic 15-zone, three-story prototype building that is common to all building types. The use and justification of the generic building approach is discussed below. See section 6.2.5 for a detailed discussion of the data analyzed.

- *Employ a building energy simulation model to obtain estimates of building air-conditioning loads for each relevant building type in each climate-representative city.* The Department used the BLAST program to calculate the building air-conditioning loads.[5]

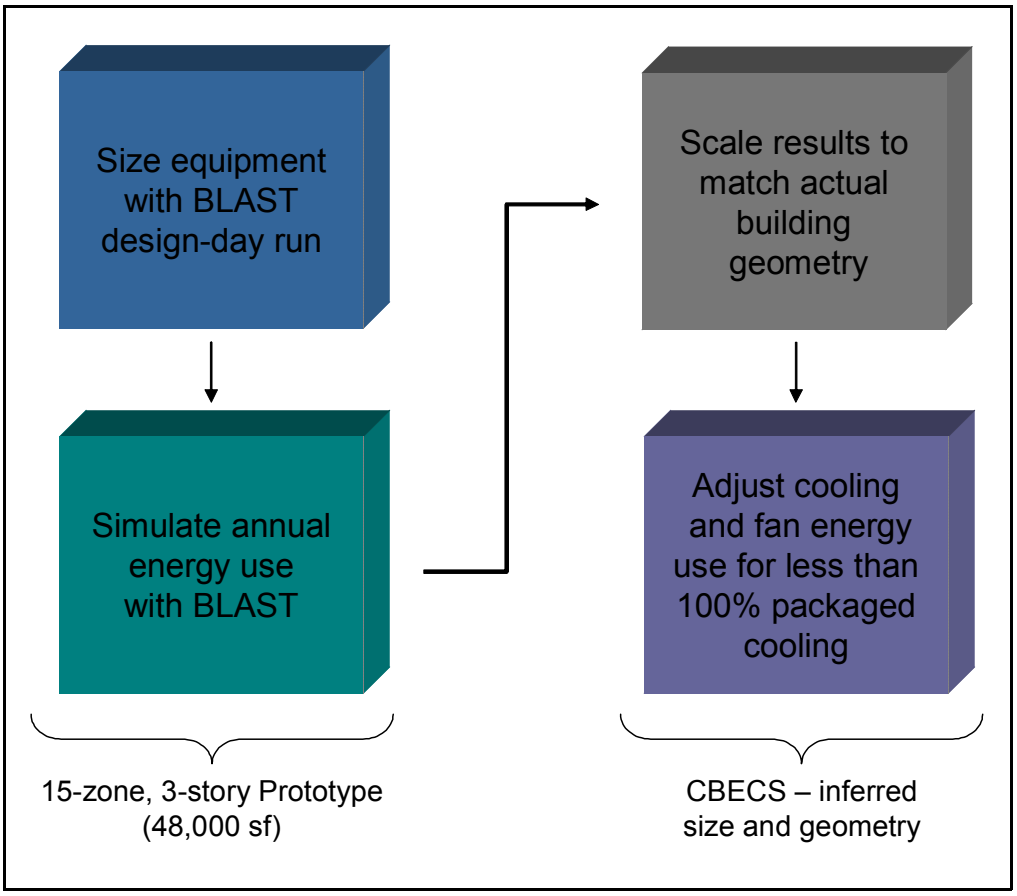

Figure 6.2.1 Simplified Flow Diagram of the Simulation Methodology

6.2.3.2 The Three-Story Prototype Building Model

The Department simulated the cooling coil loads and the building energy use using the BLAST hourly simulation tool,[5] and performed the simulations using a generic building model with fixed geometry. The generic building model is a three-story, 48,000 ft^2 building with 15 separate thermal zones (four perimeter zones and one core zone for each floor). The perimeter zones have a 15-ft depth and the building model uses a fixed 1:1 aspect ratio.

Because of the extreme diversity in building size, shape, and other characteristics, even within a particular building type category, it is generally difficult to identify a single prototype building that is adequately representative of the geometry for the stock of buildings under analysis. In this analysis, DOE transformed the loads and energy use for systems defined with the generic building's geometry to provide loads and energy use for an actual CBECS building used for the analysis. This is because the analysis reported in this document requires development of system loads representative of loads that would be experienced by unitary equipment in a diversity of actual applications, not system loads from a specific building.

The three-story, 15-zone generic building captures all the important zone types of the relevant building class. The three-story prototype has a ground level, a roof level, and an intermediate level. Buildings with more than three stories can be represented by multiplying the middle-floor loads of the generic prototype. Further, each floor is represented by a core zone (i.e., a zone that has no exterior walls or windows) and a perimeter zone facing each of the cardinal directions. System loads for buildings with greater or lesser perimeter-to-core area ratios can be developed by properly weighting the loads and energy use for the prototype building's zones. Buildings with more wall area facing one direction than others (i.e., buildings with non-square aspect ratios) can be represented by scaling or weighting the generic building zone loads to emphasize the dominant orientation(s).

Properly characterizing system loads from large classes of buildings requires eliminating any orientation biases, because the actual building stock is oriented more or less randomly. Some analysts have approached this problem by simulating a square prototype with equal glazing area facing each cardinal direction. However, most real buildings are not square and loads based on a square prototype will improperly weight the influences of internal gains and external weather on building loads. Another approach is to simulate a building with a realistic aspect ratio in each of several orientations. This approach, of course, greatly increases the effort to obtain the load estimates. A benefit of using the 15-zone prototype and properly weighting the zone loads and energy use is that non-square buildings can be represented with a proper balance of internal load and external (weather) drivers without arbitrarily biasing the results toward a particular solar orientation. Because the building stock is more or less randomly oriented, to eliminate any bias from the solar gains, zone load from all perimeters must be equally weighted while perimeter-versus-core influence is adjusted to match the desired aspect ratio.

6.2.4 Development of Equipment Efficiency Levels

The Department based the efficiency levels chosen for the simulations on assumptions appropriate for the unitary air-conditioning equipment being analyzed. Two important baselines to be analyzed were: 1) the current minimum manufacturing standard energy efficiency levels, as established under Energy Policy and Conservation Act (EPCA) legislation, and 2) the minimum energy-efficiency standards set forth by the updates to ASHRAE 90.1-1999—below which, by statute, DOE cannot set standards.

In addition, DOE analyzed two system capacities: 65,000–135,000 Btu/hr cooling capacity air-cooled unitary air conditioners and 135,000–240,000 Btu/hr cooling capacity air-cooled unitary air conditioners. The Department considered minimum efficiencies mandated by EPCA and by ASHRAE, for both equipment capacities, to be important base efficiency levels to be analyzed in the rulemaking.

The maximum efficiency analyzed in the rulemaking was an EER of 12 for both equipment size categories. As of July 2002, the were no EER 12 products in these size categories in the Air-Conditioning and Refrigeration Institute (ARI) directories of certified equipment. However, there were products with an EER of 11.8 in the 65,000–135,000 Btu/h capacity category, and products with an EER of 11.5 in the 135,000–240,000 Btu/h capacity category. Because these represent the high end of the existing market, DOE particularly examined these EER levels.

To fill in the intermediate efficiency levels, between the baseline products and the high-efficiency products currently available, the Department set efficiencies at 0.5 EER increments (i.e., 10.0, 10.5, 11.0, 11.5). The Department analyzed all efficiencies above the ASHRAE 90.1-1999 level for each equipment capacity category at these increments, up to 12.0 EER. Table 6.2.8 shows the EER increments simulated and the equipment capacities to which they applied.

Table 6.2.8 EER Levels Selected for Building Simulations

Efficiency Case	EER Level	Source	Used in Energy Analysis	
			65-135 kBtu/h	135-240 kBtu/h
1	8.5	EPCA minimum for 135-240 kBtu/h		x
2	8.9	EPCA minimum for 65-135 kBtu/h	x	
3	9.5	ASHRAE 90.1-1999 minimum for 135-240 kBtu/h		x
4	10.0	0.5 EER increment		x
5	10.1	ASHRAE 90.1-1999 minimum for 65-135 kBtu/h	x	x
6	10.5	0.5 EER increment	x	x
7	11.0	0.5 EER increment	x	x
8	11.5	Highest reported EER for 135-240 kBtu/h	x	x

9	11.8	Highest reported EER for 65-135 kBtu/h	x	x
10	12.0	0.5 EER increment	x	x

6.2.5 Engineering Assumptions

This section documents the methodologies and key assumptions used in generating the engineering input parameters required for building load simulations, for buildings for which characteristics data were not directly available from CBECS95 or other sources.

6.2.5.1 Development of Building Envelope Characteristics

The Department assumed that the base building to be simulated was of slab-on-grade construction with a flat, built-up roofing system. Built-up roofs represent the most common type of roof used in commercial buildings, based on the CBECS95 survey data. The Department inferred the remainder of the building envelope characteristics, starting from the CBECS95 data.

Table 6.2.9 shows the variables in CBECS95 that describe the building envelope characteristics.

Table 6.2.9 Building Envelope Characteristics Variables in CBECS95 Survey

CBECS95 Variable	CBECS Description	Values
WLCNS6	Wall Construction	Window/vision glass Decor/construction glass Sheet metal panels Pre-cast concrete panels Masonry Siding/shingles/shakes No one major type Don't know Not ascertained
RFCNS6	Roof Construction	Wooden materials Slate or tile Singles (not wood) Built-up Metal surfacing Single/multiple ply Concrete roof No one major type Other Refused Don't know Not ascertained
RIN6	Roof or Ceiling Insulation (presence of)	Inapplicable Yes No Refused Don't know Not ascertained
WIN6	Wall Insulation (presence of)	Inapplicable Yes No Refused Don't know Not ascertained
STW6	Storm Windows or Doors	Inapplicable Yes No Refused Don't know Not ascertained
TRG6	Tinted or Reflective Glass	Inapplicable Yes No Refused Don't know Not ascertained

Wall Insulation Levels. The description of the wall construction and roof construction variables in CBECS95 primarily describes the surface material for these portions of the building envelope and not the actual construction. The Department made inferences about whether the construction represented structural masonry construction or frame wall construction. Different methods of insulation are commonly used for these two types of wall construction.

There are few other studies of wall and roof insulation characteristics in existing commercial buildings. The Department identified two studies. The first was a 1986 Pacific Gas & Electric survey of on-site construction characteristics in existing buildings in California. The results of this survey are reported in Akbari et al.[6] The second study was a review of commercial building characteristics undertaken in 2000 by New Jersey Electric and Gas Utilities to understand typical construction and renovation practices in their service area.[7] This study observed building characteristics for a large number of newly constructed buildings and a smaller number of building retrofits, and provided the frequency of occurrences for different wall and roof R-values (thermal resistance values) from those observations. The study showed the predominance of three insulation levels—R-6, R-11, and some R-19—for wall insulation, and the predominance of R-19 or R-20 levels for roof insulation in new construction or retrofit cases. Because the of the way the data are reported, neither study clearly indicates the likelihood of an R-0 (uninsulated) roof or wall insulation level. Unfortunately, the New Jersey Electric and Gas Utilities study did not clearly define the type of construction in the binning process.

The Department reviewed these studies but, because of their localized nature, it recognized that it would be difficult to categorize either of their results as representative of U.S. construction practices.

Given the unavailability of national data, the Department chose a simplified strategy for determining wall and roof insulation levels that would capture some diversity without over-complicating the analysis. The Department chose the wall and roof insulation levels as follows.

- For frame wall construction, if the individual building data in the CBECS95 survey reported that wall insulation was present in the building, DOE assumed the wall insulation to be an R-11 equivalent. R-11 is believed to be the most common R-value historically for standard frame wall construction, since its thickness was designed to fill wall cavities created by standard 3.5-inch wall construction.

- For structural masonry-type construction, there are three common alternatives for wall insulation. The first is some type of continuous insulation (e.g., foam sheet) placed on the wall surface, over which is placed some type external protective covering (e.g., stucco). The second is some type of fibrous batt-type insulation that would be pinned to the interior wall surface. This type of insulation would commonly be framed by a non-structural wall inside the space, commonly with only an inch or two of cavity thickness. The third method of insulation involves the construction of a standard 3.5-inch, non-structural, wood or metal frame, which is placed on the inside surface to provide a cavity for insulation. Once this 3.5-inch cavity is constructed, it generally makes economic sense to fill the cavity with standard fibrous insulation. The cavities created in the second

and third alternatives would typically have an interior wall surface, such as gypsum board, for aesthetic reasons. Combinations of cavity and continuous insulation exist, but DOE did not consider these for this analysis.

