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O. Sezgen, E.M. Franconi, J.G. Koomey, S.E. Greenberg,
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TECHNOLOGY DATA CHARACTERIZING SPACE CONDITIONING IN COMMERCIAL BUILDINGS: APPLICATION TO END-USE FORECASTING WITH COMMEND 4.0

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ABSTRACT

In the United States, energy consumption is increasing most rapidly in the commercial sector. Consequently, the commercial sector is becoming an increasingly important target for state and federal energy policies and also for utility-sponsored demand side management (DSM) programs. The rapid growth in commercial-sector energy consumption also makes it important for analysts working on energy policy and DSM issues to have access to energy end-use forecasting models that include more detailed representations of energy-using technologies in the commercial sector. These new forecasting models disaggregate energy consumption not only by fuel type, end use, and building type, but also by specific technology.

The disaggregation of space conditioning end uses in terms of specific technologies is complicated by several factors. First, the number of configurations of heating, ventilating, and air conditioning (HVAC) systems and heating and cooling plants is very large. Second, the properties of the building envelope are an integral part of a building's HVAC energy consumption characteristics. Third, the characteristics of commercial buildings vary greatly by building type. The Electric Power Research Institute's (EPRI's) Commercial End-Use Planning System (COMMEND 4.0) and the associated data development presented in this report attempt to address the above complications and create a consistent forecasting framework.

Expanding end-use forecasting models so that they address individual technology options requires characterization of the present floorstock in terms of annual and peak service requirements, energy technologies used, and cost-efficiency attributes of the energy technologies that consumers may choose for new buildings and retrofits. This report describes the process by which we collected space-conditioning technology data and then mapped it into the COMMEND 4.0 input format. The data are also generally applicable to other end-use forecasting frameworks for the commercial sector.

Data were obtained from various sources including the U.S. Department of Energy, EPRI, publications of the Lawrence Berkeley National Laboratory, and cost-estimation publications used in industry. Prototype simulations using the DOE-2 building energy analysis program were used extensively to generate data related to the effectiveness of shell measures, HVAC systems, and utilization systems. Simulations were also used to characterize service demand.

ACKNOWLEDGMENTS

This report on space conditioning in commercial buildings is the second in a series summarizing technology data for various commercial end uses in the United States. Companion reports describe technology data for lighting, water heating, office equipment, and refrigeration in commercial buildings.

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ACRONYMS AND ABBREVIATIONS

CBECS	Commercial Building Energy Consumption Survey
CDD	Cooling degree days
COMMEND	Commercial End-Use Planning System
CVRH	Constant-volume reheat
DSM	Demand-side management
EIA	Energy Information Administration
EMCS	Energy management and control system
EPRI	Electric Power Research Institute
FPFC	Four-pipe fan-coil
HP	Heat pump
HDD	Heating degree days
HVAC	Heating, ventilation, and air conditioning
kBtu	One thousand Btus
LBNL	Lawrence Berkeley National Laboratory
MBH	One thousand Btus per hour (same as kBtuh)
ORNL	Oak Ridge National Laboratory
quads	Quadrillion Btu
SC	Shading Coefficient
SZRH	Single-zone reheat
VAV	Variable-air-volume
WAPA	Western Area Power Administration
WCDSR	Wisconsin Center for Demand-Side Research

1. INTRODUCTION

The 4.5 million commercial buildings in the United States (U.S.) consumed a total of 5.8 quadrillion Btu (quads) of final energy in 1989, approximately 10% of final energy consumption nationwide. This final energy represents about 11.3 quads of primary energy. In addition, energy consumption in the commercial sector is increasing more rapidly than in any other sector. Consequently, the commercial sector has become an increasingly important target for state and federal energy policies and also for utility-sponsored demand side management (DSM) programs. As a result of the increasing numbers of DSM programs in the late 1980s, there has been a growing need for utilities to forecast energy consumption by building type, end use, and technology option. Forecasting models in which energy consumption is disaggregated by technology option are also useful to state and federal policy makers in their assessment and implementation of technology-specific standards and policies.

Many of the commercial sector end-use models used today are descendants of the models developed at the Oak Ridge National Laboratory (ORNL) in the mid-1970s. Interest in forecasting energy consumption disaggregated by end use and building type increased significantly after the oil embargo in 1973. At that time, ORNL developed the first generation of end-use models that forecasted future energy consumption by end use and building type. In these early models, each end use was represented using a single cost-efficiency function.[1] Although cost-efficiency functions are built using market data, any information regarding which technology option a certain point on the function actually represents disappears once the function is created. Thus, market shares cannot be attributed to specific technologies.

In the mid-1980s the Electric Power Research Institute (EPRI) adopted COMMEND, one of the first-generation commercial-sector forecasting models. To address the need for more detailed technology representation, EPRI has developed COMMEND 4.0, an enhanced version of COMMEND that allows users to model specific heating, ventilation, and air conditioning (HVAC) technology options as well as lighting, refrigeration, and office equipment technology options. The EPRI contractor for this effort, Regional Economic Research, Inc., worked with Lawrence Berkeley National Laboratory (LBNL) to develop and test the technology modules contained in COMMEND 4.0. LBNL is also helping to develop and refine technology data for the model.

Expanding end-use forecasting models so that they address individual technology options requires characterization of the present floorstock in terms of annual and peak service requirements, energy technologies used, and cost-efficiency attributes of the energy technologies that consumers may choose for new buildings and retrofits. This report describes the process by which we collected space-conditioning technology data and then mapped it into the COMMEND 4.0 input format. The data are also generally applicable to other end-use forecasting frameworks for the commercial sector.

Figure 1.1 provides an overview of the development process that we used to produce technology and service demand input data for COMMEND 4.0.[2] To create this base-year data set, we relied on data characterizing commercial buildings and HVAC systems, previous LBNL work, and engineering judgement. To develop service demand and efficiency data, we also used regional weather data, generated DOE-2 prototypes, and ran DOE-2 simulations.

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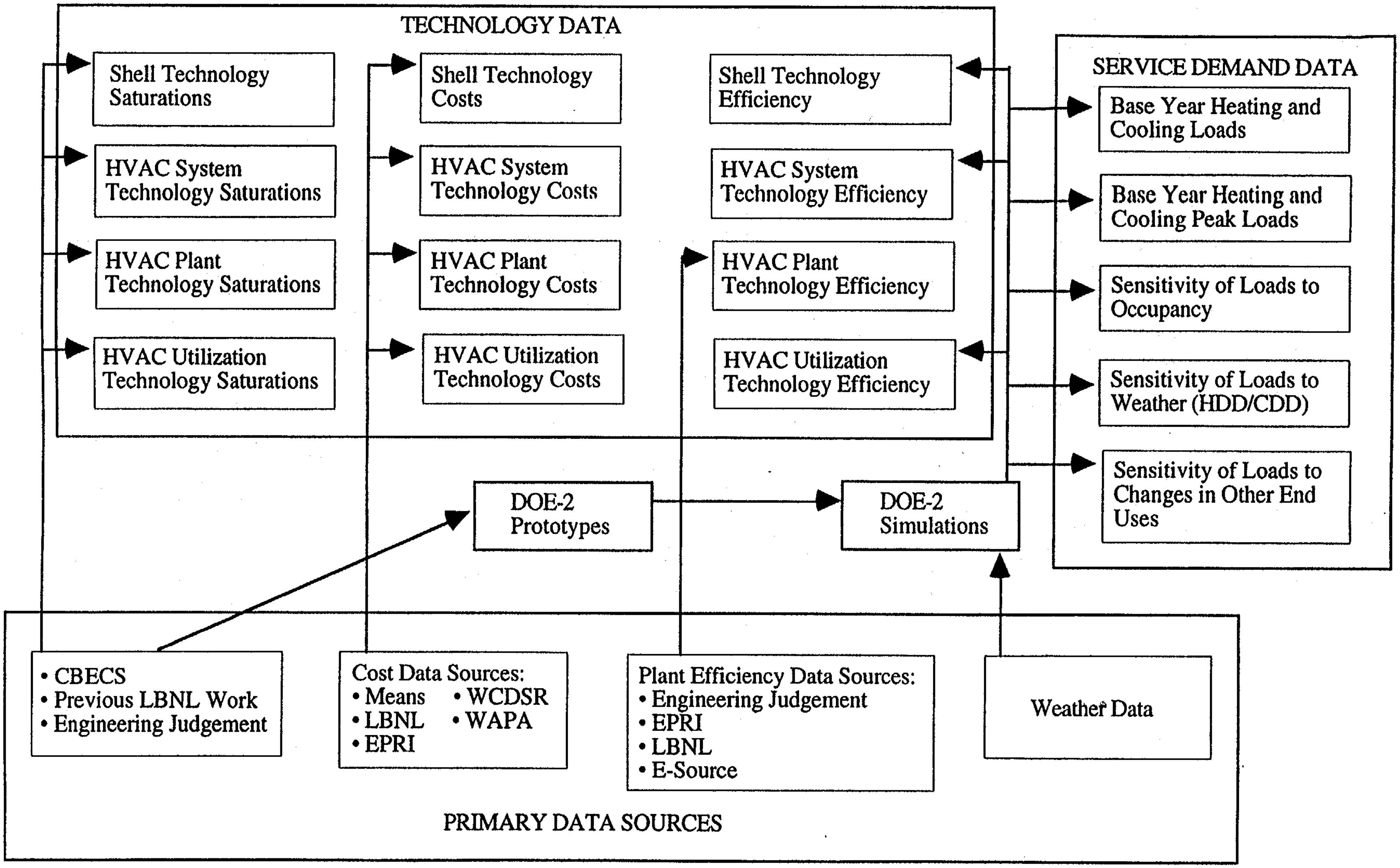
[1] Throughout this report, the term "end use" is used to represent a general category of energy-using technologies such as heating, cooling, or lighting. The term "technology" is used to refer to more specific energy-using equipment such as a heat pump or a boiler.

[2] Throughout this report, the first reference to each table and figure appears in bold.

Figure 1.1. Development of Technology and Service Demand Input Data for COMMEND 4.0



In Section 2 of this report, we provide an overview of the COMMEND model. In Section 3, we describe the development of the market input data required to run the model. In Section 4, we discuss our development of the commercial building prototypes and describe how simulation results were used to develop COMMEND input data. In Section 5, we describe the technology options covered in this report and characterize the saturation of these options in the present building stock. In Section 6, we summarize the cost and efficiency characteristics of the technology options. In Section 7, we discuss our characterization of demand for HVAC services and the sensitivity of this demand to factors external to the HVAC system. In Section 8, we summarize our conclusions regarding this data development project. In Appendix A, we present base-year characterization data for commercial buildings as well as the prototype simulation results for different regions of the U.S.