For this analysis, the Department assumed that there was a 50 percent probability that wall insulation on a masonry-type wall would be an R-6 level (representing the equivalent of approximately 1.5 inches of continuous foam or a 2-inch pinned insulation batt) and a 50 percent probability that it would be an R-11 level (representing a standard 3.5-inch insulation batt). The Department did not examine higher insulation levels.

The R-value of the wall insulation does not completely describe the thermal performance of the wall. In addition, DOE used the data on wall construction to determine the additional impact of the balance of the wall assembly. The Department categorized each of the construction types in CBECS95 as either mass, metal frame, wood frame, or metal building. It estimated the probability that a given CBECS construction would fall into each of these categories, as shown in Table 6.2.10.

Table 6.2.10 Categorization of CBECS Wall Construction Data

	Generic Construction Category			
WCNS6 Category	**Metal Frame**	**Wood Frame**	**Masonry**	**Metal Building**
	Assumed probability of being in generic construction category			
Sheet metal panels	0%	0%	0%	100%
Masonry	0%	0%	100%	0%
Window/vision glass	100%	0%	0%	0%
Decorative/construction glass	100%	0%	0%	0%
Pre-cast concrete panels	0%	0%	100%	0%
No one major type	25%	25%	25%	25%
Other	50%	50%	0%	0%
Siding/shingles/shakes	50%	50%	0%	0%

The Department assumed that the balance-of-assembly R-values for each generic assembly included air films on both the interior and exterior surfaces, gypsum board on the interior surface, and, for the metal and wood frame wall, 5/8-inch siding material. For the metal building-type construction, DOE assumed only a sheet metal layer on the building exterior. For masonry buildings, DOE assumed an external surface layer of brick.

The Department based the overall wall U-factor (thermal transmission factor) for each generic construction category and wall insulation level on wall assembly U-factors shown in Appendix A of ASHRAE 90.1-1999. These U-factors are shown in Table 6.2.11.

Table 6.2.11 U-Factors for Wall Insulation Levels by Construction Category

Wall Insulation R-Value (hr-sf-F/Btu)	Generic Construction Category			
	Metal Frame	Wood Frame	Masonry	Metal Building
	Overall U-factor used in Analysis (Btu/hr/ft^2/°F)			
0	0.352	0.292	0.580	1.180
6	NA	NA	0.129	0.184
11	0.124	0.096	0.079	0.123
19	0.109	0.067	0.048	0.070

Roof Insulation. Built-up roofs can be constructed with essentially any insulation level desired. Insulation is most commonly applied to the upper roof surface, but may also be found hung at the underside of the roof deck or, less commonly, applied to the topside of a suspended ceiling. For this analysis, DOE assumed that all roofs reported as insulated by CBECS had the equivalent of R-19 insulation, corresponding to an overall U-factor of 0.051 Btu/hr/ft^2/°F. The Department identified this as the single most common level.

Window Characteristics. The window characteristics of concern for the energy analysis are primarily the overall window U-factors and the window shading coefficient (SC). These characterize the performance of the windows in the building once the window-to-wall ratio has been established. The Department did not try to characterize the performance of awnings or separate window shading devices for this analysis, since CBECS does not indicate the size or shading value of projections, nor the use of internal movable shading devices such as Venetian blinds.

The CBECS95 data set contains information on whether windows in the building use tinted or reflective glass or other shading films (CBECS95 variable *TRG6*), whether storm windows or doors are used (CBECS95 variable *STW6*), and whether either internal or external shading devices or awnings are present (CBECS95 variable *AWN6*).

A detailed look at variable *STW6* in the original survey indicates that this variable represents the use of storm windows, storm doors, thermal pane glass, or double- or triple-pane glass. Very little triple-pane glass is used in commercial building in the U.S. For this analysis, if other-than-single pane glazing was reported used in the building (CBECS variable *STW6* = "Yes"), DOE characterized the building windows as double-pane glazing.

The degree of tinting in tinted windows is unknown from the CBECS data. For this analysis, DOE characterized any reference to tinting as equivalent to standard gray- or green-tinted glass. These represent the most common commercial glass tints in use. [8]

An important step in estimating both the U-factor and the SC for glazing is determining whether a low-emissivity (low-e) surface is used in the glazing. This attribute is not

characterized by the CBECS95 data, and would typically be found only in newer construction (post 1980), or in replaced windows. Current estimates are that approximately 20 percent of the glazing sold for commercial buildings has low-e coating. [8] Virtually all of this low-e coated glass is dual-pane to ensure longevity of the low-e coating. For this analysis, DOE assumed a linear growth for the commercial low-e glass market, from an initial product availability in 1985 through providing 20 percent of the double-pane market in 2000. Table 6.2.12 shows the Department's estimates of the probability of any double-pane window constructed between 1985 and 1995 having a low-e coating.

Table 6.2.12 Estimated Fraction of Low-E Glass in Commercial Fenestration

Year of Construction	Low-E Fraction
1985	1.2%
1986	2.4%
1987	3.5%
1988	4.7%
1989	5.9%
1990	7.1%
1991	8.2%
1992	9.4%
1993	10.6%
1994	11.8%
1995	12.9%

Because low-e glazing generally helps to reduce heating loads in a building, the Department assumed that it is not used in the southernmost climate zone identified by CBECS (>2000 cooling degree-days (CDD), <4000 heating degree days (HDD). The result of the application of this approach resulted in only a few percent of the buildings actually modeled having low-e glazing.

The CBECS information with respect to the presence of awnings provided virtually no detail on the size or shading capability of awnings. Because no other source of information on this capability could be identified, DOE did not address this variable in this analysis.

The Department created a table of U-factor and SC combinations for each possible occurrence of tinted glass or multi-pane windows. It assigned the presence of low-e coatings on multipane glazing using a probability curve based on the market fractions for low-e glazing reported in Table 6.2.12. Table 6.2.13 shows the selected U-factor and SC combinations.

Table 6.2.13 Window U-Factor and Shading Coefficient Combinations

Multipane	Tinted or reflective glass	Low-E	Assumed Characteristics		
			Window U-Factor	Window SC	Glass Type
Yes	Yes	Yes	0.59	0.48	Double Glazed, Grey Tint, e=0.10, 1/4inch space, SHGC=0.42
Yes	Yes	No	0.69	0.54	Double Glazed, Heat Absorbing, 1/4inch space, SHGC=0.47
Yes	No	Yes	0.59	0.57	Double Glazed, Clear, e=0.10, 1/4inch space, SHGC=0.50
Yes	No	No	0.69	0.8	Double Glazed, Clear, 1/4inch space, SHGC=0.70
No	Yes	No	1.13	0.68	Single Glazed, Heat Absorbing, SHGC 0.59
No	No	No	1.13	0.94	Single Glazed, Clear, SHGC 0.82

6.2.5.2 Window-Wall Ratio

The Department assigned a WWR to each of the 1033 buildings, using a random assignment based on a weighted distribution derived from the CBECS92 data set for each of the six building categories. The first weighted random assignment determined which WWR bin was assigned to the building. The second random assignment determined the actual WWR assigned to the building.

No information on the WWR was available in the CBECS95 data. However, in the CBECS92 data, a "percent glass on exterior" variable was reported for each building in one of the five bins shown below:

- 10 percent or less
- 11–25 percent
- 26–50 percent
- 51–75 percent
- 76 –100 percent

The Department extracted an equivalent 1033-building set from the CBECS92 database, using the same criteria as it did in generating the 1033-building set from the CBECS95 data. Using this new building set, DOE determined the frequency of occurrence of WWRs for each building type. It used these as a proxy for the WWR bin frequency in the 1995 building set. The Department based the frequency of occurrence of each building type in each of the WWR bins on the total adjusted building weight (total number of buildings represented by the CBECS building). It further differentiated three of the PBAs by building size because there was an

observed difference in WWR between large and small buildings for those building types. The Department defined the breakpoint between small and large buildings as the building size associated with the median of the cumulative frequency distribution of CBECS92 building weights, ordered by building size for each building type. The median size is 6,000 ft^2 for education and office buildings, and 4,500 ft^2 for retail buildings.

Table 6.2.14 shows the weights developed from the CBECS92 data for each WWR bin by building type and size category. After DOE assigned the WWR bin to each building, it used a second weighted random assignment to assign a specific WWR value within each of the WWR bins. Table 6.2.15 shows the second set of weights for this assignment.

Table 6.2.14 Assigned WWR Weight for Each PBA in the 1995 Building Set

Building Type	WWR Bin				
	10%	11-25%	26-50%	51-75%	76-100%
Assembly	0.73	0.19	0.04	0.04	0.00
Education > 6000sf	0.43	0.41	0.14	0.02	0.00
Education ≤ 6000sf	0.68	0.20	0.12	0.00	0.00
Food Service	0.44	0.27	0.22	0.07	0.00
Office > 6000sf	0.39	0.30	0.19	0.08	0.04
Office ≤ 6000sf	0.57	0.24	0.17	0.02	0.00
Retail > 4500sf	0.46	0.26	0.26	0.02	0.00
Retail ≤ 4500sf	0.57	0.24	0.17	0.02	0.00
Warehouse	0.88	0.08	0.04	0.00	0.00

Table 6.2.15 Weights for Random Assignment Within Each WWR Bin

WWR Bin	Assigned WWR	Weight
10% or less	0%	0.00
	2%	0.10
	4%	0.15
	6%	0.20
	8%	0.25
	10%	0.30
11-25%	15%	0.33
	20%	0.34
	25%	0.33
26-50%	30%	0.20
	35%	0.20
	40%	0.20
	45%	0.20
	50%	0.20
51-75%	55%	0.20
	60%	0.20
	65%	0.20
	70%	0.20
	75%	0.20
76-100%	80%	0.50
	85%	0.30
	90%	0.15
	95%	0.05
	100	0.00

6.2.5.3 Aspect Ratio

The Department randomly assigned an aspect ratio to each of the CBECS buildings to be modeled, based on a weighted distribution derived from the CBECS92 data for each of the six building categories. The Department further split the Retail and Office buildings into a small and large category at 4500 ft^2 and 6000 ft^2, respectively, using the criteria described previously for WWR assignments.

The Department calculated the actual aspect ratio for the CBECS92 data from the reported length and width of the building. The CBECS92 buildings were also classified as "Rectangle" or "Rect/Square with Courtyard." The Courtyard buildings did not have the length and width reported. The CBECS95 data did not report either the building length and width or whether it was a courtyard building or not.

The aspect ratio is defined as the reported building length divided by the building width:

$$AspectRatio = \frac{BuildingLength}{BuildingWidth}$$

Appendix E contains data on the frequency of occurrence of the reported aspect ratio for each of the 18 bins for each of the six building types. Table 6.2.16 shows the total adjusted floor area for each of the building types.

For those buildings assigned a courtyard aspect ratio, DOE calculated the aspect ratio using the procedures described in Appendix F.

The Department compared the distribution of aspect ratios for different-size buildings to identify any differences due to building size. It found a notable difference in the Education, Retail, and Office PBAs. The Department used the same size breakpoint that it used in the WWR ratio to divide these building types into small and large categories.

Table 6.2.16 Total Building Adjusted Floor Area for each Building Type and Aspect Ratio Bin (Millions of Square Feet)

Aspect Ratio Bin	Aspect Ratio Range mm	ASM	EDU	FDS	OFF-Lg	OFF-Sm	RET-Lg	RET-Sm	WHS
1.0	< 1.05	58.7	18.0	114.5	231.4	21.4	282.4	29.1	0
1.1	≤ 1.05 to < 1.15	13.8	0	12.8	28.8	18.1	61.0	1.7	0
1.2	≤ 1.15 to 1.25	0	4.1	10.5	61.7	0	5.2	10.1	21.4
1.3	≤1.25 to 1.35	44.0	74.5	49.9	232.4	8.3	94.4	29.6	0
1.4	≤1.35 to 1.45	39.7	0	62.4	72.8	60.1	174.5	3.8	0
1.5	≤1.45 to 1.55	27.5	30.2	25.3	166.1	7.2	181.8	0	0
1.6	≤1.55 to 1.65	0.8	85.2	6.8	5.1	17.1	60.6	9.8	0
1.7	≤1.65 to 1.75	1.7	34.6	0	93.1	123.4	151.6	7.8	81.6
1.8	≤1.75 to 1.85	99.6	0	0	0	0	159.1	0	0
1.9	≤1.85 to 1.95	0	45.6	0	16.8	90.3	58.9	0	0
2.0	≤1.95 to 2.05	89.8	4.2	47.9	197.9	56.7	385.7	7.3	59.0
2.33	≤2.05 to 2.75	87.7	83.0	87.9	401.3	99.7	640.2	17.4	5.2
3.0	≤2.75 to 3.25	66.5	1403	91.7	192.0	25.7	215.5	9.0	7.8
3.5	≤3.25 to 3.75	7.5	19.7	9.8	113.2	0	295.8	1639	4.8
4.0	≤3.75 to 4.25	14.7	81.0	24.3	50.2	15.4	203.0	17.8	5.8
4.5	≤4.25 to 4.75	104.9	0	0	72.7	1.6	176.6	21.5	0
5.0	≤4.75 to 5.25	4	24.5	31.8	33.9	15.8	22.9	11.5	0
10.0	≤5.25 to 15.5	162.5	315.3	70.4	197.3	2.9	345.9	14.2	55.0
20.0	≤15.5 to 25.5	13.4	62.5	0	214.8	1.6	187.6	0	22.4
30.0	≤25.5 to 35.5	1.9	9.3	0	11.3	0	119.6	0	41.7
40.0	≤35.5	0	0	0	0	0	95.0	0	0

6.2.5.4 Schedules and Load Densities

Modeling the commercial buildings and equipment using the BLAST simulation tool[5] required assumptions about the buildings' internal loads, key envelope characteristics, occupancy characteristics, and ventilation rates, and the heating, ventilating, and air-conditioning (HVAC) and service water-heating (SWH) equipment operation schedules. This section describes the building characteristics that DOE used to estimate the loads for the representative building types selected for the technical analysis.

For heating and cooling equipment, the annual energy use is primarily a function of the heating or cooling loads the equipment must meet. These loads can vary by hour of the day, day of the week, and time of the year. The variations are driven by factors such as the

type of building in which the equipment is installed, the activities and internal loads (lighting, occupant, and receptacle loads) in the building, and the building's internal and external environmental conditions, ventilation rates, and HVAC control strategy.

Lighting and Plug Load Profiles. Lighting and plug loads represent a significant fraction of building internal loads for many representative building types. Typically, these loads are represented by a peak power density (in watts per square foot or watts per conditioned zone being modeled) and a profile that describes the hourly magnitude with respect to the peak (as shown in Figure 6.2.2). These profiles are typically "hat-shaped" with a "crown" representing the peak period and a "brim" representing the off-hours (base-load). In between the "crown" and "brim" is a transition period representing the period between when the light and plug loads first start to increase and when these loads are fully "on" during the "crown" period. The significant characteristics of the profile are the duration of the "crown," the duration of the transition period, and the relative magnitude of the off-hour "brim" with regard to the peak.

The peak load and profile are unique for each building, but much similarity exists for buildings of the same type and occupancy. While each building is unique, building performance researchers often choose a representative description of the lighting and plug loads for simulation purposes. In the energy-efficiency standards arena, ASHRAE's SSPC 90.1 has developed several typical profiles for use in their energy cost budget (ECB) compliance method, which estimates the annual energy consumption of a design building. These profiles, while not representative of any particular building, reflect the professional judgment of the members of the committee about the appearance of plug and light profiles for various building types. This judgment is influenced by another major source of information: metered data from individual buildings. These data are available from several sources and are usually collected by utilities or government agencies for use in energy conservation and demand-side management programs. Some of them are discussed below.

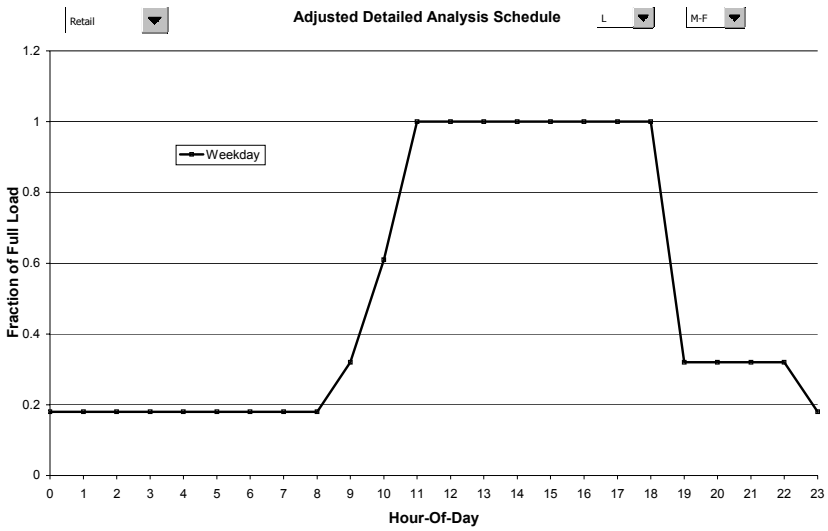

Figure 6.2.2 Typical Lighting Schedule for a Retail Store Open Monday Through Friday

The End-Use Load and Consumer Assessment Program (ELCAP) developed profiles from metered data for several commercial building types.[9, 10, 11] Taylor and Pratt (1989)[10] provide average profiles for several building types, Taylor (1992)[9] provides more detailed average information for five building types, and Taylor and Pratt (1990)[11] provide similar information for individual retail and office buildings. Kasmar (1992)[12] provides useful profile information for several building types. Metering the DOE Headquarters Building by the Federal Energy Management Program (FEMP) provided plug and light profiles for this building, as documented in Halverson et al (1994).[13]

The lighting and plug load profiles in Standard 90.1-1989 (ASHRAE 1989a) were modified through ASHRAE's addenda process. ASHRAE's proposed Addendum 90.lj to Standard 90.1-1989 (referred to as "Addendum 90.1j") revises several simulation profiles by increasing the magnitude of off-hour loads. The modified ASHRAE load shapes were the basis for the previous screening analysis work[2] and, therefore, are the basis for this analysis, as well as for the six representative building types.

For the screening analysis,[2] PNNL developed lighting and equipment load profiles from the profiles recommended by ASHRAE for each of the building types considered. Where metered data were available,[11] PNNL used observed peak and base loads to scale the profiles to reflect loads observed in "real" buildings. For the details on how the profiles were adjusted using the peak and base loads, refer to the screening analysis report.[2]

For this analysis, the peak densities remained unchanged compared to the Screening Analysis. However, DOE adjusted the profiles as necessary to the duration of "on" periods to reflect typical occupancy patterns observed in the CBECS data.[3, 4]

Building Schedules. The lighting, plug load, HVAC, and occupancy schedules in a building differ widely by building type. Although there could be some variations in schedules within the same class of buildings, for this analysis DOE used an average schedule to represent a single building type. The analysis of the CBECS95[4] database indicated that there are five distinct building schedules: (1) open 24 hours a day and seven days a week (24/7); (2) open business hours Monday through Friday; (3) open business hours Monday through Saturday; (4) open business hours Monday through Friday and Sunday; (5) open business hours all week. The Department computed the average number of hours a building is open each week by further analyzing the CBECS95 database for each of the five schedule types. These hours are tabulated in Table 6.2.17. The Department also computed the number of buildings in each of the five schedule categories by building type; these are listed in Table 6.2.18.

Table 6.2.17 Number of Hours a Building is Open Each Week

Building Type	**24/7 (247)**	**Monday-Friday (M-F)**	**Monday - Friday and Saturday (MFS)**	**Monday - Friday and Sunday (MFU)**	**Monday - Friday and Saturday and Sunday (ALL)**
Assembly	168	45	49	36	83
Education	168	48	79	49	71
Food Service	168	77	88	NA	91
Office	168	48	61	45	86
Retail	168	45	59	NA	80
Warehouse	168	48	63	94	84

Table 6.2.18 Number of Sample Buildings in Each Schedule Category

Building Type	**24/7 (247)**	**Monday-Friday (M-F)**	**Monday - Friday and Saturday (MFS)**	**Monday - Friday and Sunday (MFU)**	**Monday - Friday and Saturday and Sunday (ALL)**
Assembly	1	15	9	5	35
Education	1	70	11	5	8
Food Service	3	2	7	NA	41
Office	40	202	92	3	10
Retail	30	8	76	NA	277
Warehouse	6	19	5	2	1
Total	86	316	202	15	372

Adjustment of Modified ASHRAE Profiles. Using the modified ASHRAE profiles used for the screening analysis work[2] and the number of hours the buildings are open each week (see Table 6.2.17), DOE generated new profiles for lighting, plug loads, and occupancy. The steps followed in the adjustment process are listed below:

- First, DOE estimated the number of hours the building is open each day. For example, the total number of open hours for the schedule category "ALL" is 100. The number of hours the building is open each day is estimated by dividing 100 by 7 (number of days in the "ALL" category), which equals 14.2. The Department rounded the result off to the nearest hour—in this example, the result is 14. For this schedule category, the building must be open 14 hours a day to meet the weekly open hours.

- Second, because it was adjusting pre-existing profiles, DOE selected a schedule threshold value (possible values between 0 and 1.0) to be used in determining whether the building was open. A schedule threshold is defined as a level or value above which the schedule is considered "open" and counted toward the number of hours the schedule is "open."

- Third, DOE chose the start time (i.e., when the building is occupied). In almost all cases, DOE used the start times from the modified ASHRAE profiles.

- Fourth, DOE estimated the number of open hours using the threshold value established in the second step by counting the hours when the schedule threshold was exceeded. If the number of hours was greater than the hours established in the first step, DOE stretched the modified ASHRAE profile to provide longer hours of operation; for fewer hours of operation, DOE shrunk the profile.

Appendix G contains tables of the schedule profiles for each of the six building types and five schedule types.

Lighting Densities. The lighting peak power densities were identical to the values used for the screening analysis.[2] Because of the importance of lighting energy in commercial building loads and the rapid changes in lighting technology, DOE based the lighting peak densities on a projection of future lighting power. This section provides a brief description of how DOE established those values.

For each representative building, DOE estimated the lighting density the building would use in the year 2015. The Department derived the year 2015 lighting power density estimates using a combination of interior space type lighting models and estimated future lighting technology and application trends. This combination allowed the estimates to be based on individual components of a lighting power density (design elements, technologies, and application where known) rather than an escalation of any existing power density values.

A major input in developing the 2015 estimates was the estimated market shares of electronic and magnetic fluorescent lamp ballasts in 2015. The Department developed these

estimates using the national energy savings (NES)[1] model with a 2027 base case. The Department used the ballast model and an internal Lawrence Berkeley National Laboratory (LBNL) spreadsheet, developed to supplement the NES, to run energy-efficiency standards scenarios to estimate magnetic ballast shipments. The Department assumed that the 2027 base scenario covered renovated buildings whose magnetic ballasts would be removed at a fixture turnover rate of once every 16 years. In accordance with the LBNL spreadsheet, DOE added to the electronic ballasts in the existing stock a number of new magnetic ballasts each year, as projected by the NES model; this number goes to zero by a certain year under the standard. The Department assumed that the new building growth rate would be 1.07 percent per user; it based this assumption on projections of historical commercial and industrial floor space (including Federal buildings) from 1980 to 2030, and data developed by building type by Regional Economic Research, Inc. (RER), San Diego, California.[14]

The results show that, by 2015, magnetic ballasts are likely to make up 30 percent of the total fluorescent lamp ballast market under the anticipated standards. Fluorescent lamp systems represent 77 percent of lighted floor space, according to CBECS95.[3]

The interior space models used in this derivation were the same as those developed for the ASHRAE Standard 90.1-1999 lighting standards. Lighting design professionals and practitioners consider these models to represent good quality and innovative lighting design. Although these models do not represent the mix of existing building lighting designs, interest in good quality design and human factor effects of the workplace environment are expected to dominate much of the building stock by 2015. By 2015, a portion (estimated up to 16 percent) of the building stock will consist of new buildings constructed with these design elements in mind. Further, a larger portion of the existing building stock is expected to be retrofitted with partially- or fully-redesigned lighting. This redesign would be primarily caused by replacing degraded 15+ year-old systems, and building redesigns for other purposes, such as new tenants and changing building space functions.