2. *BASIC OVERVIEW OF THE COMMEND MODEL*[3]

The COMMEND model forecasts future commercial-sector energy consumption by fuel type, building type, and end use. First, COMMEND users enter data that characterizes the commercial energy end-use market in the base-year. The model then forecasts future levels of energy consumption by simulating consumer decisions regarding energy end-use technology options for each year of the forecast. Fuel prices and the growth rate for commercial floor space during the forecast period are exogenous to the model. Based on these exogenous time series data, COMMEND incorporates consumer energy and equipment choices for both new and retrofitted commercial buildings into its updated market characterization for each forecast year. Decisions regarding fuel-switching and the efficiency levels of technologies are determined using a probabilistic choice approach.

In earlier versions of COMMEND, each space-conditioning end use was represented with a technology trade-off curve that related operating costs to equipment costs.[4] In COMMEND 4.0, modeling at the end-use level is still possible. In addition, it is possible to perform a more detailed analysis based on the modeling of specific building characteristics, HVAC distribution systems, and a wide variety of heating and cooling technologies.

The primary features of the detailed HVAC model are as follows:[5]

- In place of general end-use categories, the model uses an expanded set of technology definitions.

- The model determines energy use in three steps. First, building loads are computed based on thermal shell attributes, weather conditions, and internal gains. Second, loads are modified according to the type of HVAC system and saturation of system control options. Third, heating and cooling plant energy usage are computed based on the modified loads and plant efficiencies.

- The model explicitly accounts for the key elements of heating and cooling loads, including conductive gains and losses, solar transmission gains, infiltration, and internal heat gains from both people and end-use equipment.

- The model treats numerous types of HVAC distribution systems. The type of system affects heating and cooling equipment energy use through a set of system factors.

- In addition to the system type, the model considers system controls. This allows estimation of the impacts of simple controls such as cooling/heating set-up/set-back, as well as advanced controls such as energy management and control systems (EMCS). For cooling, economizer cycles are included.

- A wide variety of plant options are considered, including conventional heating equipment, chillers, unitary equipment, packaged equipment, and heat pumps (HPs). For heating equipment, dual fuel options are included. For cooling equipment, electric auxiliary loads are included, as well as primary and secondary plant fuel requirements.

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[3] See Appendix E for a more detailed discussion of the structure of COMMEND.

[4] For end uses that consumed more than one type of fuel, a trade-off curve was defined for each fuel type.

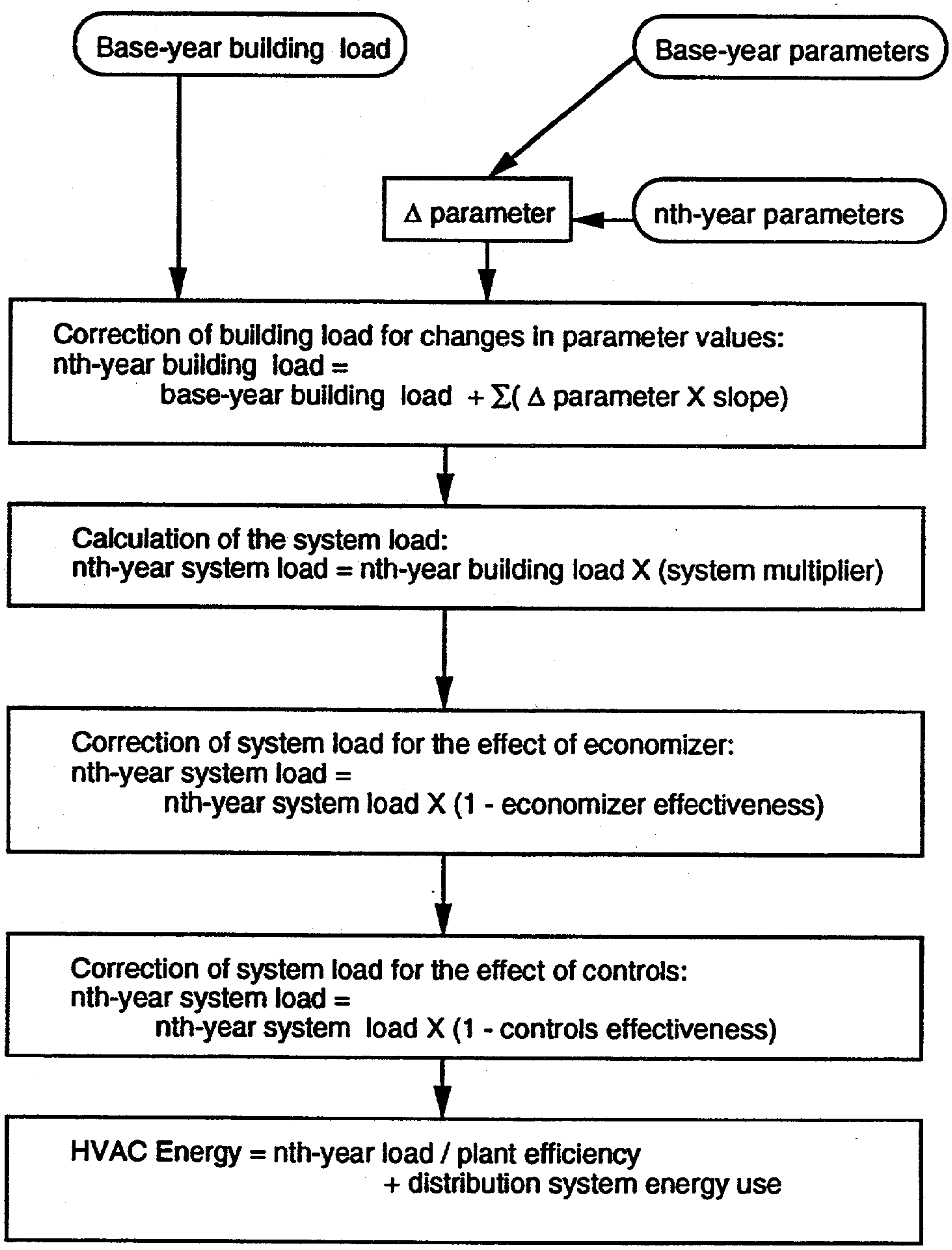
[5] Adapted from COMMEND 4.0 User's Guide [1].

- Changes in equipment efficiency levels can be modeled directly through efficiency equations or in detail through the specification of detailed design options.

- System and plant shares are computed using a set of decision models. These models include: (1) new construction models, which provide system and plant shares in new buildings; (2) plant replacement models, which allow efficiency changes at the time of equipment decay and replacement; and (3) system conversion models, which account for changes in distribution system and in heating and cooling plant.

Figure 2.1 depicts how energy use is calculated based on the variables mentioned above. In essence, for each distinct segment of the floorstock (e.g., newly constructed large offices in Climate Zone 1), the procedure shown in Figure 2.1 is repeated and the consumption is summed over all the segments to get the sectoral energy consumption for the HVAC end use.

Figure 2.1 . Calculation of HVAC loads and energy



* The above figure is applicable to both stock -vintage and new-vintage buildings.

3. DATA REQUIREMENTS

The COMMEND model requires two major data sets in order to generate future patterns of energy consumption: (1) market data for technologies and level of service demand and (2) data on consumer decision-making.

3.1 Market Data

3.1.1. Technologies

HVAC-related technologies can be classified into four groups: shell measures; HVAC distribution systems; HVAC plant; and systems related to the utilization of energy services. Shell measures include wall and roof insulation, window technologies, and weatherization measures. HVAC distribution systems are used to distribute heating, cooling, and/or ventilation to different parts of a building. HVAC plant are where heat and coolth are generated. Utilization technologies, such as controls and economizers, are used to conserve energy while maintaining the same level of energy service.[6]

For each of the four technology categories mentioned above, COMMEND requires three types of market data: saturation, cost, and efficiency. Although saturation, cost, and efficiency data for many technologies are explicitly entered into COMMEND, the input procedure is more complex in some cases. **Table 3.1** summarizes the form of input data accepted by COMMEND.

Table 3.1. COMMEND Input Format for Saturation, Cost, and Efficiency Data

Energy Technology	Saturation	Cost	Efficiency
Shell measures (roof/wall insulation, window technologies, infiltration, etc.)	By building type: Imbedded in the stock and new averages for key parameters such as the window-shading coefficient and R-values for walls and windows	By building type: For retrofit and new applications as a function of R-value, shading coefficient, etc.	By building type: Heating and cooling slopes[a, b]
HVAC Distribution Systems (multizone, ducted variable-air-volume, ducted constant-volume, fan-coil, hydronic, etc.)	By building type	By building type: For retrofit and new applications, as a function of size	By building type: System multipliers to modify load and also system electricity use for fans, pumps, etc.[b]
HVAC Plant (boilers, furnaces, heat pumps, chillers, package units, etc.)	By building type	As a function of capacity and design option (efficiency)	Stock and marginal average efficiencies for all plant technologies and their design options
Utilization Systems (controls, economizers, etc.)	By building type	By building type: For retrofit and new applications	By building type: Impacts of controls, economizers and thermal energy storage systems on energy use[b]

(a) After the heating and cooling loads are developed for the base year, they are modified for forecast years using heating and cooling slope parameters to calculate new building loads that account for the introduction of conservation measures. The heating and cooling slopes quantify the sensitivity of heating and cooling loads to changes in certain shell attributes, such as R-value and window-shading coefficients. These slope parameters are developed using prototype simulations.

(b) Derived from prototype simulation outputs.

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6 With the exception of thermal energy storage systems, which are used to reduce peak demand rather than to conserve energy.

As seen in Table 3.1, saturation data for shell measures are not explicitly specified in the model, but are implicit in the stock and new building averages for shell attributes. On the other hand, saturation data for equipment are input explicitly and are disaggregated by building type. Costs for shell measures are input as functional forms relating cost to key attributes of the measure such as R-value and/or shading coefficient. Equipment costs are generally expressed as a function of capacity for different levels of efficiency (if applicable). Many of the efficiency data are developed using DOE-2 simulations of building performance; the details of the simulation process are described in Section 4.

3.1.2. Service Demand

Users of COMMEND must also enter service demand data into the model. Service demand is characterized by the annual heating and cooling loads in the base year; peak-heating and -cooling requirements in the base year; and the sensitivity of heating and cooling loads to changes in the efficiency of other end uses, building occupancy, and environmental factors such as weather conditions.

Average heating and cooling loads by building type are developed using prototype simulations and are used by COMMEND to calculate energy consumption. Average peak-heating and -cooling requirements are also developed from the simulations and are used to size the HVAC equipment as well as calculate its cost.

Service demand data also account for non-HVAC conservation measures that interact with HVAC service requirements. A good example is the interaction between lighting measures and HVAC equipment, where improved lighting efficiency can decrease cooling requirements and increase heating requirements. To deal with such interactions, coincidence factors are defined in COMMEND. Using prototype simulations, we developed coincidence factors for lighting and equipment interactions by building type.

Changes in environmental conditions can affect building energy loads. Over time, occupancy patterns in commercial buildings may change and thus lead to changes in the heating and cooling loads. Such load changes can be accounted for using parameters that quantify the sensitivity of the loads to changes in occupancy level; these parameters are developed using simulation results. Similarly, over time, the average heating and/or cooling degree days for the building stock may change (e.g., as a result of more building construction in one part of the U.S. than in another). Where there is a change in a building's average degree days, the building's average load will be affected; using simulation results, sensitivity parameters can be developed to account for the consequent load change.