The ASHRAE Standard 90.1-1999 lighting standard models also include specific characteristics appropriate for year 2015 estimation. These models incorporate the upper range of energy-efficient equipment and ignore equipment that is generally on the trailing edge of the market as it is replaced with newer, more efficient, and upgraded versions. The models use the current leading-edge T8 fluorescent lamp technology as the basis for all linear fluorescent applications. The current trend in the development of smaller, cheaper, better compact fluorescent lamp (CFL) products could lead building lighting design and retrofits toward the application of CFLs in most previous incandescent applications. The models automatically incorporate compact fluorescent technology wherever it is possible to replace incandescent systems. The models also incorporate halogen lamps as replacements for incandescent lamps, and small metal halide lamps as replacements for some fluorescent lamp applications where appropriate (e.g., retail buildings).

The Department did not consider the impact of building lighting controls. Because the installed wattage would not change, no data existed to support an estimate of the impact of

lighting controls on overall HVAC system performance. The HVAC systems would likely be designed for the full (undimmed) lighting load.

Table 6.2.19 lists the lighting power densities used for the six representative building types. Brief descriptions of the profiles and the power densities follow.

Table 6.2.19 Peak Lighting Power Densities for Each of the Six Building Types

Building Type	**Power Density (W/ft^2)**
Assembly	1.59
Education	1.45
Food Service	1.75
Office	1.32
Retail	1.88
Warehouse	1.19

Building Type: Assembly

Discussion of Profile: Assembly includes museums, dance halls, auditoriums, gymnasiums, sports facilities, and churches. The assumed assembly building lighting profile is hat-shaped, with a peak lighting integrity in 2015 estimated at 1.59 watts per square foot (W/ft^2). Metered data were not available for this building type.

Building Type: Education

Discussion of Profile: Education includes school buildings. The typical school building lighting profile is hat-shaped. Usually, the lights are either all on or all off in a school building. Note that school buildings include elementary schools that may be expected to operate from 8 a.m. to 5 p.m., secondary schools that may have significant extracurricular activities at night, and colleges and universities that may have evening classes. This building type is highly varied.

Measured peak load estimates range from 0.9 W/ft^2 to 2.3 W/ft^2, with most estimates falling between 1.4 W/ft^2 and 2.3 W/ft^2. Off-hour base-load estimates range from 0 W/ft^2 to 0. 1 W/ft^2, with 0. 1 W/ft^2 providing a representative average. The estimated peak lighting intensity in the year 2015 was 1.45 W/ft^2.

Building Type: Food Service

Discussion of Profile: The typical restaurant building lighting profile is hat-shaped, with all lights either on or off. The lights are on when food is being served. Obviously, a 24-hour restaurant will have a much different profile than a lunch counter that serves only breakfast and lunch.

Measured peak-load estimates range from 1.2 W/ft^2 to 2.0 W/ft^2. Off-hour base-load estimates range from 0.14 W/ft^2 to 0.8 W/ft^2. The estimated peak lighting intensity in the year 2015 was 1.75 W/ft^2.

Building Type: Office

Discussion of Profile: The typical office building lighting profile is the classic hat shape, with a single peak period occurring for most of the working day and a lower off-hour period. The peak period is typically six to ten hours in duration. A transition period between the peak and off-hour period is typically one to three hours, depending on occupant behavior and lighting control schemes. Office buildings are typically active Monday through Friday, with minimal activity on Saturdays and even less on Sundays.

Measured peak working day estimates range from 0.7 W/ft^2 to 1.9 W/ft^2, with most of the estimates falling in the range of 1.3 W/ft^2 to 1.5 W/ft^2. The base off-hour load estimates range from 0 W/ft^2 to 0.6 W/ft^2, with most metered estimates in the range of 0.2 W/ft^2 to 0.4 W/ft^2. The estimated peak lighting intensity in the year 2015 was 1.32 W/ft^2.

Building Type: Retail

Discussion of Profile: The typical retail building lighting profile is hat-shaped. Usually, the lights in a retail building are on if the business is open and off if the business is closed. The peak period is typically 10 hours in duration. Retail buildings are typically active all days of the week, with reduced hours on Sundays.

Peak lighting load estimates range from 1.1W/ft^2 to 2.9 W/ft^2, with metered results tending to fall in the lower part of the range. Off-hour base-load estimates range from 0 W/ft^2 to 0.3 W/ft^2, with metered data indicating 0.1 W/ft^2 to 0.3 W/ft^2. The estimated peak lighting intensity in the year 2015 was 1.32 W/ft^2.

Building Type: Warehouse

Discussion of Profile: The typical warehouse building lighting profile is hat-shaped. Usually, the lights in a warehouse are on if the business is open and off if the business is closed. Weekends show minimal loads.

The peak load estimates range from 0.4 W/ft^2 to 0.7 W/ft^2, with most values falling near 0.6 W/ft^2. Off-hour base-load estimates range from 0 W/ft^2 to 0.2 W/ft^2, with 0.1 W/ft^2 representing a suitable average. The estimated peak lighting intensity in the year 2015 was 1.19 W/ft^2.

Plug Load Densities. The plug load power densities for six representative building types are shown in Table 6.2.20, and a brief description of the profiles and the power densities follow.

Table 6.2.20 Peak Plug Load Power Densities for Each of the Six Building Types

Building Type	Power Density (W/ft^2)
Assembly	0.19
Education	0.48
Food Service	1.20
Office	0.64
Retail	0.40
Warehouse	0.15

Building Type: Assembly

Discussion of Profile: The typical assembly building plug load profile is hat-shaped.

Metered data were not available for this building type. The assumed peak and off-hour base loads for the screening analysis were 0.19 W/ft^2 and 0.01 W/ft^2, respectively.

Building Type: Education

Discussion of Profile: The typical education building plug load profile is hat-shaped.

Because the sample size for metered data was very small, the proposed Standard 90.1-1999 profiles and associated peak and off-hour base loads were used for the screening analysis. The peak and off-hour base loads for the screening analysis were 0.475 W/ft^2 and 0.01 W/ft^2, respectively.

Building Type: Food Service

Discussion of Profile: The typical food service building plug load profile is hat-shaped. Obviously, a 24-hour restaurant will have a much different profile than a lunch counter that serves only breakfast and lunch.

The screening analysis used the ASHRAE peak and off-hour base-load values. The peak and off-hour base loads for the screening analysis were 1.2 W/ft^2 and 0.5 W/ft^2, respectively.

Building Type: Office

Discussion of Profile: The typical office building plug load profile is the classic hat shape, with a single peak period occurring for most of the working day and a lower off-hour period. The peak period is typically six to ten hours. A transition period between the peak and off-hour period is typically one to three hours, depending on occupant behavior. Office buildings are typically active Monday through Friday, with minimal activity on Saturdays and even less on Sundays.

Peak-load estimates range from 0.2 W/ft^2 to 0.8 W/ft^2, with most falling in the range of 0.6 W/ft^2 to 0.8 W/ft^2. Off-hour base-load estimates range from 0 W/ft^2 to 0.4 W/ft^2, with many falling near 0.3 W/ft^2. The peak and off-hour base loads for the screening analysis were 0.64 W/ft^2 and 0.3 W/ft^2, respectively.

Building Type: Retail

Discussion of Profile: The typical retail building plug profile is hat-shaped.

Peak-load estimates range from 0.2 W/ft^2 to 0.6 W/ft^2. Off-hour base loads range from 0 W/ft^2 to 0.2 W/ft^2. The peak and off-hour base loads for the screening analysis were 0.4 W/ft^2 and 0.1 W/ft^2, respectively.

Building Type: Warehouse

Discussion of Profile: The typical warehouse building plug load profile is hat-shaped.

Metered data indicate that relatively little difference exists between the peak and off-hour base plug loads in a warehouse, so the peak and off-hour base loads for the screening analysis were 0.15 W/ft^2 and 0.1 W/ft^2, respectively.

Building HVAC Operation and Occupancy Assumptions. For the BLAST loads calculations, DOE assumed the occupant activity level to be 425 British thermal units per hour (Btu/h) per person for all building types, except food services and warehouses. For food services, DOE assumed the activity level to be 550 Btu/h per person; for warehouses, the activity level was 1,000 Btu/h per person. The Department derived these values from data in the ASHRAE Fundamentals Handbook 1993. It did not vary the occupant activity levels with climate.

6.2.5.5 Ventilation and Infiltration

The Department based the ventilation rate assumptions on the acceptable ventilation rates provided by ASHRAE Standard 62-2001 [15] (Table 2) for each building type. The Department entered the ventilation for each building into the Parm files as estimated cubic feet of outdoor air per minute, per square foot of building floor area (cfm/ft^2).

For two of the building types (Retail and Warehouse), the ventilation rate in ASHRAE Standard 62-2001 is based on defined quantities of outdoor cfm/ft^2; DOE directly translated these into the parameter files for its simulations. Conversations with former and current ASHRAE Standard 62 Chairmen both confirmed that this was a reasonable interpretation of the ASHRAE Standard 62 requirements for these spaces. For the remaining four building types (Office, Food Service, Education, and Public Assembly), the ventilation rates are prescribed in terms of cfm/person, and therefore an estimate of the ventilation rate must be based on an estimate of the space occupancy.

The CBECS provides information on the number of workers during the peak shift for all building types; however, this value reasonably reflects building occupancy for only one of the building types: Offices. For the other buildings types (e.g., Retail), occupancy is not driven by workers, but by other users of the building (e.g., customers, students, or the general public). The Department based occupancy estimates used for establishing ventilation rates for the other building types on ASHRAE Standard 62-2001 estimates of peak space occupancy/1000 ft^2 of "net occupiable space," shown in Table 2 of ASHRAE Standard 62-2001. As defined by ASHRAE Standard 62-2001, net occupiable space is the floor area of an occupiable space defined by the inside surface of its walls but excluding shafts, column enclosures, and other permanently enclosed, inaccessible, and unoccupiable areas. Obstructions in the space such as furnishings, and display or storage racks, whether temporary or permanent, may not be deducted from the space area. Hence, net occupiable space is roughly equivalent to building floor area for most of the building types examined. For the purposes of this study, DOE equates net occupiable space with building floor area.

Issues develop when estimating the design occupancy. ASHRAE Standard 62-2001 states explicitly that, where occupant density differs from that in Table 2, the designer should use the per-occupant ventilation rates for the anticipated occupancy load. However, in most cases, the building designer still must determine the anticipated occupancy load for the space. Different sources for estimates of the design occupancy that are used by engineers for ventilation design include: recommended ASHRAE Standard 62 peak occupancies, fire code exit occupancies, peak occupancies defined by other code minimums (e.g., California's Title 24), and estimated peak occupancy loads from the building owner. Previous consultation with design engineers suggested that the ASHRAE Standard 62-2001 peak occupancies are likely the most representative of current engineering design practice, unless other building codes have predefined more specific methodology for establishing occupancy-based ventilation rates (as is done in Title 24).

The ASHRAE Standard 62-2001 ventilation design occupancies are commonly well above the reported CBECS workers-per-peak-shift requirements for office buildings, and are generally above the average daily occupancy rates used in the development of the occupant load schedules (see discussion of schedules in Section 7.2.6.5). Concern over this discrepancy led to further discussion of the use of the ASHRAE Standard 62-2001 occupancy estimates with other professional design engineers. Follow-up conversations with practicing engineers confirmed that the ASHRAE Standard 62-2001 design occupancies are likely the most common occupancy estimates used by design professionals today, particularly given the current attention paid to indoor air quality issues.

It is important to define the difference between the occupancy rates used in establishing the ventilation requirements for the building (and thus the ventilation-driven loads on the HVAC system) and the occupancy rates used in establishing the occupancy-driven thermal loads on the building. The Department used the occupancy schedules for the building simulation to drive the occupant thermal (and latent) load additions to the space in a way that reasonably estimates those loads for different hours of the year. However, the occupancy rates used in establishing the ventilation requirements are "design" values that define the required ventilation capability in the design. The Department assumes that this ventilation level is fixed for the year and does not vary with occupancy. Control systems do exist that would allow variation of the ventilation level in the space, dependent on occupancy (demand control ventilation), but DOE has not examined them in this study.

In addition, it is important to note that ASHRAE Standard 62-2001 provides for adjustments for space types that are occupied intermittently. If the occupancy peak is expected to last less than three hours, the outdoor air-flow rate may be determined on the basis of average occupancy, provided that average occupancy used for the determination of ventilation is not less than one-half the maximum. Space types such as auditoriums and food service buildings can take advantage of average occupancy considerations to reduce the ventilation requirements.

Table 6.2.21 shows the ventilation rates used in the study for each building type. The strategy used to set ventilation rates for each building type is discussed below.

Table 6.2.21 Ventilation Rates Used for Each Building Type (cfm/ft^2)

Building Type	Ventilation Rate (cfm/ft^2)
Assembly	0.890
Education	0.450
Food Service	0.600
Office	0.140
Retail	Avg 0.283; Range 0.210 to 0.300
Warehouse	0.050

Office Building

The Department based the ventilation rate on a typical office building described by ASHRAE Standard 62-2001. The ASHRAE Standard 62-2001, Table 2, lists four space types under "Offices," one being "Office Space" with a maximum occupancy of seven persons/1000 ft^2 net occupiable space, and three being "Reception Areas," "Telecommunication Centers/Data Entry Areas," and "Conference Rooms" for higher-density occupancy (50–60 persons/1000 ft^2 net occupiable space). For all but reception areas, ASHRAE Standard 62-2001 recommends 20 cfm/person for ventilation. For the reception areas, it recommends 15 cfm/person. For the purposes of this study, DOE used an average occupancy of seven persons /1000 ft^2 to set the ventilation requirements for all of the office buildings examined. Using 20 cfm/person results in an average ventilation rate of 0.14 cfm/ft^2. There are areas of a building that require higher ventilation and areas that require lower ventilation, but based on the previously noted discussions with practicing engineers, it was apparent that assuming the entire space as "office" would provide ventilation rates reasonably representative of building totals without requiring detailed space-by-space breakdowns. The ventilation rate chosen for this analysis is the same ventilation rate that was used for office buildings in the original 1994 ASHRAE analysis of the cost-effective efficiency levels for cooling equipment, based on the ASHRAE 90.1 Mechanical Subcommittee's professional judgement.

Education Buildings

ASHRAE Standard 62-2001 has a category for education buildings where it lists the space types shown in Table 6.2.22.

Table 6.2.22 ASHRAE Standard 62-2001 Data for Education Building Spaces

Education Space Type	Peak Occupancy (Person/ft)^2*	cfm/person	Calc. cfm/ft^2*
Classroom	50	15	0.75
Laboratories	30	20	0.6
Training Shop	30	20	0.6
Music Rooms	50	15	0.75
Libraries	20	15	0.3
Locker Rooms**			0.5
Corridors**			0.1
Auditoriums	150	15	2.25
Smoking Lounges	70	60	4.2

* Net occupiable space, no modification for intermittent occupancy.
** Only cfm/ft^2 value provided in ASHRAE Standard 62-2001

Most of the space of a typical elementary school is composed of classrooms, followed closely by corridors, libraries, and office space. Secondary schools are more likely to have other facilities, such as training shops, music rooms, and science laboratories. Separate auditoriums also become more prevalent in secondary schools. Elementary schools often have smaller gymnasium spaces that also serve as auditoriums or cafeterias.

The Department did not identify a typical breakdown of space types for the entire education category for this work. However, discussions with designers revealed that, frequently, corridor spaces in elementary schools did not receive significant separate ventilation, because these were temporary-use spaces (e.g., when students were in corridors they were not in classroom). Typical average ventilation requirements for school buildings reported by designers appeared to be in the 0.3–0.7 cfm/ft^2 range. To provide a reasonable estimate, DOE used the following methodology: A simple average of the "teaching-like spaces" in Table 6.2.22 (Classrooms, Laboratories, Training Shops, Music Rooms, Libraries) yields a typical ventilation requirement of 0.6 cfm/ft^2. The Department assumed that approximately 70 percent of the building floor space is composed of spaces such as this. The remaining 30 percent is composed of corridors or office space, for which DOE assumed a 0.1 cfm/ft^2 value. An area-weighted average of these yields a typical ventilation rate of 0.45 cfm/ft^2 for the building, which falls in the range of values reported by design professionals. The Department used this value for the air-conditioning loads analysis.

Food Service Buildings

The ASHRAE Standard 62-2001 has a category for food service buildings where it lists the space types shown in Table 6.2.23.

Table 6.2.23 ASHRAE Standard 62-2001 Data for Food Service Building Spaces

Food Service Space Type	Peak Occupancy (Person/ft^2) *	cfm/person	Calc. cfm/ft^2*
Dining Rooms	70	20	1.40
Cafeteria/Fast Food	100	20	2.0
Bars/Cocktail Lounge	100	30	3.0
Kitchen/Cooking	20	15	0.3

* Net occupiable space, no modification for intermittent occupancy

The ASHRAE Standard 62-2001 notes that exhaust flow from a kitchen should typically be approximately 1.5 cfm/ft^2. This is important because a common ventilation strategy for a restaurant (particularly a fast food restaurant) is to supply virtually all the outside air into the dining area, and exhaust virtually all of the building through the kitchen cooking hoods. A second common strategy is to bring in unconditioned air to provide for any needed makeup air to the cooking hoods. Both of these strategies make understanding food service ventilation more complicated than simply providing an area-weighting of the space types shown above.

For the purposes of this study, the Department estimated restaurant ventilation levels assuming two different scenarios. The first scenario was a fast food building with approximately 60 percent dining area and 40 percent kitchen; the second scenario was a sit-down type restaurant with 80 percent dining area and 20 percent kitchen. In both cases, DOE assumed that the ventilation for the kitchen space was not provided by the primary space-conditioning unit for that space (e.g., ventilation loads on the building come through the dining space ventilation requirements). The Department also assumed that the peak occupancy periods would be of short enough duration to take advantage of a 50 percent reduction in flow rate. This practice results in:

Building ventilation = Dining area space fraction × Dining area occupancy density × Ventilation rate/person × 50 percent reduction for intermittent use

For the fast food restaurant:

Ventilation = 60% × 100 persons/1000 ft^2 × 20 cfm/person × 50% = 600 cfm/1000 ft^2

For the sit down restaurant:

Ventilation = 80% × 70 persons/1000 ft^2 × 20 cfm/person × 50% = 560 cfm/1000 ft^2

Both of the above examples would result in kitchen exhaust rates that would meet the ASHRAE Standard 62-2001 1.5 cfm/ft minimum. For the purposes of this analysis, the Department adopted a typical exhaust rate of 0.6 cfm/ft^2 for all food service buildings.

Assembly Buildings

Assembly buildings are a tremendously diverse group. However, in general, they are characterized by the need to respond to very high and generally intermittent peak occupancy rates. Table 6.2.24 shows a list of typical assembly building space types from ASHRAE Standard 62-2001.

Table 6.2.24 ASHRAE Standard 62-2001 Data for Assembly Building Spaces

Assembly Building Space Type	Peak Occupancy (Person/ft^2)*	cfm/person	Calc. cfm/ft^2*
Theater Lobby	150	20	3.0
Auditoriums	150	15	2.25
Stages, Studios	70	15	1.05
Bowling Alleys	70	25	1.75
Ballrooms	100	25	2.5
Playing Floors (Gymnasium)	30	20	0.6
Swimming Pools**			0.5
Ice Arena**			0.5
Game Rooms	70	25	1.75
Spectator Areas	150	15	2.25
Transportation Waiting Room	100	15	1.5
Platforms	100	15	1.5

* Net occupiable space, no modification for intermittant occupancy
** Only cfm/ft^2 value provided in ASHRAE Standard 62-2001

An examination of all the assembly building types with an occupancy listed shows an average peak occupancy from ASHRAE Standard 62-2001 of 99 persons/ft^2. Ventilation rates vary from 15 to 25 cfm/person. No particular breakdown of these space types in the general population is known, nor is this a complete list of all assembly building space types. Again, DOE used a simple strategy to estimate the typical ventilation rate that might be experienced by assembly buildings under ASHRAE Standard 62-2001. The Department estimated the ventilation rate for assembly buildings by assuming that, on average, 90 percent of the building space would be available for public assembly and 10 percent would be unoccupied or not separately vented space. The Department assumed the average ventilation rate to be 20 cfm/person, and gave all space designs a 50 percent credit for intermittent occupancy. This results in 0.89 cfm/ft^2 for assembly spaces. The Department used this value to represent a typical ventilation rate for assembly buildings for the purposes of this study.

Retail buildings

The ASHRAE Standard 62-2001 has straightforward requirements for retail buildings. Ground-level floors for retail building spaces have a requirement of 0.3 cfm/ft^2 ventilation. Upper-floor levels of retail spaces are required to have 0.2 cfm/ft^2 ventilation rates. By using these figures in conjunction with the number-of-floors variable published in CBECS (*NFLOORS6*), the Department was able to estimate the cfm/ft^2 requirement for each retail building in the DOE 1033-building subset. The Department used this methodology to estimate retail building ventilation requirements.

Warehouse buildings

The ASHRAE Standard 62-2001 has a requirement of 0.05 cfm/ft^2 for warehouse spaces. The Department used this value for all warehouse buildings in the 1033-building set.

6.2.5.6 Economizer Use and Control Assumptions

The CBECS95 data set has a single variable (*ECN6*) that indicates whether the building in question has an economizer to provide free cooling. The survey provides no indication of the control or operation status of the economizer, or whether it is used on all building systems. Comments from the industry indicated that enthalpy-based economizers had been available for a long time and were a reasonable assumption for humid climates. For the ANOPR analysis, DOE based all economizers used in the building system simulation on differential enthalpy economizers. This control decision has relatively little impact in dry climates, where economizers are expected to be more prevalent, but is expected to reduce cooling loads somewhat in humid climates, in comparison with other possible economizer control strategies.

6.2.5.7 Heating and Cooling Setpoint

The CBECS95 data set contains no information on internal building operating temperatures, but does contain a variable that indicates the reduction of heating in off hours (*RDHTNF6*) or reduction in cooling during off hours (*RDCLNF6*). No indication is provided as to whether this reduction is achieved via thermostatic setback or setup or equipment shutdown. For the purpose of this analysis, the Department assumed a 70°F heating setpoint and a 75°F cooling setpoint during occupied hours. If a reduction of heating in off hours was indicated, DOE assumed a 10°F temperature setback (to 60°F) for off hours. If a reduction of cooling during off hours was indicated, DOE assumed a 10°F temperature setup (to 85°F) for off hours. If neither heating nor cooling reduction was indicated during off hours, the Department assumed occupied-hour control setpoints for all hours.

6.2.5.8 Equipment Sizing

The term "sizing" refers to the method used to determine the cooling capacity for air conditioning and the heating capacity for heating equipment selected for use in serving a given building thermal zone. It is commonly a two-step process. The first step is the mathematical determination of the cooling or heating load on a given zone. This is commonly done by calculating the thermal load for a set of environmental conditions. The second step is the selection of equipment that will meet the calculated design thermal load from the discrete equipment capacities available for purchase.

Design-Day Conditions. For the ANOPR analysis, DOE calculated thermal loads for sizing using the "design systems" algorithm built into BLAST. These algorithms create cooling and heating "design days" based on user entries for summer and winter design conditions. The data needed for the design days include the maximum and minimum temperatures for the day, coincident wet bulb temperature, barometric pressure, the wind speed and direction, the clearness index (0.0 = total cloud cover, 1.0 = clear skies), and a precipitation index indicating either snow or rain.

The Department created both summer and winter design days for each location, based on available "design" temperature and weather condition assumptions. By default, BLAST immediately creates two design days for cooling and two for heating. The first design days are assumed to have weekday (Monday) operating schedules and the second are assumed to have a weekend (Sunday) operating schedule. The model assumes that the summer design days occur on July 21 and the winter design days occur on January 21. Table 6.2.25 shows the sources for the necessary BLAST design-day weather parameters. The Department used climate data for design-days presented in the ASHRAE Fundamentals Handbook 2001. The column label for each variable in that table is shown in Table 6.2.25. The clearness index variable is set to 1.0 for the summer design day and 0.0 for the winter design day, to provide extreme conditions.