3.2 Consumer Decision-Making Data

The parameters used to forecast consumer decision-making include consumer price expectations based on past fuel prices; short-term utilization elasticities; equipment- and fuel-choice elasticities; discount rate preferences; and consumer resistance to change in retrofit situations. In our analysis, we did not create a new data set to describe consumer decision-making or how consumer choices may change in the future; instead, we rely on the COMMEND default choice parameters.

4. PROTOTYPE SIMULATIONS

As mentioned in the previous section, a large portion of the HVAC technology and service demand input data for COMMEND was generated using prototype simulations. In this section, we describe our development of prototypes that represent the U.S. commercial building stock. In addition, we discuss the limitations of the data sources that were used to develop the prototypes and describe how the simulation results were used to develop COMMEND input data.

4.1 Developing Commercial Building Prototypes

To generate input data for characterizing the U.S. commercial building stock in COMMEND, we used the DOE-2 computer program to simulate the performance of 12 categories of commercial building prototypes:

- Large Offices,
- Small Offices,
- Large Retail,
- Small Retail,
- Warehouses,
- Schools,
- Hospitals,
- Fast-food Restaurants,
- Sit-down Restaurants,
- Large Hotels,
- Small Hotels, and
- Supermarkets.

The prototypes are based on average building characteristics determined from the Commercial Building Energy and Consumption Survey (CBECS) [2], engineering judgement, and some of the original assumptions used in a previous LBNL study by Huang et al. [3], titled "481 Commercial Building Prototypes for Twenty Urban Market Areas." The prototype models for large offices, large retail, schools, warehouses, hospitals, small and large hotels, restaurants, and supermarkets were adapted from Huang et al. [3]. The warehouse model is based on a DOE-2 model that was developed in a study by Akbari et al. [4]. We developed the small office and small retail simulation models specifically for this analysis.

Building survey statistics from the 1989 CBECS were used to characterize the 12 categories of commercial building prototypes. The 1989 survey contains data for more than 6000 buildings. Since the inception of CBECS in 1979, five commercial building surveys have been completed by the Energy Information Administration (EIA). The 1992 CBECS was not available in an electronic format at the time these prototypes were developed. *Tables B.1 through B.8* in Appendix B present summaries of the 1989 CBECS data for each building type.[7] *Tables C.1 through C.8* summarize the building characteristics for each building prototype category.

EIA develops a weighting factor for each building surveyed by CBECS based on region and floor area. The factor represents the number of buildings in one of the four census regions that are similar to the surveyed building in terms of floor area. The weighting factor and the floor area of each surveyed building are used to extrapolate total floor area by building type. We also used this

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[7] CBECS does not distinguish between sit-down and fast-food restaurants. Thus, we assumed that the building shell characteristics determined from CBECS were identical for both types of restaurants; however, as a result of their different types of operation, the DOE-2 models for the two restaurant types are different.

CBECS weighting factor to determine building characteristics related to floor area such as shell and occupancy. We assume that buildings of the same type and floor area, if they are located in the same region, have the same construction, equipment, and operating characteristics. Although this is not necessarily precisely correct, using the weighting factor to characterize many buildings based on a sample of buildings is a reasonable first-order approximation.

Based on the 12 prototype building categories listed above, as well as differences in climate and building vintage, we developed 36 specific building prototypes for the simulations that were used to generate input data for the COMMEND model. These 36 prototypes are indicated in **Table 4.1**.

Table 4.1. The 36 Commercial Building Prototypes

Building Prototype Categories	Stock Prototype	New Prototype
Large Offices	North & South	North & South
Small Offices	North & South	North & South
Large Retail	North & South	North & South
Small Retail	North & South	North & South
Warehouses	North & South	North & South
Schools	North & South	North & South
Hospitals	Entire U.S	Entire U.S
Fast-food Restaurants	Entire U.S	Entire U.S
Sit-down Restaurants	Entire U.S	Entire U.S
Large Hotels	Entire U.S	Entire U.S
Small Hotels	Entire U.S	Entire U.S
Supermarkets	Entire U.S	Entire U.S

Separate prototypes for northern and southern climates were developed only for building types in which energy use was significantly affected by climate (large and small offices, large and small retail, warehouses, and schools). The other six building prototype categories are characterized for the U.S. as a whole. This climatic disaggregation is discussed in greater detail below.

In addition, each of the 12 building types is characterized and modeled as both "stock" and "new". Stock building prototypes are based on 1989 CBECS data for all vintages in the survey. New building prototypes are based on CBECS data for buildings constructed between 1980 and 1989. Each table in Appendices B and C presents building characteristics for both building vintages.

4.2 Prototype Characteristics

For each prototype building category, we developed climate, shell, operating, and lighting characteristics. We based our development of building characteristics on engineering judgement and CBECS data (provided in Appendix B) and, in this section, we describe the development process. In general, except for lighting and equipment energy use, the shell and operating characteristics presented for each building type in Appendix C are based on CBECS data. Because our goal in developing input data for COMMEND was to represent energy use for each building type rather than specifically matching the energy use of individual buildings, we specified prototype floor areas based on mean rather than median values for building floor area.

4.2.1 Climate Categorization

As mentioned above, we characterized six of the 12 prototype building categories by regional data for the North and South. Our regional categorization of "North" includes the CBECS northeast and midwest census regions; "South" includes the CBECS south and west census regions. The other six building categories are characterized for the entire U.S. Generally, the buildings subdivided by region were better represented in the CBECS data base because they make up a larger percentage of the commercial building floor area.

Table 4.2 presents five CBECS degree-day categories and the five cities that we chose to represent these climate categories: Minneapolis, Chicago, Washington D.C., Pasadena, and Charleston. Table 4.2 also presents the cooling degree days (CDD) and heating degree days (HDD) for each of the five cities. Minneapolis and Pasadena were selected because they are large population centers within their climate classification. Chicago and Charleston were selected because they represent the population-weighted average climate for the northern and southern U.S., respectively. Washington, D.C. was selected because it is the population-weighted, national average climate [5]. The CDD and HDD for these five cities represent those for the entire zone. **Figure 4.1** depicts the five CBECS climate zones referred to in this study.

Table 4.2. Cities Representing the CBECS Climate Categories

CBECS Climate Classification	Location	CDD*	HDD*
Zone 1: CDD<2000; HDD>7000	Minneapolis	750	8070
Zone 2: CDD<2000; 5500<HDD<7000	Chicago	998	6194
Zone 3: CDD<2000; 4000<HDD<5500	Washington, D.C.	1425	4236
Zone 4: CDD<2000; HDD<4000	Pasadena	1053	1670
Zone 5: CDD>2000; HDD<4000	Charleston	2047	2193

* At 65° F

For the six building types that were modelled using regional data, the floorstock in Zones 1 and 2 was modeled using the North prototypes and the appropriate climates (Minneapolis and Chicago, respectively). The floorstock in Zones 4 and 5 was modeled using the South prototypes and the corresponding climate data (Pasadena and Charleston, respectively). The floorstock in Zone 3, represented by Washington, D.C. climate data, is divided into two parts. One part of Zone 3's floorstock is modeled using the North prototypes and the other part is modelled using the South prototypes. **Figure 4.2** summarizes the relationship between the building prototypes and the climate zones defined and used in this study. For the remaining six building types that were not modelled using regional prototypes, the same prototype was simulated in all five climates.

Based on the CBECS data, there is a small percentage of building area in the South that is located in the two coldest climates. This is due to the fact that some of the Western Census Division buildings are located in Climate Zones 1 and 2. In the prototype tables in Appendix C, we adjusted the floor area for the North in Minneapolis and Chicago to include the floor area for the southern buildings located in colder climates. As a result, the percentages of northern floor areas add up to more than 100% and the percentages of southern floor areas add up to less than 100% but the total floor area is correct.

Figure 4.1. U.S. Climate Zone Map [2]