Table 6.2.25 Development of Design-Day Data for BLAST Simulations

Design Day	BLAST Design-Day Parameter	Source Data*
Winter	Date	Jan 21
	Dry Bulb (HI)	99% Heating Dry Bulb (Heat Col 2b) + 1°F
	Dry Bulb (LOW)	99% Heating Dry Bulb (Heat Col 2b)
	Wet Bulb	Wet bulb temperature corresponding to 30% RH and 99% Heating Dry Bulb (Heat Col 2B) + 1°F
	Barometric Pressure	Std Pressure (Heat Col 1f)
	Wind Speed	1 % Windspeed for coldest month (Heat Col 4c)
	Wind Direction	Wind Direction Corresponding to 99.6% dry bulb temperature (Heat Col 5b)
	Clearness Index	Set to 0 (representing extreme low clearness index and hence solar)
Summer	Date	Jul 21
	Dry Bulb (HI)	1% Dry Bulb (Cooling Col 2c)
	Dry Bulb (LOW)	1% Dry Bulb (Cooling Col 2c) – Mean Daily Dry Bulb Range During Hottest Month (Cooling Col 5)
	Wet Bulb	1% Mean Coincident Wet Bulb Condition (Col 2d)
	Barometric Pressure	Std Pressure (Heat Col 1f)
	Wind Speed	Wind Speed Corresponding to 0.4% Drybulb Condition (Heat Col 5c)
	Wind Direction	Wind direction corresponding to 0.4% Drybulb condition (Heat Col 5d)
	Clearness Index	Set to 1 (representing extreme high clearness index)
Annual	Time Zone	From TMY File

*Column references refer to column labels in ASHRAE *Fundamentals Handbook* 2001, Chap 27 Table 1a

Equipment Oversizing Factor. For the second step in sizing the equipment, it was necessary to estimate how much a given system would likely be sized above that required by the thermal loads. There is significant anecdotal evidence that many cooling systems are sized well above what is required to meet the design thermal loads in the space. However, just because a system may be significantly oversized in practice does not necessarily mean that it should be modeled as such for the ANOPR analysis. DOE's analysis depends on balancing the first costs for higher-efficiency equipment with the energy cost savings from higher-efficiency equipment. Increasing the efficiency of equipment that is grossly oversized will be more expensive than increasing the efficiency of equipment that is properly sized and this would impact the economics of higher efficiency equipment. It is clear, however, that the discrete capacities of unitary equipment that can be purchased will result in the equipment capacity purchased being somewhat larger than the design loads for the building.

To provide some assessment of oversizing, DOE examined two product lines of year-round unitary packaged equipment from different manufacturers. The Department identified ranges of discrete capacities between each product and the next-larger-capacity product for each manufacturer, and selected the midpoint of each capacity range as the average system size within that capacity range. The Department assumed that shipments of future products covered under this rulemaking could be apportioned across all capacity ranges, based on the ratio of the size of each capacity range relative to the overall capacity range for covered products. With this simplifying assumption, it was possible to provide a weighted average of the capacity required by the building and the average size of the units that would need to be purchased if the purchaser stayed within a given manufacturer's product line. Table 6.2.26 shows the results of this simplified analysis. In the case of Manufacturer A, the average of the capacity purchased was 11.8 percent higher than the average capacity required. For Manufacturer B, the average of the capacity purchased was 14.7 percent higher than the average capacity required.

Table 6.2.26 Estimate of Capacity Purchased Versus Capacity Required for Two Manufacturers

MFG A			
Capacities Available (kBtu/h)	**Avg. Capacity within Capacity Range (kBtu/h)**	**Required Capacity Purchased (kBtu/h)**	**Estimated Fraction of Shipped Products**
65	68.0	71	0.036
71	79.5	88	0.102
88	89.0	90	0.012
90	105.0	120	0.180
120	125.0	130	0.060
130	134.0	138	0.048
138	159.0	180	0.251
180	206.0	232	0.311
232	NA	NA	NA
	Wt. Average Capacity Required	**Wt. Average Capacity Purchased**	**Ratio of Avg. Capacity Purchased vs Capacity Required**
	148.5	166.0	1.118

MFG B			
Capacities Available (kBtu/h)	**Avg. Capacity within Capacity Range (kBtu/h)**	**Required Capacity Purchased (kBtu/h)**	**Estimated Fraction of Shipped Products**
65	68.5	72	0.041
72	78.5	85	0.078
85	85.5	86	0.006
86	87.0	88	0.012
88	94.5	101	0.078
101	109.0	117	0.096
117	118.0	119	0.012
119	154.5	190	0.425
190	191.0	192	0.012
192	212.0	232	0.240
232	NA	NA	NA
	Wt. Average Capacity Required	**Wt. Average Capacity Purchased**	**Ratio of Capacity Purchased vs Capacity Required**
	148.5	170.3	1.147

Limitations on obtaining additional data—such as the sales volume of these and other manufacturers, sales between product lines, the actual shipments by product capacity range

for manufacturers, and the frequency with which a purchaser of equipment might specify products from different manufacturers—suggested that further investigation using this methodology would not provide greater accuracy. Instead, DOE used the analysis to estimate the range of oversizing that might occur due to the discrete sizes available from manufacturers. For the ANOPR analysis, DOE selected a random oversizing factor for each building, assuming a uniform distribution of oversizing factors between 0 percent and 25 percent of design capacity requirements. The Department applied the selected oversizing factor to all equipment used in the building.

6.2.6 GeoClimate Locations and TMY2 Station Assignments

The Department assigned each of the 1033 buildings meeting the criteria for inclusion in the analysis to a GeoClimate region, defined as the union of the nine Census Divisions and the five climate zones reported in CBECS95. The climate zones are defined by ranges of HDD values and CDD values, as shown below:

Zone 1: <2000 CDD, >7000 HDD
Zone 2: <2000 CDD, 5500–7000 HDD
Zone 3: <2000 CDD, 4000–5499 HDD
Zone 4: <2000 CDD, <4000 HDD
Zone 5: >2000 CDD, <4000 HDD

The Department assigned each TMY2 station to a GeoClimate region, based on the station's HDD and CDD values and locations by city and state. This resulted in 45 potential GeoClimate regions (nine census divisons × five climate zones). However, because some of the climate zones do not naturally occur in some census divisions and not every GeoClimate region had a TMY2 station, the final number of GeoClimate regions selected for this analysis was 26. For example, Climate Zone 1, with more than 7000 HDD, is found only in census divisions encompassing the northern tier of states or regions of the mountainous western U.S.

Thus, there is a set of TMY2 stations and CBECS buildings in each of the 26 GeoClimate regions. Within each census/CBECS cell, DOE assigned a relative weight to each TMY2 station, based on the population of cities that can be shown to be most climatically similar to that TMY2 location. For this, the Department used the United States Geological Survey (USGS)'s Populated Places (PPL) database. The PPL database contains information for more than 165,000 locations ("features," in USGS parlance). For each feature, the database lists location, known latitude and longitude, elevation, and population (for smaller places without a known population, the database assigns a population of one). To map all 165,000 PPL locations to a best representative TMY2 station, DOE used a second climate dataset of 4775 National Oceanographic and Atmospheric Administration (NOAA) cooperative observer stations. First, DOE mapped each PPL location to the best NOAA station; then it mapped each NOAA station to the best TMY2 station. The two-step mapping was necessary because the PPL data have no climatic information. The NOAA stations provided enough geographical coverage to allow mapping each PPL to a NOAA station, knowing only location (by latitude and longitude) and elevation. The PPL-to-NOAA

mapping algorithm chose, for each PPL location, the closest NOAA station—unless that station differed in elevation by more than 300 feet. If the difference in elevation of the closest NOAA station was more than 300 feet, the algorithm chose, from among the next 20 closest stations, the one with the closest elevation.

Mapping the NOAA stations to TMY2 stations was more involved and relied on proximity, elevation, and HDD indicators. As a result of mapping a PPL to a TMY2 within each Census/CBECS cell, the total population of NOAA stations pointing at each TMY2 station was known. Dividing the total population mapped to each TMY2 by the total population of all TMY2s in the U.S. Census Bureau/CBECS cell gave the final relative weights.

The Department assigned each of the CBECS buildings in the same GeoClimate region to one of the TMY2 stations in that GeoClimate region by a random assignment process, based on the population-weighted distribution.

Table 6.2.27 lists the number of TMY2 stations in each of these regions, and Table 6.2.28 lists the number of CBECS buildings in the same geographic regions. A zero entry means that the climate zone did not occur in that census division. Appendix H contains a list of the number of buildings assigned to each TMY2 station assignment, and Appendix I shows the TMY2 assignments for each of the 1033 buildings. The Department assigned at least one CBECS observation to 157 of the 239 TMY2 locations.

Table 6.2.27 TMY2 Stations by Census Region and Climate Zone, Including Alaska and Hawaii, and Excluding Puerto Rico and Guam

Census Division	**Climate Zone**					**Total**
	1	**2**	**3**	**4**	**5**	
East North Central	14	15	1	0	0	30
East South Central	0	0	5	8	1	14
Middle Atlantic	5	8	4	0	0	17
Mountain	21	9	4	0	3	37
New England	4	4	0	0	0	8
Pacific	19	5	8	7	6	45
South Atlantic	0	1	10	13	8	32
West North Central	16	7	6	0	0	29
West South Central	0	0	3	4	18	25
Total	79	49	41	32	36	237

Table 6.2.28 Number of CBECS Buildings by Climate Zone and Census Region

Census Division	Climate Zone					Total
	1	2	3	4	5	
East North Central	20	113	12	0	0	145
East South Central	0	0	14	53	16	83
Middle Atlantic	0	33	65	0	0	98
Mountain	5	25	0	5	16	51
New England	17	33	0	0	0	50
Pacific	8	0	26	164	12	210
South Atlantic	0	0	64	47	86	197
West North Central	21	6	28	0	0	55
West South Central	0	0	0	33	111	144
Total	71	210	209	302	241	1033

6.2.7 Simulation and Data Manipulation

This section describes the process used to simulate energy consumption for 10,330 hypothetical buildings. Given 1033 unique building descriptions, DOE modeled each at ten different air-conditioning equipment EERs. The Department then used the output of the simulation process to model the relevant CBECS sample.

The Department modeled each CBECS building using BLAST. The Department developed the BLAST inputs from CBECS95 data, where available; for parameters not available in CBECS95, DOE used random draws from distributions of possible values, and sound engineering judgment.

The Department used additional strategies to facilitate the modeling of so many unique buildings. First, it computed each building's loads by simulating the same prototype building: a three-story, 48,000 square-foot building with five thermal zones per floor. The Department "scaled" the results of that prototype's simulation to match the specifics of the CBECS building in question, including conditioned floor area, aspect ratio, number of floors, and number of thermal zones per floor. The scaling procedure was described in detail in Barwig et. al[1] and will not be repeated here. Second, DOE programmed into the computer software the "administrative" aspects of developing simulation input files and post-processing output. Third, DOE managed the processing steps using a date-based dependency-checking software tool. Finally, DOE ran the simulations on a small, 18-Central Processing Unit (CPU) computing cluster.

The simulation/analysis process for each CBECS building has 10 steps:

1. Develop BLAST design-day input file (BLAST input file, BLIN file) for sizing equipment.

2. Run BLAST design-day simulation.

3. Extract equipment sizing results from the BLAST design-day run output.

4. Modify the design-day BLIN files (from step 1) for an annual simulation by inserting the equipment sizing results from steps 1–3.

5. Run BLAST annual simulation.

6. Reformat hourly BLAST output into comma-separated-value format.

7. Extract system sizing results from the annual-run BLAST output.

8. "Scale" annual-run hourly outputs and sizing results to match specific CBECS building geometries.

9. Aggregate across building zones to get building-total results.

10. Adjust building totals to account for less-than-100 percent air-conditioned buildings and buildings partially air conditioned with non-unitary air-conditioning equipment.

Each of the above steps is described in detail below. Most steps are straightforward data manipulations that warrant mention only because they have to be done so many times. Steps 8, 9, and 10 involve the most substantive manipulations. Figure 6.2.1 shows a simplified flow diagram of the simulation process.

<u>Step 1 – Develop BLAST design-day input file.</u>

Development of the 10,330 BLAST input files is facilitated by a PNNL-developed software program known as *gparm*. Written in the Perl language, *gparm* works much like the "mail merge" function available in many word processors. It combines a template BLIN file containing replaceable parameter tags with parameter values held in a separate parameter file. The template file is in legal BLAST input language format, except for the replaceable tags. The parameter file is a rectangular table (in comma-separated-value format) with as many rows are there are runs (10,330 in this case) and as many columns as there are parameters to vary. *Gparm* repeatedly reads values from the next row of the parameter file, "fills in" the template with those values, and writes out an associated BLIN file.