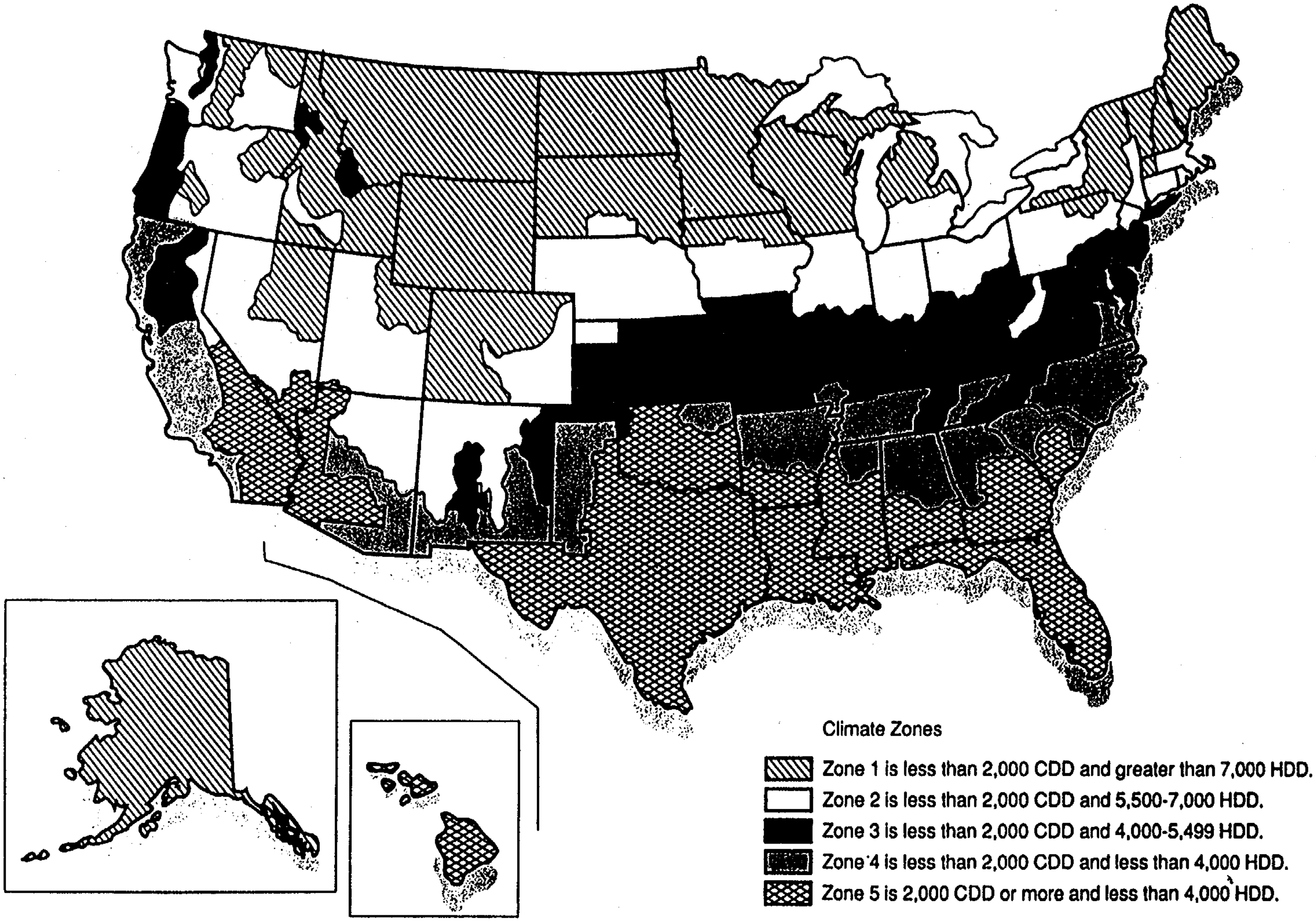
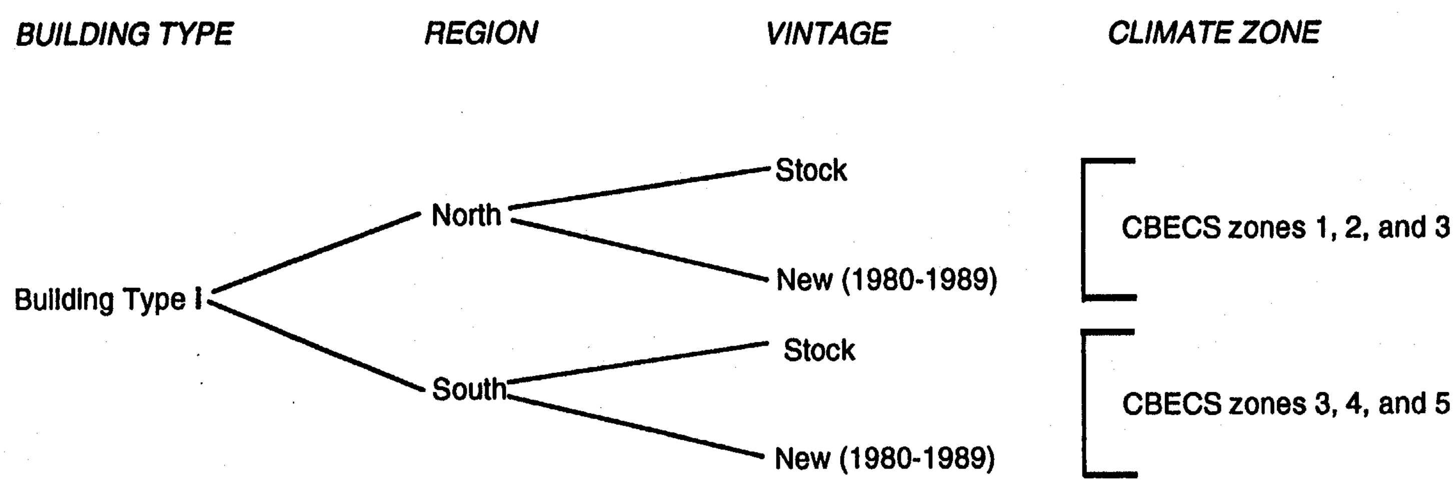


Figure 4.2. Building prototypes and associated weather



4.2.2. Shell Characteristics

To specify shell characteristics for the prototypes, we used floor area weighted averages determined from CBECS "present" or "not present" percentages and nominal R-values which we specified. For wall insulation, we used a nominal value of R-7. For roof insulation, the nominal value was R-14. For windows, the nominal value for single glazing was R-1.1; for double glazing (storm windows present) the value was R-2.0. To determine the prototype shading coefficient (SC), we averaged nominal SC values for tinted and non-tinted single- and double-paned windows. We assumed that if 40% of the windows were reported to be tinted, 40% of both the single-paned and double-paned windows were tinted. To calculate the SC for each prototype, we set the SC of single-paned non-tinted office windows to 0.9, single-paned tinted windows to 0.75, double-paned non-tinted windows to 0.77, double-paned tinted windows to 0.65, and found the weighted average.

4.2.3. Operating and Lighting Characteristics

CBECS provides limited information regarding energy end uses. For lighting, CBECS specifies the percentage of floor area lit by different categories of lighting equipment, but the extent to which the systems overlap and the amount of energy they use is not provided. In addition, details on office equipment are not requested by the survey. The energy use of lighting and equipment that is specified in the prototypes is based on values established in previous prototype studies and measured end-use studies [3, 4, 6]. When reconciling inconsistent lighting power density values from different studies, we used the CBECS equipment combination data to choose the more appropriate value.

Because we are developing annual load estimates and not evaluating peak demand, total energy use is of primary importance. The annual energy use from lights and equipment is dependent on the number of hours of operation and the fraction of their capacity that is used. For many of the prototypes, the power densities for lighting and equipment as well as their operating schedules differ by building zone. Therefore, we calculated a floor-area weighted average power density for lighting and equipment for each prototype. These values are presented in Appendix C. Also reported in the tables are the equivalent full load operating hours for lighting and equipment (plug loads). Multiplying the power density by the full load hours gives the total annual load. We verified that the annual consumption was consistent with measured building loads. The comparison was made with the values in Akbari et al. [4].

4.2.4. Building Prototypes

This section provides the details of, and the data sources for, development of the 12 commercial building prototypes used in our simulations.

Offices

Offices represent 11.8 trillion square feet (ft^2) or 19% of U.S. commercial building floor area. Their total site energy consumption in 1989 was 1.23 quads, 21% of the total site energy consumption for commercial buildings. The 1989 CBECS data base contains survey data for 1028 offices. To develop office prototypes, we divided offices into two size categories (small and large) and two region categories (north and south). We defined small offices as having floor areas less than 25,000 ft^2 and large offices as having floor areas greater than or equal to 25,000 ft^2. The prototype characteristics for shell and climate are based on CBECS data. For large offices, the DOE-2 building models are adapted from the LBNL prototype model for a large 12-hour office [3]. The large office model consists of five zones per floor, one core and four perimeter zones. We developed a small office model that consists of two zones per floor - a warmer zone in the southern portion of the office and a cooler zone in the northern portion of the office.

Retail

Retail buildings (mercantile and service) comprise 12.4 trillion ft^2 or 20% of U.S. commercial building floor area. Their total site energy consumption in 1989 was 1.05 quads or 18% of the total site energy consumption for commercial buildings. The 1989 CBECS data base contains survey data for 1162 retail buildings. To develop retail prototypes, we divided the building category into two sizes (small and large) and two regions (north and south). Small retail buildings have floor areas less than 25,000 ft^2 and large retail buildings are greater than or equal to 25,000 ft^2. The retail building prototype characteristics for shell and climate are based on CBECS data. The large retail building models are adapted from the LBNL prototype model for a large retail building [3]. The large and small retail prototypes are modeled with one zone per floor. The number of floors for small and large retail prototypes varies by region and is reported in Appendix C.

Warehouses

Warehouses comprise 15% of commercial building floor area. Their total site energy consumption in 1989 was 0.54 quads or 9% of the total site energy consumption for commercial buildings. Warehouses are classified as being refrigerated or unrefrigerated in CBECS. According to the survey, there are 8.8 trillion ft^2 of unrefrigerated warehouses and 0.4 trillion ft^2 of refrigerated warehouses in the U.S. The 1989 CBECS data base contains survey data for 855 warehouses. To develop the warehouse prototypes, we divided the building category into two regions (north and south).

Our warehouse model describes a non-refrigerated warehouse. Because we are concerned with HVAC in this study, we did not model refrigeration energy use. In addition, refrigeration equipment for most warehouses is located outside the warehouse; thus, waste heat from the equipment does not affect HVAC energy use. Our warehouse prototype models are adapted from an LBNL study for Pacific Gas & Electric [4]. The warehouse model has two zones: storage and office. The storage area is 80% of the total floor area and is not conditioned. The office area makes up the remaining 20% of the floor area and is conditioned.

Schools

Educational buildings represent 8.1 trillion ft^2 or 13% of total commercial building floor area. Their total site energy consumption in 1989 was 0.7 quads or 12% of the total site energy consumption for commercial buildings. The 1989 CBECS data base contains survey data for 679 educational buildings. To develop school prototypes, we divided the building category into two regions (north and south). We developed school prototypes for the U.S. based on the prototype for secondary schools used in the LBNL prototype study [3]. The school prototypes are based on shell and climate characteristics determined from CBECS. The DOE-2 school model consists of six zones: library, gymnasium, auditorium, kitchen, cafeteria, and classrooms. Occupant density, equipment power density, lighting power density, and operating schedules are defined separately for each zone. During the school year, the classrooms are occupied after regular school hours for extracurricular activities. During the summer, the classrooms are occupied for about half the day.

Hospitals

Inpatient health-care facilities comprise 1.6 trillion ft^2 or about 3% of U.S. commercial building floor area. Their total site energy consumption in 1989 was 0.29 quads, 5% of the total site energy consumption for commercial buildings. The 1989 CBECS data base contains survey data for 137 hospitals. We developed one regional hospital prototype based on the hospital prototype used in the LBNL study [3]. Shell and climate characteristics for the prototype are based on the 1989 CBECS data for inpatient health-care facilities. The DOE-2 model consists of five zones: perimeter rooms; core and public spaces; kitchen; hallways; and clinic. Occupant density, equipment power density, lighting power density, and operating schedules are defined separately for each zone.

Restaurants

Food service buildings comprise 1.2 trillion ft^2 or 2% of U.S. commercial building floor area. Their total site energy consumption in 1989 was 0.25 quads or 4% of the total site energy consumption for commercial buildings. The 1989 CBECS data base contains survey data for 189 food service buildings. We divided food service buildings into two building types: fast-food restaurants and sit-down restaurants. We assumed the total food service building area was divided equally between the two restaurant types. This assumption is based on census data for restaurants in the U.S. [7]. We assumed that the shell R-values and climate data are the same for both restaurant types, and based these values on 1989 CBECS data. The DOE-2 models are adapted from the LBNL study [3]. Floor areas, window wall ratios, and power densities for the restaurant prototypes are also based on the LBNL values for fast-food and sit-down restaurants. The floor area in the fast-food restaurant is divided equally between the kitchen zone and the dining zone. The kitchen area of the sit-down restaurant is 20% of the floor area and the dining area is 80%.

Lodging

Lodging represents 3.5 trillion ft^2 or 5.5% of total U.S. commercial building floor area. Their total site energy consumption in 1989 was 0.4 quads or 7% of the total site energy consumption for commercial buildings. The 1989 CBECS data base contains survey data for 234 lodging establishments. We divided lodging into two building types: large hotels (those with floor area greater than 50,000 ft^2) and small hotels (those with floor area equal to or less than 50,000 ft^2). The large and small hotel prototypes are adapted from the hotel and motel LBNL prototypes, respectively [3]. The prototypes' shell and climate characteristics are based on 1989 CBECS data for lodging. The DOE-2 model for the large hotel consists of three zones: rooms; lobby and conference area; and kitchen and laundry area. The room area is 70% of the floor area, lobby/conference area is 25%, and kitchen/laundry is 5%. Occupant density, equipment power density, lighting power density, and operating schedules are defined separately for each zone. Similarly, the small hotel has three zones: rooms, lobby, and laundry. The room area is 90% of the total area, the lobby 5%, and the laundry 5%.

Food Stores

Food sales buildings comprise 0.8 trillion ft^2 or 1% of U.S. commercial building floor area. Their total site energy consumption in 1989 was 0.14 quads or 2% of the total site energy consumption for commercial buildings. The 1989 CBECS data base contains survey data for 86 food stores. Based on CBECS data, we found that more than 70% of the food service floor area is accounted for by buildings greater than 5000 ft^2. Thus, for our analysis, we modeled a supermarket.[8] The DOE-2 supermarket models are adapted from the LBNL 18-hour supermarket prototype [3]. The shell and climate characteristics are based on 1989 CBECS data. Building area and power densities are based on the LBNL prototype description. The DOE-2 model consists of five zones: sales area, deli, bakery, office, and storage. Occupant density, equipment power density, lighting power density, and operating schedules are defined separately for each zone.

[8] Smaller food stores might be better characterized as "groceries". Because of the small amount of food service floor area in groceries compared to supermarkets, grocery energy use is assumed to be far less significant than supermarket energy use.

4.2.5. System Prototypes

Efficiencies of the different HVAC systems are also developed through prototype simulations. Each prototype building described above is modelled with the following nine HVAC systems:

- Hydronic
- Constant-Volume Reheat
- Constant-Volume Reheat with Economizer
- Multizone
- Multizone with Economizer
- Variable-Air-Volume with Reheat
- Variable-Air-Volume with Reheat and Economizer
- Fan-Coil
- Heat-Pump Loop

The details of how we modelled each system are described below. See the Technology Data Sheets in Appendix D for general information about each system type.

<u>Hydronic Baseboards with Window Air Conditioners</u>

To determine the system load for hydronic heating, we modeled hot water baseboard heating in the prototypes with DOE-2. We coupled the baseboards with window/wall air conditioning units. The baseboard/window AC system does not include mechanical ventilation although operable windows are modeled. One system factor is defined for heating: it equals the system heat load divided by the base-case building heat load. The system heat load determined by DOE-2 and listed in the tables is not much greater than the building load since heat is only delivered when needed and the distribution losses are small. Part of the energy used by the circulation pump is absorbed by the hot water and helps to meet the load. The energy required for the hydronic system is the energy used by the circulation pump.

<u>Constant-Volume Reheat System</u>

The constant-volume reheat (CVRH) system supplies a constant volume of cooled air to the zone terminals. We modeled this system slightly differently for small buildings (small office, small retail, fast-food restaurant, sit-down restaurant, and small hotel) and large buildings (large office, large retail, school, hospital, warehouse, large hotel, and supermarket). The large buildings' system is modeled in DOE-2 with a CVRH system that produces cool air at a constant temperature. If any or all of the zones require heating, the cool air is reheated at the zone terminal and delivered to the space. The small buildings' system is modeled as a single zone reheat (SZRH) system that conditions the air to meet the requirements of a control zone (usually specified as the zone that needs the most cooling). The air supplied to other zones is reheated at the zone terminal, if necessary. This system tends to do less cooling and reheating than the CVRH system. The SZRH system's heat load is low compared to the base-case building load because part of the fan energy, accounted for in the system electrical energy-use value, contributes to the heat load.

We simulated CVRH and SZRH systems both with and without an economizer. An economizer enables the system to use 100% outdoor air to help reduce the cooling load. A minimal amount of outdoor air is used if the outdoor air temperature is greater than the return air temperature or if cooling is not required. For the CVRH system, cooling always occurs so the economizer is always enabled. This results in an increase in the CVRH system heating load when an economizer is used. Two system factors are defined for the reheat systems, one for heating and one for cooling. Electrical energy is required by the system supply and exhaust fans.

<u>Multizone System</u>

A multizone system is a constant-volume air system that supplies both heated and cooled air to the zone terminal. The air is mixed at the terminal in appropriate proportions to meet the conditioning requirements of the zone with a fixed amount of air. We modeled this system with and without an economizer. Due to the economizer control strategy and the configuration of the system, heating energy greatly increases when the economizer is used. When in operation, the economizer supplies outdoor air to both heating and cooling coils, causing cooling energy to be reduced and heating energy to increase. Two system factors were calculated for this system, one for heating and one for cooling. Electrical energy is required by the system supply and exhaust fans.

Variable-Air-Volume System with Reheat
Variable-air-volume (VAV) systems are among the more efficient air distribution systems. Cooled air is supplied at a constant temperature to the zone terminal boxes. If the zone cooling load is high, the boxes are wide open; if low, the boxes supply a minimal amount of cool air. If heating is required, the air is reheated and then introduced to the zone. The variable supply volume results in decreased reheating, air flow, and fan energy use. We modeled this system with and without an economizer. Since reheating is decreased in this system, there is less of a heating penalty when the economizer is used. Two system factors were calculated for this system, one for heating and one for cooling. Electrical energy is required by the system supply and exhaust fans.

Fan Coils
We used a four-pipe fan-coil (FPFC) system to model fan coils in DOE-2. This system has a cold supply and return, a hot supply and return, and a fan-coil unit in each zone. Outdoor air is introduced at each fan coil to meet ventilation requirements. Since the FPFC system is hydronic, the air flow rates are lower than for systems using air distribution systems. Thus, energy consumption in this system is much lower for the fan than for the air distribution. Since the piping losses are low, the FPFC system loads are not much higher than the base-case office loads. We determined two system factors for fan coils, one for heating and one for cooling. Electrical energy is required for pumping the hot and cold water and also for the zone fans.

Heat-Pump Loop
The heat-pump loop circulates working fluid to HP units located in individually controlled zones. The HPs provide a fixed quantity of outside air to the zones for ventilation. Each HP unit supplies heating or cooling to the zone as needed and has a working-fluid-to-refrigerant heat exchanger. The working fluid absorbs heat from zones that are cooling and gives up heat to zones that are heating. The working fluid is allowed to float within a specified temperature range. When the range is exceeded, excess heat is ejected; when the temperature falls below the range, heat is added.

4.3 The Limitations of Energy and Building Characteristics Data

The lack of data characterizing the national building stock and end-use energy consumption limits our ability to develop building characteristics and prototypes, and it is *because* of this lack that we are developing data for the COMMEND forecasting program. Thus, in spite of limitations, we are using the available data, making engineering judgments, and analyzing technologies and their efficiencies in order to form a more detailed and technologically-oriented description of national building energy consumption. As discussed below, some of our estimates of building characteristics are rough as a result of limited data. However, by recognizing the limitations of existing data sources, we hope to encourage the development of more reliable data in the future.

Although the CBECS survey is one of the most exhaustive sources of U.S. building characteristics, it does not ask all of the questions that we need answered to determine the condition of the U.S. building stock. For example, the presence of wall and roof insulation are noted in the survey, but the amount of insulation is not. Individual pieces of heating and cooling equipment are specified, but the fraction of floor area that each conditions is not. In addition, because heating equipment is reported separately from cooling equipment, one cannot directly determine the combinations of equipment found together. It is also difficult to distinguish between primary and secondary equipment.

Analysis is further complicated by the fact that, for most CBECS questions related to HVAC, more than one answer can be selected for a single question. Where there were multiple answers for an equipment question, we added together the weighted floor area of each piece of equipment reported.[9] Consequently, where buildings had more than one piece of equipment, the sum was greater than the total floor area. To correct for this overcounting, we normalized the sum of question responses to the total floor area.

Additionally, some of the 1989 CBECS data describing HVAC distribution systems and controls were very different from values published in other sources. In general, examining the raw data without discretion can lead one to discern differences between size and vintage categories that may not exist. Although CBECS is a valuable source for describing commercial buildings in the U.S., the data it supplies must be further synthesized and coupled with engineering judgment in order to be useful for describing prototype buildings.

4.4 DOE-2 Simulations

To capture the effect of conservation measures, climate, and HVAC systems on building energy use, we completed more than 3400 DOE-2 simulations. We modeled the prototypes using the DOE-2 computer simulation program to determine the building loads, system loads, and HVAC system energy use required by COMMEND. The DOE-2 input files for the prototypes are available upon request from LBNL.

DOE-2 calculates hourly energy use for a year for a building in a specific location. The northern building prototypes are simulated with weather data for Minneapolis, Chicago, and Washington D.C. The southern building prototypes are simulated for Washington D.C., Pasadena, and Charleston. The national prototypes are simulated in all five cities. The program uses hourly weather data in its calculations. For this analysis, we used the following weather files: Minneapolis WYEC data, Chicago TMY data, Washington DC WYEC data, California Climate Zone 9 data for Pasadena, and Charleston WYEC data.

4.4.1 Building Loads

In our analysis, the building load is defined as the amount of heating or cooling the system must supply to a building in order to meet the temperature set-points. In COMMEND, the building load factor or load elasticity is the ratio of the change in building load to the change in building characteristics. Elasticities (slopes) for eight different building characteristics are analyzed for each prototype in this study: window R-value, window-shading coefficient, wall R-value, roof R-value, air leakage rate, window area to wall area ratio, lighting power density, and number of occupants. For most of the parameters, we modeled a low and high value case. The base-case loads fall between the loads determined for the low and high retrofit values. The base-case condition of the prototype is based on the characteristics presented in Appendix C. The high and low retrofit conditions are specified based on engineering judgment and are intended to cover the range of options available in the market.

Because we wanted to include the load from ventilation with the building load, we developed a user-defined DOE-2 function to modify the load calculation so that it included the outdoor air load during the hours that the system fan was scheduled to be on. The ventilation requirement for the

[9] Each answer to a question is credited with the floor area of the building times its weight factor.

modeled buildings is 15 ft^3 of fresh air per person per minute. The model determines the total flow rate based on the building's occupant density, floor area, and ventilation requirement.

4.4.2. HVAC Distribution System Load Factors and Electrical Energy Use

The system load is the amount of heating and cooling the HVAC plant has to provide to the distribution system in order for the building load to be met. The system factor is a multiplier used with the base-case building load to translate the building load to the system load; the system factor varies depending on the type of distribution system and its control strategy. In addition to affecting the heating and cooling loads, the HVAC system uses electrical energy to drive fans and pumps. COMMEND accounts for this electricity consumption with the system electric energy-use variable.

System load factors were calculated as the ratio of the system load to the building load (both of which are DOE-2 outputs). System electricity use is calculated as the sum of the pump and fan electricity use. For air conditioners, packaged unitary systems, and heat-pump loops, the system efficiency and the system electricity use are included as part of the plant efficiency. Thus, for these equipment types in COMMEND, we use a system factor of 1.0 and a system electricity use of 0.0. The effect of economizers is represented as a percent reduction in load in COMMEND; this load reduction is calculated based on simulated loads with and without economizers.