Appendix J shows a text listing of one filled-in BLIN file.

Steps 2 and 3 – Run BLAST design-day simulation and extract relevant results.

The Department combines each design-day BLIN file with the appropriate weather file and simulates it using the BLAST software. The relevant results for each of the 15 zones from this design-day simulation are supply and exhaust-air flowrates in cubic feet per minute, heating peak, and sensible, latent, and total cooling peaks. These values are taken from the two BLAST output reports "Fan System Parameters" and "System Load Summary."

At this stage in the processing, fan power ratios (the ratio of fan power draw to cooling system capacity) are also calculated and stored for later use. The peak fan power values are taken from BLAST's design-day output files with a "dday03" and/or "dday04" filename extension. (The 03 and 04 represent weekend and weekday runs.)

Step 4 – Convert design-day BLIN file to annual-run BLIN file.

The Department performs annual BLAST runs with the exact same input (BLIN) files as for design-day runs, but with the now-known system capacities inserted and the appropriate run control statements modified. This process is automated with a Perl script (des2ann.pl).

Steps 5 and 6 – Run annual BLAST simulation and reformat hourly output.

The Department runs the annual BLAST simulation as before, and pipes the hourly output (which comes out of BLAST in files named with a ".rwd" extension) through a reformatting script to produce a simple, rectangular, comma-separated-value file. This file contains 8760 rows (one per hour of the year) and 120 columns (eight output variables for each of 15 simulated zones). The output variables collected for each zone include lighting, equipment (electric appliances and other "internal gains"), heating and cooling space loads, heating and cooling energy, fan power, and building-total electric.

Step 7 – Extract system sizes from annual run output.

BLAST re-estimates system sizes during the annual run, even though they were specified in the input and taken from the design-day runs (steps 2 and 3). The annual-run-based capacities often differ slightly from the design-day-based capacities because fan flowrates, and consequently ventilation loads, differ between the two runs. The annual-run-based capacities better reflect the system operation as simulated, so DOE collects them here and uses them henceforth.

Step 8 – Scale annual hourly output to specific CBECS geometries.

The scaling process transforms the simulation results for the 15-zone prototype to the specific geometry of a particular CBECS building. Although this strategy was originally conceived as a means to leverage a single simulation to accurately represent multiple

buildings, this work uses a one-to-one correspondence between BLAST runs and CBECS buildings. It would be simpler, and arguably a bit more accurate, to simulate each building directly, forgoing the need for scaling. However, since both the preliminary findings[1] and the screening analysis[2] used the scaling procedure, DOE used it again here to maintain context and facilitate comparisons across those analyses.

The scaling procedure is designed to accurately transform simulated building loads for the 15-zone prototype into corresponding loads for a building with different geometry (square footage, number of floors, aspect ratio, and number of zones per floor). The procedure is not intended to transform building energy consumption (i.e., after accounting for heating and cooling system performance). The previous analyses cited above were based only on building loads, so the scaling process was a natural fit. However, this work uses BLAST to estimate system performance (efficiency variations with part-load ratio and ambient temperature/ humidity), which requires additional steps in the scaling process.

The scaling of energy results for the 15-zone prototype to specific CBECS geometries proceeds as follows:

A. Scale BLAST loads as before (see *Preliminary Findings*[1]).

B. Infer hour-by-hour system EER by finding the ratio between energy consumption and cooling load.

C. At each hour, transform the 15 zonal EERs to CBECS building-specific zone EERs, using a modified version of the scaling procedure. This modified version uses the same scaling matrix as used in Step A, but with negative elements set to zero. This has the effect of computing a weighted-average EER for each hour, based only on those zones in the 15-zone prototype that contribute positively to each scaled-to zone in the CBECS building.[a]

D. Compute cooling energy by dividing the scaled-to loads (Step A) by the averaged EERs (Steps B and C).

E. Scale lighting and equipment energy consumption, using the same scaling matrix as for cooling loads. Because no efficiency adjustments are involved, the energy results can be scaled directly. Also, since all schedules and intensities are identical on a per-square-foot basis, the scaling is simply a matter of maintaining the same end use intensities (EUIs) or energy-per-square-foot, between the 15-zone prototype and the CBECS building.

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[a] The scaling matrix can have negative elements for several reasons. For example, computing the loads for a one-story building requires summing loads from the bottom and top floors of the 15-zone prototype and subtracting those from the middle floor. Similar strategies are applied to accurately mix core and perimeter loads when scaling to a building with a different perimeter-zone depth.

F. Scale cooling equipment capacities and fan power ratios using the same scaling matrix as for cooling loads; store for later use.

Step 9 – Aggregate all energy end uses across zones.

This step sums, at each hour, the CBECS building-specific end-use energy values across zones to obtain building totals.

Step 10 – Adjust building-level results for partially-cooled buildings.

Many CBECS buildings in the sample of 1033 are not 100 percent air conditioned. Also, the sections of buildings that are air conditioned are often partially air conditioned with other kinds of air-conditioning equipment that are not affected by this rulemaking. This final processing step adjusts the building's total end-use energy values to account for the relevant air-cooled unitary air-conditioning fractions. This involves three steps:

A. The Department reduces cooling energy and corresponding fan energy proportionately to account for only the fraction of the building that is cooled by unitary air-conditioning equipment according to CBECS.

B. The Department creates an "other cooling" column to account for sections of the building that are air conditioned by non-unitary air-conditioning systems. This is computed by multiplying the simulated cooling energy of the baseline-efficiency building by the fraction of floor space cooled by non-unitary air conditioning equipment. The Department uses the baseline efficiency (EER = 8.9) run for all buildings because there is no way to know the actual efficiency of the non-unitary air-conditioning equipment.

C. The Department creates an "other fan energy" column to account for fan energy use in portions of the building not cooled by unitary air-conditioning equipment. This is computed by multiplying the building's simulated fan energy by the fraction of floor space not air conditioned by unitary air-conditioning equipment. The Department assumes that the entire building requires air movement, including those portions that are not air conditioned at all.

6.3 SUMMARY OF RESULTS

For heating and air-conditioning equipment, the annual energy use is a function of the heating and cooling loads the equipment must meet. The Department used the BLAST hourly simulation program to calculate building (zone) loads using the generic three-story prototype building. The Department used the coil loads from BLAST as generic estimates of zone loads (core versus perimeter, ground versus roof) of the different building types. The Department scaled the zone coil load estimates to equivalent coil loads for each of the 1033 buildings in the representative building set, then converted them to energy consumption required to meet that load, using the heating and cooling system efficiency.

6.3.1 Comparison of Simulation End-Use Intensities to CBECS-Calculated EUIs

The Department compared the EUIs from the building model simulations with those from the CBECS data to determine how close simulations came to real building data.

The CBECS EUIs are not based on metered data. Instead, EIA derived the CBECS cooling energy from the reported total annual electric energy using simulations. The cooling EUI is then calculated from the CBECS-derived cooling energy estimate and the total building floorspace. The air-conditioning EUIs were calculated from the BLAST simulation output, scaled to the actual building size. For this purpose, the comparison was for a cooling system with an EER of 8.9.

Figure 6.3.1 represents a comparison of the cooling EUIs (kBtu/sf/yr) from the BLAST simulations and the CBECS data aggregated by building type and weighted by square footage. For all building types combined, the BLAST cooling EUI estimates slightly exceed the CBECS EUI estimates. The largest variations occur in assembly and food service buildings, while the smallest variations occur in the office buildings.

Figure 6.3.2 shows the frequency distribution of cooling EUIs for the same two data sets described above. The shape of the distribution is similar, but with a shift toward higher cooling EUIs in the simulated results. At the individual building level comparison, there appears to be little correlation between the simulated EUIs and CBECS EUIs. Given all the unknowns and assumptions made in characterizing the building, DOE expected this result.

Next, DOE aggregated the cooling EUIs by climate regions (see Figure 6.3.3). It appears that, when the results are aggregated into a small number of groups consisting of many buildings within a given climate region, the correlation between the two data sets appears more favorable. When aggregating the results by GeoClimate regions, for the vast majority of the regions, the simulated cooling EUIs are greater than the CBECS-reported EUIs, which is similar to the trend shown by the frequency distribution in Figure 6.3.2.

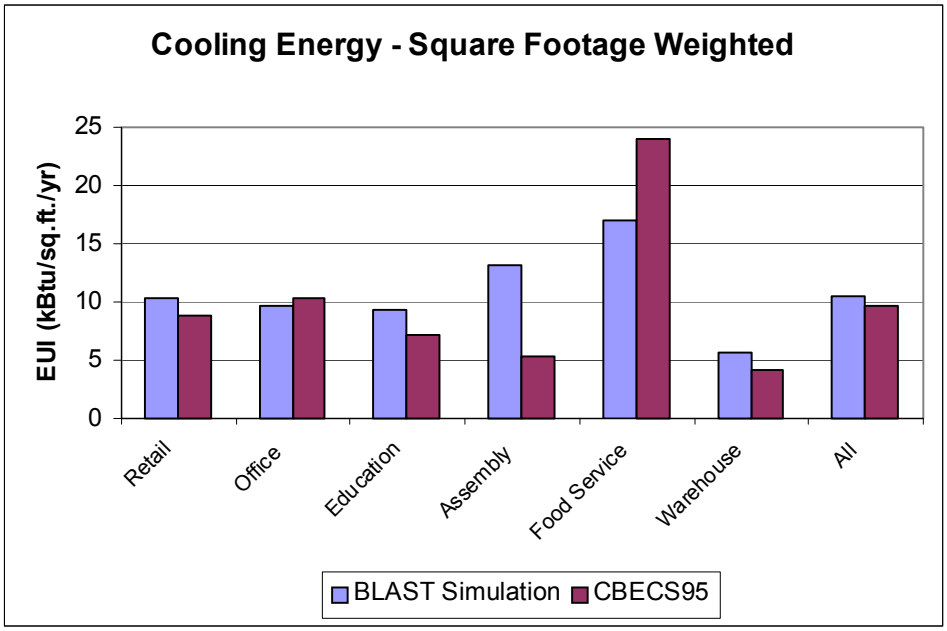

Figure 6.3.1 Plot of BLAST Cooling EUIs versus CBECS EUIs by Building Type

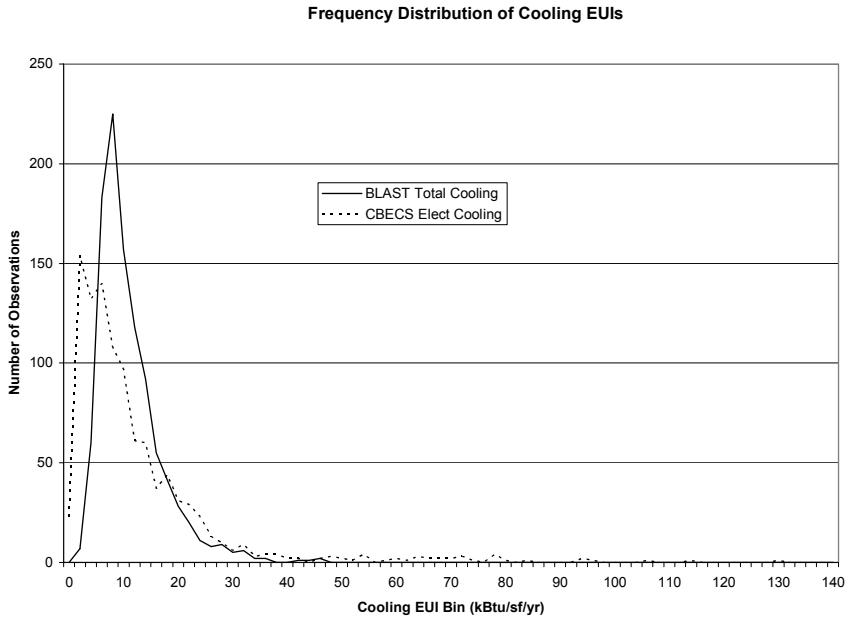

Figure 6.3.2 Frequency distribution of the BLAST EUIs and the CBECS reported EUIs