4.4.3. Plant Energy Use

Using DOE-2, we were able to simulate the central plant and obtain energy use as an output. Although we used DOE-2's plant simulation option, the plant model was just a place holder and we did not rely on the output of the plant section for estimating the plant efficiencies presented in this report.[10] The default parameters in DOE-2 for plant components (e.g., chiller efficiency, tower capacity) do not necessarily represent such parameters for the stock of equipment that is in use. There was not enough data available for us to estimate the features of a central plant model that represented the equipment stock. We therefore relied on empirical and anecdotal data when we developed plant efficiencies for input to COMMEND.

4.5 Compilation of Prototype Data and Simulation Results in Default COMMEND Format for the U.S.

As described above, 36 prototypes were developed and their energy responses were simulated using representative climates in the U.S. The regional nature of the prototype data and simulation results are preserved in this report so that our findings may also be used for regional simulations and/or analysis. The characterization data and simulation results are presented by: (1) building prototype category; (2) vintage (stock and new); and (3) climate zone. *Tables A.1 through A.9* in Appendix A present COMMEND data related to building prototypes and simulation results.[11]

COMMEND data requirements for building characteristics and efficiency parameters for the U.S. as a whole can be developed by averaging the regional data in Appendix A using weights based on the floor-area distribution. These weights are also provided in Appendix A. The distribution of the total floor area by building prototype category, vintage, and climate zone is presented in Table A.1. Averages for the characterization and efficiency data can be developed using three sets of area-related matrices: total area, percent cooled, and percent heated. Some results are averaged using only the distribution of total area as weights, while others are averaged using the distribution of conditioned area as weights.

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[10] Except for the window air conditioner and the heat pump loop, all of the systems described above were modeled in DOE-2 with the same plant – a gas boiler, centrifugal chiller, and cooling tower.

[11] Although the data in a few of the tables is somewhat redundant, we have used this table format in order to represent the precise format in which the data would be entered electronically.

Building types in COMMEND are user-defined and there is no practical limit on the number of them or what they should be. On the other hand, there is one set of building types that has traditionally been used. Many of the default parameters for COMMEND are for this traditional set of building types. The building types covered in this report are very close to the default COMMEND building types. In COMMEND's default set of building types, there is only one type of restaurant, one type of lodging, and one type of retail building. In contrast, in this report we use two types of restaurants (fast-food and sit-down), two types of lodging (large and small hotels), and two types of retail (large and small). The data in this report can be averaged using the appropriate weights mentioned above to get input data for restaurants, lodging, and retail buildings. We modelled restaurants, lodging, and retail buildings using sub-models where we believed that there were significant distinctions among buildings within a single prototype category; for example, the characteristics of fast-food restaurants are very different from those of sit-down restaurants.

The COMMEND model includes default building types for both schools and colleges. The school data that we developed for this report can be used for the COMMEND school building type. In general, colleges are different from schools: for our forecasts at LBNL, we assume the floor area of colleges to be 27% of the total CBECS floor area for educational buildings and 5% of the total CBECS floor area for assembly buildings. Consequently, about 85% of college floor area resembles school floor area in terms of building characteristics, and the other 15% is accounted for by assembly buildings such as theaters. Operating hours for assembly buildings tend to be low. On the other hand, operating hours in the other educational buildings are longer for colleges than for secondary schools. Thus, compared to school buildings, college educational buildings have an increased load; however, the inclusion of assembly buildings decreases the load. Because of the balancing effect of the load changes, we use the same data for colleges that we use for schools. In the future, if prototypes for assembly buildings are developed, data based on these prototypes can be used in combination with school data to generate more accurate college data.

5. *TECHNOLOGY OPTIONS AND SATURATION*

In this section, we summarize the technology options considered in this study and estimate current saturation levels for these options. Saturation indicates how much floorspace is already equipped with the type of equipment or measure under consideration. The primary source of our saturation data is the 1989 CBECS [2].

5.1 Shell Options

Technology options related to the building shell include variations in the following shell characteristics: roof, wall, and window R-values, window-shading coefficients, window-to-wall ratios, and air change rates (infiltration) for the building. Saturation of different levels of these attributes for the existing stock and new buildings are not characterized explicitly. Instead, shell measure saturations are imbedded in the stock and marginal averages for these parameters.

The shell characteristics of the prototype buildings were selected to meaningfully represent the floorstock based on CBECS 1989 data. The methodology is discussed in detail in Section 4. The average U.S. values for these characteristics, by building type, are given in **Table 5.1**; Table A.2, Appendix A, presents the data by region.

5.2 HVAC Options

An HVAC application is a combination of a heating plant, a cooling plant, and an HVAC system that distributes the heat and/or coolth in the building. More than one of these three components may be embedded in a single piece of equipment. For example, heat pumps and package units function as both heating and cooling plant. Also, unitary systems do not always utilize an external distribution system - in this case, the system and the plant overlap.

HVAC technologies covered in this study are summarized in **Table 5.2**. This table provides a general overview of the compatibility of classes of HVAC systems and plants. Each plant class can be divided into subclasses which we refer to as design options. Electric chillers, for example, can be divided into centrifugal, reciprocating, and screw types. In our data base, design options are defined for gas furnaces, gas boilers, heat pumps, and electric chillers.

Many of the HVAC systems are summarized in the Technology Data Sheets in Appendix D. These sheets provide a general description of each technology covered and discuss the physical characteristics, applicability, energy performance, reliability and lifetime, impacts on the user and utility, product availability, and comments and caveats.

It is also important to consider conversion measures in our analysis. A conversion measure is a measure that is used to replace an existing technology (e.g., a multizone system could be converted to a VAV system or an electric boiler could be replaced with a gas boiler). It is not meaningful to define saturations for conversion activity because conversions are already accounted for in the saturations of the technologies considered in our analysis. Conversions of both HVAC plant and distribution systems are allowed in COMMEND.

Table 5.1. Baseline Characteristics in Commercial Buildings (U.S. Average)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Roof_R	11.6	10.6	9.8	11.0	10.5	12.3	12.2	6.8	10.9	11.2	11.2	7.7
Wall_R	4.7	3.4	2.9	3.2	3.8	4.3	4.6	3.9	3.1	3.6	3.6	2.8
Window_R	1.6	1.5	1.3	1.5	1.5	1.4	1.8	1.5	1.5	1.5	1.5	1.4
Window Shading Coeff	0.81	0.78	0.84	0.79	0.81	0.80	0.71	0.82	0.80	0.80	0.80	0.84
Window/Wall Ratio	0.20	0.45	0.15	0.15	0.24	0.30	0.25	0.15	0.27	0.30	0.20	0.06
Air Change (air change/hour)	0.40	0.30	0.30	0.30	0.25	0.25	0.20	0.30	0.80	0.25	0.25	0.25
Occupancy (ft2/person)	440	430	180	360	120	210	90	227	105	65	50	2085
Heating Degree Day (65°F)	3816	3994	4295	4503	3599	4418	4486	4328	4671	4591	4591	4504
Cooling Degree Day (65°F)	1313	1243	1337	1266	1402	1284	1301	1346	1343	1207	1207	1391

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Roof_R	12.8	11.0	12.7	12.8	13.2	14.0	11.5	11.8	12.9	13.2	13.2	10.4
Wall_R	5.8	5.4	5.4	5.5	5.3	6.2	6.9	5.8	5.5	4.9	4.9	4.2
Window_R	1.7	1.7	1.5	1.6	1.7	1.7	2.0	1.6	1.7	1.5	1.5	1.7
Window Shading Coeff	0.74	0.70	0.81	0.75	0.76	0.74	0.66	0.79	0.72	0.80	0.80	0.81
Window/Wall Ratio	0.15	0.50	0.15	0.15	0.21	0.35	0.25	0.15	0.18	0.20	0.15	0.03
Air Change (air change/hour)	0.40	0.30	0.30	0.30	0.25	0.25	0.25	0.30	0.80	0.25	0.25	0.25
Occupancy (ft2/person)	470	390	180	360	120	210	190	227	105	65	50	1635
Heating Degree Day (65°F)	3578	3772	4090	4007	3452	4435	4314	3399	4385	2842	2842	4392
Cooling Degree Day (65°F)	1273	1255	1300	1427	1548	1423	1373	1485	1378	1615	1615	1600

Table 5.2. Compatibility of HVAC Plant and Various Distribution Systems

	Type of Distribution System						
	Multizone & Dual-Duct	Ducted Constant-Volume	Ducted Variable Volume	Fan-Coil	Hydronic	Water -loop HP	Unitary
Plant Class							
Resistance Heater							✔
Electric Furnace							✔
Electric Boiler	✔	✔	✔	✔	✔		
Gas Furnace	✔	✔	✔				✔
Gas Boiler	✔	✔	✔	✔	✔		
Oil Furnace							✔
Oil Boiler	✔	✔	✔	✔	✔		
Package Unit (Electric)		✔	✔				✔
Air-Source Heat Pump			✔				✔
Dual-Fuel Heat Pump			✔				✔
Water-Loop Heat Pump						✔	
Package Unit(Gas)		✔	✔				✔
Electric Chiller	✔	✔	✔	✔			
Gas Chiller	✔	✔	✔	✔			
Window/Wall Unit					✔		✔
Controls	✔	✔	✔	✔	✔	✔	✔
Economizers	✔	✔	✔				

A ✔ indicates that a particular type of HVAC equipment and distribution system can be used together.

Tables 5.3 through 5.13 summarize the HVAC equipment saturation levels obtained from the 1989 CBECS [2]. Saturations for heating and cooling were developed separately. For the saturations of the heating and/or cooling plant, percentages of floor area associated with the plant types defined in CBECS by primary fuel type are listed. The classes of equipment that clearly do not belong with a certain fuel type are discarded. For example, it would be uncommon to find resistance heaters or heat pumps fueled by gas or oil. After the exclusion of such plant types, the figures are normalized and corrected to represent saturations as a percentage of total floor area. For the saturations of distribution systems, the percent area associated with a certain distribution system is first normalized so that the sum of such percent areas adds up to the percentage of the conditioned space. This is necessary because such percentages usually add to a larger number since a single building may be conditioned by more than one distribution system. Tables 5.3 through 5.13 also present data on the saturations of utilization systems such as time clocks and economizers as a percentage of the total commercial floor area.

The format that COMMEND uses for saturation is similar to the format of Tables 5.3 through 5.13.[12],[13] For other types of analysis, however, it is sometimes more convenient to use the fraction of the floorstock that uses different heating and cooling equipment combinations. Direct estimations of the saturation of HVAC equipment combinations are not possible using only the 1989 CBECS. However, we combined the CBECS data with engineering judgment regarding the compatibility of combinations of heating/cooling equipment and distribution systems to estimate saturations by building type. Saturations of heating/cooling equipment combinations are shown in **Tables 5.14 and 5.15** for both stock and new buildings. Tables 5.14 and 5.15 also show the weighted average of the saturations for the different building types, using the 1989 floor areas attributable to each building type from CBECS 1989. Based on CBECS 1989, it is impossible to estimate the saturations of different types of ducted distributed systems (multizone, VAV, and constant-volume); therefore, all ducted systems are grouped into a single category. We ignored the less important equipment combinations within each building type to create a rough characterization of these saturations.

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12 We developed data for multizone and dual-duct, constant volume (CV), and VAV ducted systems. These three types of systems have very different characteristics, and therefore had to be analyzed and modeled separately. CBECS data is not detailed enough to generate market shares for these different types of systems. In our own forecasts, we assume that multizone and dual-duct systems, CV, and VAV systems represent 35%, 50% and 15% of the floor area served by ducted systems in the building stock, respectively. Half of the floor area in new buildings that use ducted systems are served by VAV systems; the other half are served by CV systems.

13 In the "Cooling" columns of Tables 5.2 through 5.13, the percentage for "Package Units" includes both combined heating/cooling equipment and dedicated cooling equipment. In COMMEND, we used the values in the "Heating" columns for the shares of combined heating/cooling equipment. To calculate the share of packaged cooling equipment (dedicated) for COMMEND, we then added the difference between the shares of package units under Cooling and Heating to the share of window/wall units.

Table 5.3.
Plant, System, and Measure Saturations for Small Retail Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	6%		4%	
Electric Furnace	5%		4%	
Electric Boiler	1%		1%	
Gas Furnace	36%		32%	
Gas Boiler	3%		6%	
Oil Furnace	2%		7%	
Oil Boiler	1%		5%	
Package Unit(Electric)	4%	26%	4%	25%
Package Unit(Gas)	18%		13%	
Air-Source Heat Pump	13%	10%	5%	5%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		1%		1%
Gas Chiller		3%		1%
Window/Wall Unit		8%		13%

SYSTEM

Ducted without Reheat	58%	24%	44%	19%
Ducted with Reheat	2%		3%	
Fan Coil	1%	1%	2%	0%
Hydronic	1%		9%	
Unitary	28%	23%	24%	26%

SUM (Conditioned Area)	89%	48%	81%	45%

UTILIZATION SYSTEM

Load Management	1%	0%
Time Clock	2%	2%
Economizer	0%	0%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.4.
Plant, System, and Measure Saturations for Large Retail Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	4%		7%	
Electric Furnace	7%		4%	
Electric Boiler	1%		3%	
Gas Furnace	15%		18%	
Gas Boiler	5%		11%	
Oil Furnace	1%		2%	
Oil Boiler	1%		3%	
Package Unit(Electric)	23%	51%	15%	35%
Package Unit(Gas)	28%		24%	
Air-Source Heat Pump	5%	5%	3%	5%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		2%		9%
Gas Chiller		2%		2%
Window/Wall Unit		12%		11%

SYSTEM				
Ducted without Reheat	41%	47%	31%	32%
Ducted with Reheat	20%		18%	
Fan Coil	3%	2%	7%	5%
Hydronic	2%		12%	
Unitary	24%	23%	23%	25%
SUM (Conditioned Area)	90%	72%	90%	62%

UTILIZATION SYSTEM	NEW	STOCK
Load Management	1%	0%
Time Clock	0%	4%
Economizer	1%	1%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.5.
Plant, System, and Measure Saturations for Small Office Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	10%		9%	
Electric Furnace	6%		5%	
Electric Boiler	2%		2%	
Gas Furnace	13%		23%	
Gas Boiler	5%		10%	
Oil Furnace	1%		1%	
Oil Boiler	2%		5%	
Package Unit(Electric)	19%	50%	12%	48%
Package Unit(Gas)	9%		12%	
Air-Source Heat Pump	22%	28%	12%	14%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		5%		6%
Gas Chiller		3%		3%
Window/Wall Unit		2%		13%
SYSTEM				
Ducted without Reheat	35%	42%	41%	41%
Ducted with Reheat	5%		7%	
Fan Coil	2%	3%	2%	2%
Hydronic	3%		8%	
Unitary	45%	43%	31%	41%
SUM (Conditioned Area)	90%	88%	91%	84%
UTILIZATION SYSTEM				
Load Management	1%		1%	
Time Clock	2%		3%	
Economizer	4%		1%	

Source: CBECS 1989 [2].
(a) All values are percentages of the total floor area for the building type.
(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.6.
Plant, System, and Measure Saturations for Large Office Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	19%		13%	
Electric Furnace	3%		2%	
Electric Boiler	6%		4%	
Gas Furnace	4%		6%	
Gas Boiler	20%		31%	
Oil Furnace	0%		1%	
Oil Boiler	2%		7%	
Package Unit(Electric)	17%	40%	10%	33%
Package Unit(Gas)	7%		11%	
Air-Source Heat Pump	13%	12%	8%	8%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		32%		30%
Gas Chiller		1%		2%
Window/Wall Unit		4%		11%

SYSTEM				
Ducted without Reheat	12%	31%	11%	27%
Ducted with Reheat	23%		26%	
Fan Coil	10%	18%	13%	15%
Hydronic	9%		17%	
Unitary	37%	40%	26%	41%

SUM (Conditioned Area)	91%	89%	93%	84%

UTILIZATION SYSTEM		
Load Management	2%	4%
Time Clock	5%	4%
Economizer	6%	8%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.7

Plant, System, and Measure Saturations for School Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	4%		2%	
Electric Furnace	5%		1%	
Electric Boiler	4%		1%	
Gas Furnace	5%		11%	
Gas Boiler	34%		46%	
Oil Furnace	0%		2%	
Oil Boiler	10%		14%	
Package Unit(Electric)	11%	41%	3%	21%
Package Unit(Gas)	16%		13%	
Air-Source Heat Pump	6%	11%	2%	4%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		15%		10%
Gas Chiller		4%		3%
Window/Wall Unit		10%		21%
SYSTEM				
Ducted without Reheat	29%	26%	17%	12%
Ducted with Reheat	16%		21%	
Fan Coil	19%	9%	20%	6%
Hydronic	12%		28%	
Unitary	18%	45%	9%	42%
SUM (Conditioned Area)	95%	81%	95%	59%
UTILIZATION SYSTEM				
Load Management	0%		0%	
Time Clock	20%		8%	
Economizer	0%		2%	

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.8.
Plant, System, and Measure Saturations for Restaurant Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	0%		3%	
Electric Furnace	1%		1%	
Electric Boiler	2%		2%	
Gas Furnace	36%		27%	
Gas Boiler	4%		13%	
Oil Furnace	1%		5%	
Oil Boiler	1%		9%	
Package Unit(Electric)	12%	73%	5%	41%
Package Unit(Gas)	26%		14%	
Air-Source Heat Pump	2%	3%	6%	7%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		0%		3%
Gas Chiller		5%		7%
Window/Wall Unit		3%		16%

SYSTEM	New Heating	New Cooling	Stock Heating	Stock Cooling
Ducted without Reheat	57%	58%	41%	25%
Ducted with Reheat	14%		7%	
Fan Coil	0%	0%	2%	1%
Hydronic	7%		17%	
Unitary	7%	26%	18%	47%

SUM (Conditioned Area)	85%	84%	85%	74%

UTILIZATION SYSTEM	New	Stock
Load Management	0%	0%
Time Clock	0%	1%
Economizer	8%	2%

Source: CBECS 1989 [2].
(a) All values are percentages of the total floor area for the building type.
(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.9.
Plant, System, and Measure Saturations for Hospital Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	7%		2%	
Electric Furnace	0%		0%	
Electric Boiler	7%		4%	
Gas Furnace	0%		4%	
Gas Boiler	62%		54%	
Oil Furnace	N/A		0%	
Oil Boiler	N/A		7%	
Package Unit(Electric)	7%	25%	2%	24%
Package Unit(Gas)	17%		14%	
Air-Source Heat Pump	0%	15%	1%	6%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		33%		35%
Gas Chiller		4%		4%
Window/Wall Unit		20%		18%

SYSTEM				
Ducted without Reheat	0%	22%	1%	23%
Ducted with Reheat	36%		32%	
Fan Coil	33%	21%	29%	21%
Hydronic	22%		23%	
Unitary	7%	54%	3%	42%

SUM (Conditioned Area)	100%	97%	88%	87%

UTILIZATION SYSTEM		
Load Management	0%	0%
Time Clock	1%	5%
Economizer	4%	3%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.10.
Plant, System, and Measure Saturations for Small-Hotel Buildings (a, b)

PLANT	NEW Heating	NEW Cooling	STOCK Heating	STOCK Cooling
Electric Resistance	35%		26%	
Electric Furnace	5%		5%	
Electric Boiler	3%		4%	
Gas Furnace	25%		16%	
Gas Boiler	0%		15%	
Oil Furnace	N/A		5%	
Oil Boiler	N/A		3%	
Package Unit(Electric)	15%	26%	7%	20%
Package Unit(Gas)	3%		3%	
Air-Source Heat Pump	1%	3%	3%	4%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		12%		4%
Gas Chiller		2%		3%
Window/Wall Unit		38%		39%

SYSTEM	NEW Heating	NEW Cooling	STOCK Heating	STOCK Cooling
Ducted without Reheat	17%	26%	13%	16%
Ducted with Reheat	22%		13%	
Fan Coil	0%	11%	8%	7%
Hydronic	4%		17%	
Unitary	44%	44%	36%	47%
SUM (Conditioned Area)	87%	81%	87%	70%

UTILIZATION SYSTEM	NEW	STOCK
Load Management	0%	0%
Time Clock	1%	2%
Economizer	4%	1%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.11.
Plant, System, and Measure Saturations for Large-Hotel Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	16%		10%	
Electric Furnace	0%		1%	
Electric Boiler	2%		4%	
Gas Furnace	12%		14%	
Gas Boiler	21%		38%	
Oil Furnace	N/A		0%	
Oil Boiler	N/A		3%	
Package Unit(Electric)	15%	29%	8%	19%
Package Unit(Gas)	22%		10%	
Air-Source Heat Pump	1%	2%	6%	5%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		26%		25%
Gas Chiller		19%		4%
Window/Wall Unit		18%		18%

SYSTEM

Ducted without Reheat	13%	36%	21%	25%
Ducted with Reheat	21%		15%	
Fan Coil	20%	25%	21%	18%
Hydronic	10%		16%	
Unitary	25%	33%	21%	28%

SUM (Conditioned Area)	89%	94%	94%	71%

UTILIZATION SYSTEM

Load Management	4%	1%
Time Clock	4%	1%
Economizer	2%	2%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.12.
Plant, System, and Measure Saturations for Grocery Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	6%		9%	
Electric Furnace	15%		3%	
Electric Boiler	0%		0%	
Gas Furnace	19%		16%	
Gas Boiler	0%		10%	
Oil Furnace	N/A		5%	
Oil Boiler	N/A		7%	
Package Unit(Electric)	17%	55%	9%	39%
Package Unit(Gas)	6%		12%	
Air-Source Heat Pump	4%	8%	9%	9%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		1%		7%
Gas Chiller		N/A		1%
Window/Wall Unit		10%		15%