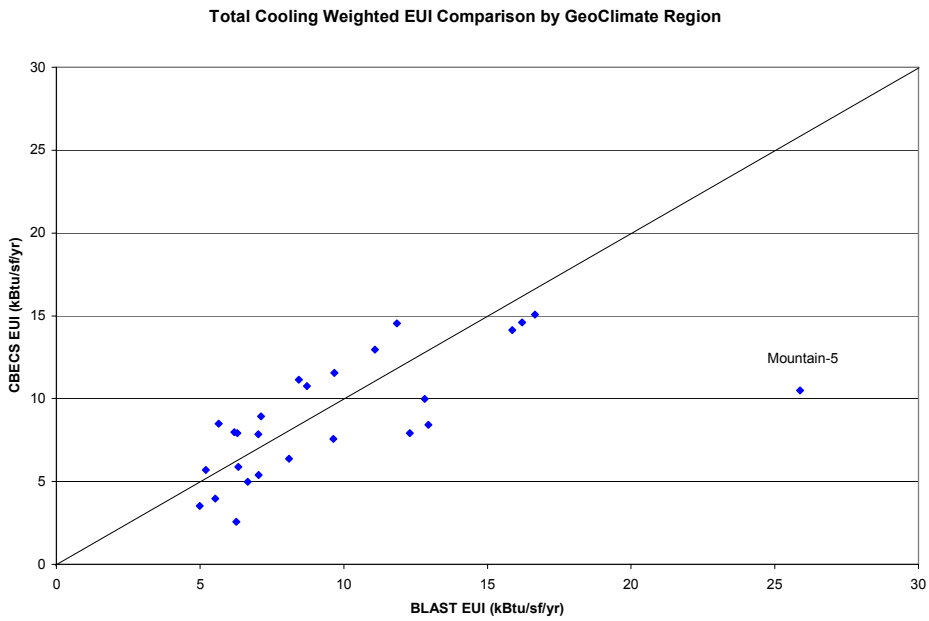

Figure 6.3.3 Comparison of BLAST and CBECS reported EUIs aggregated by GeoClimate region

6.3.2 Annual Building Energy Use

The Department weighted the annual energy consumption from the simulations for each of the individual buildings using the CBECS Adjusted Weight that reflects the portion of the square footage each building represents at the national level. The simulated energy end-use splits for each of the six building categories analyzed in this analysis are shown in Figure 6.3.4 for the baseline cooling equipment (Case 2—8.9 EER). Shown in this figure is the fraction of the represented building's total weighted energy consumption for each of the five major energy end uses. The fuel source for heating is natural gas; all other end uses are electric.

Figure 6.3.5 shows the change in cooling EUI for two specific buildings in the representative building set, as the equipment efficiency increases from an EER of 8.5 to an EER of 12.0. These two buildings are an arbitrarily-selected small retail building and a large office building in different climate regions. The EUIs do not include the fan energy.

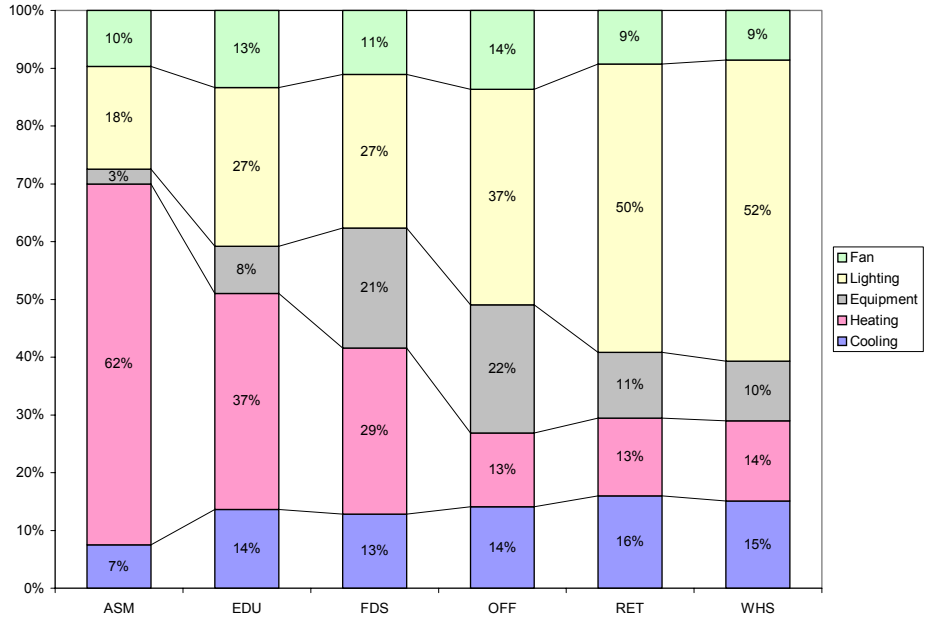

Figure 6.3.4 Fraction of Simulated Annual Building Energy Use by Major End Use and Building Type.

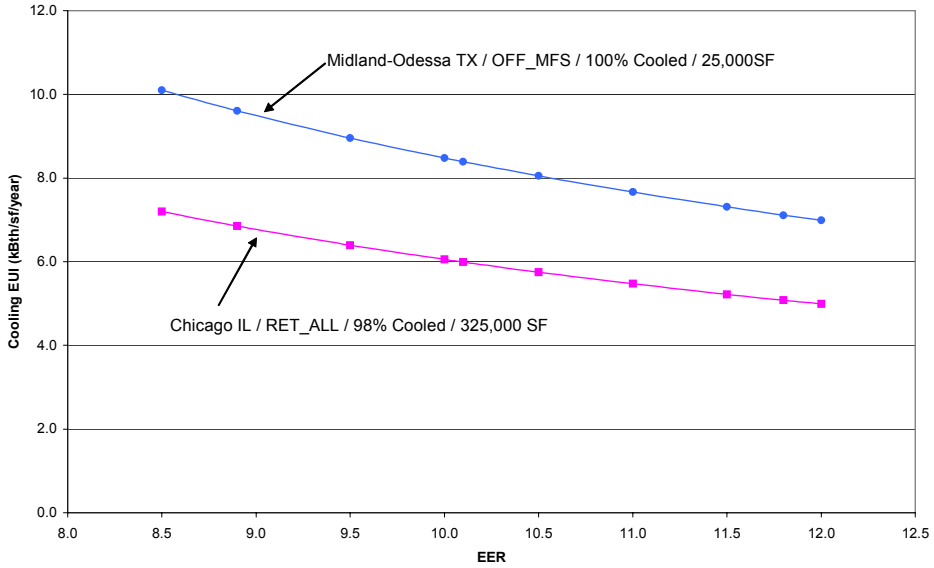

Figure 6.3.5 Change in BLAST Package Cooling EUIs with Increase in EER for Arbitrary Large and Small Buildings

6.3.3 Comparison of Results to the Screening Analysis

Table 6.3.1 presents the national energy savings estimates across all building types and efficiency levels analyzed in this analysis. Using the electric consumption of the combined, air-cooled unitary air conditioning and component fan per ton of cooling capacity as a common metric to compare the DOE screening analysis, it can be seen that the methodology used in this ANOPR analysis is generating slightly higher energy consumption than the previous DOE screening analysis. However, the incremental savings compared to the baseline equipment (EER=8.9) are approximately the same. The comparison of the Cooling + Fan EUI versus EER is shown in Figure 6.3.6 and the energy use per ton is shown in Figure 6.3.7.

Table 6.3.1 Comparison of Annual Consumption for the Cooling and Fan Energy at Each of the 10 EER Levels, for the ANOPR Analysis and the 2000 DOE Screening Analysis. Percent Savings Based on EER=8.9

EER	ANOPR Agg. Wt. Annual Cooling+Fan (MMBtu/yr)	Energy Use per Ton ANOPR (kWh/ton/yr)	Energy Use per Ton Screening Analysis (kWh/ton/yr)	Percent Savings ANOPR (kWh/ton/yr)	Percent Savings Screening Analysis (kWh/ton/yr)	EUI Annual Cooling + Fan (kBtu/sf/yr)
8.5	175,983,907	2223	2170	4.6%	4.7%	19.5
8.9	167,941,046	2126	2072	--	--	18.6
9.5	157,268,739	1997	1942	-6.1%	-6.3%	17.4
10.0	149,436,865	1901	1845	-10.6%	-11.0%	16.6
10.1	147,966,760	1883	1826	-11.4%	-11.9%	16.4
10.5	142,422,945	1816	1757	-14.6%	-15.2%	15.8
11.0	136,057,580	1738	1677	-18.3%	-19.1%	15.1
11.5	130,266,270	1666	1604	-21.6%	-22.6%	14.4
11.8	127,058,276	1627	1563	-23.5%	-24.6%	14.1
12.0	125,025,284	1602	1537	-24.6%	-25.5%	13.9

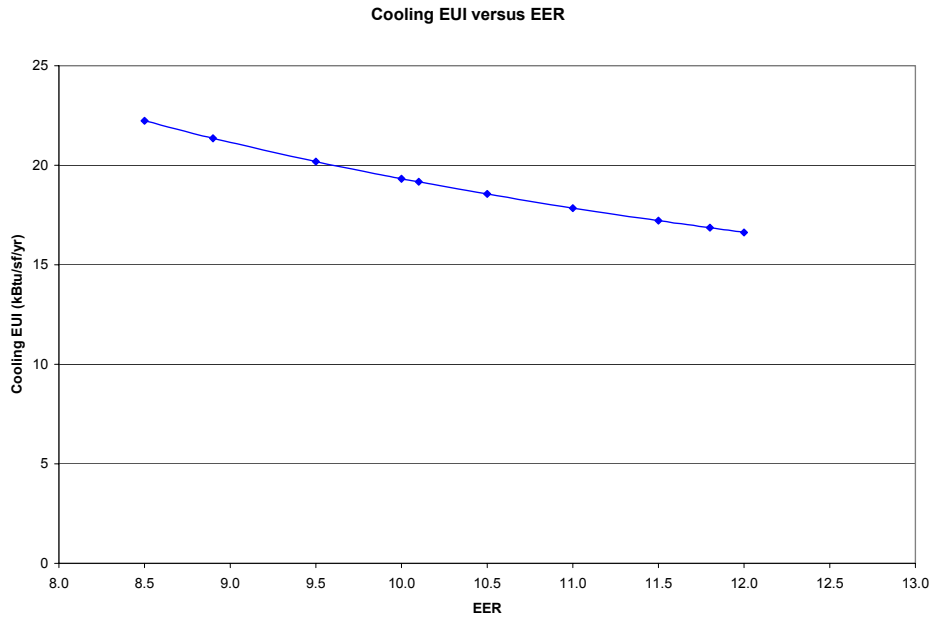

Figure 6.3.6 Weighted Cooling EUI Across all 1033 Buildings

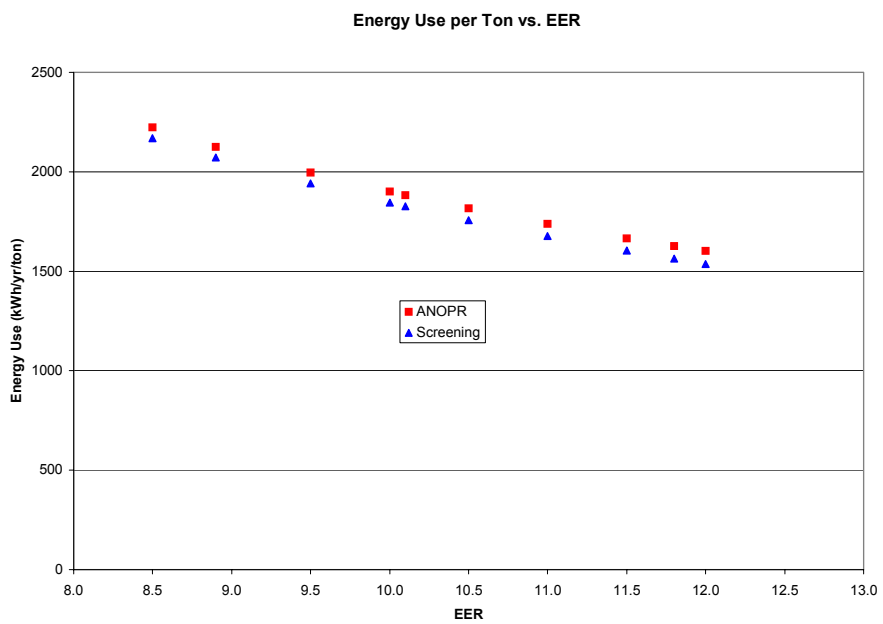

Figure 6.3.7 Comparison of Cooling Equipment Energy Use with DOE Screening Analysis

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