SYSTEM				
Ducted without Reheat	22%	37%	27%	30%
Ducted with Reheat	13%		9%	
Fan Coil	0%	0%	1%	2%
Hydronic	0%		4%	
Unitary	32%	37%	39%	39%
SUM (Conditioned Area)	67%	74%	80%	71%

UTILIZATION SYSTEM		
Load Management	0%	0%
Time Clock	0%	1%
Economizer	0%	0%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.13.
Plant, System, and Measure Saturations for Warehouse Buildings (a, b)

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	4%		3%	
Electric Furnace	2%		1%	
Electric Boiler	0%		0%	
Gas Furnace	9%		9%	
Gas Boiler	2%		6%	
Oil Furnace	1%		2%	
Oil Boiler	0%		2%	
Package Unit(Electric)	4%	17%	3%	9%
Package Unit(Gas)	7%		8%	
Air-Source Heat Pump	4%	5%	2%	3%
Water-Source Heat Pump				
Duel-Fuel Heat Pump				
Electric Chiller		1%		1%
Gas Chiller		1%		1%
Window/Wall Unit		5%		5%

SYSTEM				
Ducted without Reheat	16%	11%	14%	7%
Ducted with Reheat	3%		3%	
Fan Coil	1%	1%	4%	0%
Hydronic	0%		5%	
Unitary	12%	17%	10%	11%
SUM (Conditioned Area)	33%	29%	36%	19%

UTILIZATION SYSTEM		
Load Management	1%	1%
Time Clock	6%	4%
Economizer	3%	1%

Source: CBECS 1989 [2].

(a) All values are percentages of the total floor area for the building type.

(b) Boxes cutting across several technologies represent the sum of the floor areas for those technologies.

Table 5.14. Saturations of combinations of heating/cooling equipment and system options (Stock buildings), based on Tables 5.3 through 5.13 and engineering judgement

System	Cooling/Heating Equipment	Small Retail	Large Retail	Small Office	Large Office	School	Restaurant	Hospital	Small Hotel	Large Hotel	Grocery	Warehouse	Total
Ducted	Package Unit w/Electric Heat	3%	10%	7%	4%	1%	3%	1%	3%	3%	5%	2%	4%
	Package Unit w/Gas Heat	9%	15%	7%	4%	4%	8%	4%	1%	4%	7%	5%	7%
	Package Unit / Electric Resistance Heat	3%		12%	2%		5%	2%	6%	1%	9%		2%
	Air Source HP	3%	2%	7%	3%	1%	3%		1%	2%	5%	1%	2%
	Electric Chiller / Electric Boiler		1%		1%			1%		1%			
	Electric Chiller / Gas Boiler		4%	2%	7%	2%	1%	8%	1%	10%	2%		3%
	Electric Chiller / Oil Boiler		1%	1%	2%	1%		1%		1%	2%		1%
	Electric Chiller / District Heat				0%			0%					
	Gas Furnace / No Cooling	23%	11%	13%	3%	4%	14%	2%	8%	6%	9%	5%	8%
Unitary System	Package Unit w/Electric Heat	1%	5%	4%	4%	1%	2%		4%	3%	6%	1%	3%
	Package Unit w/Gas Heat	4%	8%	4%	5%	2%	3%	2%	2%	4%	7%	3%	4%
	Package Unit / Electric Furnace	1%	1%	1%	1%				1%		1%		1%
	Package Unit / Gas Furnace	6%	3%	6%	2%	1%	5%		2%	2%	5%	1%	3%
	Package Unit / Oil Furnace	1%					1%		1%		2%		
	Package Unit / Electric Resistance Heat	1%	1%	6%	11%	10%	15%	15%	6%	3%	3%		5%
	Air Source HP	2%	1%	4%	4%	1%	2%		2%	3%	6%	1%	2%
	Window Wall Unit / Electric Furnace	1%	1%	1%					2%		1%		
	Window Wall Unit / Gas Furnace	5%	3%	3%	1%	2%	3%		7%	4%	4%	2%	2%
	Window Wall Unit / Oil Furnace	1%							2%		1%		
	Window Wall Unit/Resistance Heating	1%	1%	3%	6%	13%	8%	12%	17%	7%	3%	1%	5%
Fan Coil System	Electric Chiller / Electric Boiler		1%		1%			1%	1%	1%			
	Electric Chiller / Gas Boiler		3%	1%	8%	2%		12%	3%	13%	1%		3%
	Electric Chiller / Oil Boiler		1%		2%	1%		2%	1%	1%			1%
	Electric Chiller / District Heat				2%				0%				
Hydronic System	Electric Boiler /No Cooling	1%	2%	1%	2%		1%	1%	3%	1%			1%
	Gas Boiler / No Cooling	4%	8%	4%	11%	16%	8%	15%	11%	14%	2%	4%	9%
	Oil Boiler / No Cooling	4%	2%	2%	3%	5%	5%	2%	2%	1%	2%	1%	3%
Other		13%	9%	11%	13%	34%	16%	24%	15%	17%	4%	11%	16%
Fraction of area with heating and/or cooling equipment		87%	94%	100%	100%	100%	100%	100%	100%	100%	87%	38%	84%

Table 5.15. Saturations of combinations of heating/cooling equipment and system options (New buildings), based on Tables 5.3 through 5.13 and engineering judgement

		Small Retail	Large Retail	Small Office	Large Office	School	Restaurant	Hospital	Small Hotel	Large Hotel	Grocery	Warehouse	Total
Ducted	Package Unit w/Electric Heat	3%	18%	11%	9%	5%	8%	2%	11%	6%	13%	3%	8%
	Package Unit w/Gas Heat	14%	22%	5%	4%	6%	18%	5%	2%	9%	5%	5%	8%
	Package Unit / Electric Resistance Heat			9%	2%	1%	16%		1%		14%		2%
	Air Source HP	6%	4%	12%	4%	2%	2%		1%		3%	2%	4%
	Electric Chiller / Electric Boiler			1%	3%			1%	2%	1%			1%
	Electric Chiller / Gas Boiler		1%	1%	8%	3%		6%		5%			3%
	Electric Chiller / Oil Boiler			1%	1%	1%							
	Electric Chiller / District Heat								5%	5%			
	Gas Furnace / No Cooling	28%	12%	8%	2%	2%	25%		20%	5%	14%	7%	9%
Unitary System	Package Unit w/Electric Heat	1%	7%	11%	10%	3%	1%	1%	7%	5%	8%	2%	6%
	Package Unit w/Gas Heat	6%	8%	5%	4%	5%	2%	3%	2%	7%	3%	3%	5%
	Package Unit / Electric Furnace	1%	1%	2%	2%	1%			1%		6%	1%	1%
	Package Unit / Gas Furnace	5%	1%	5%	2%	1%	2%		3%	1%	7%	2%	2%
	Package Unit / Oil Furnace												
	Package Unit / Electric Resistance Heat	1%		4%	11%	13%	14%	11%	4%	4%	5%	3%	6%
	Air Source HP	4%	1%	12%	7%	2%			1%		2%	2%	4%
	Window Wall Unit / Electric Furnace		1%			1%			2%		2%		
	Window Wall Unit / Gas Furnace	3%	2%			1%			9%	3%	2%	1%	1%
	Window Wall Unit / Oil Furnace												
	Window Wall Unit/Resistance Heating	1%	1%		2%	5%	1%	12%	12%	8%	1%	2%	2%
Fan Coil System	Electric Chiller / Electric Boiler				2%	1%		1%		1%			1%
	Electric Chiller / Gas Boiler		1%	1%	7%	4%		11%		10%		1%	3%
	Electric Chiller / Oil Boiler				1%	2%							
	Electric Chiller / District Heat				8%					3%			2%
Hydronic System	Electric Boiler /No Cooling			1%	2%	1%	2%	1%	4%	1%			1%
	Gas Boiler / No Cooling	1%	1%	1%	6%	7%	3%	13%		8%			3%
	Oil Boiler / No Cooling			1%	1%	2%	1%						1%
Other		15%	9%	11%	6%	33%	6%	32%	14%	19%	3%	3%	10%
Fraction of area with heating and/or cooling equipment		89%	90%	100%	100%	100%	100%	100%	100%	100%	88%	37%	82%

6. COST AND EFFICIENCY DATA FOR TECHNOLOGY OPTIONS

In this section, we describe the development of cost and efficiency data for shell technologies, HVAC technologies, HVAC plant, and utilization systems. The cost data used in our analysis were obtained from several sources. **Table 6.1** summarizes the availability of cost data from Means Construction, the Western Area Power Administration (WAPA), EPRI, LBNL, and the Wisconsin Center for Demand-Side Research (WCDSR).

A more detailed description of the nature of the cost data available from each source can be found in Appendix F. In general, the cost of HVAC equipment is a function of efficiency and capacity/size. Shell measure costs are generally expressed as a cost per applied area and are assumed to be constant regardless of size. For HVAC systems, cost is expressed as a function of size. For much of the plant equipment, cost is expressed as a function of capacity alone because design options are not defined for that equipment class (e.g., resistance heaters). For plant equipment such as gas furnaces and electric chillers, cost is considered to be a function of both size and design option (efficiency). For economizers, cost is a function of size; for controls, cost is more dependent on equipment capabilities.

Efficiencies of shell measures, HVAC systems, and utilization systems are dependent on region and climate. Therefore, the efficiencies were developed based on building simulations. As mentioned above, the prototypes used for our analysis are based on CBECS [2] data. We developed most of the plant efficiency input data based on a review of manufacturer catalogues at LBNL.

6.1 Shell Technologies

6.1.1. Roof and Wall Insulation

Means [9] estimates the cost of perlite/urethane composite roof insulation for new construction to be \$1.33 to \$1.38 /ft^2 (1992\$). According to LBNL [12], for retrofit insulation jobs, blown-in insulation or insulating with rolled batts costs about 2¢ to 4¢/R-value-ft^2 (1985\$). Blown-in insulation for walls costs significantly more because of the costs to drill and then refinish walls. Retrofitting batts into walls is not practical except during extensive remodeling. Spray-on fiberglass costs about 5¢/R-value-ft^2 (1985\$), and rigid foam board costs 6¢ to 9¢/R-value-ft^2 (1985\$) if applied at the time of re-roofing or re-siding. Installed costs for new construction are slightly less. COMMEND requires insulation costs for new buildings and retrofit situations by building type.

Insulation efficiency is a function of building type, climate, and building vintage. Simulation results using the prototypes are averaged over the U.S. to develop overall impacts of insulation in the U.S. These values are input to COMMEND in the form of heating and cooling slopes that indicate changes in heating and cooling requirements for a given building type as a result of changes in roof and wall insulation levels. The average slopes for U.S. buildings are presented in **Table 6.2**. In Table A.5, Appendix A, the data are presented by region.

Table 6.1. The Availability of Cost Data from Various Sources

	Means [8, 9]	WAPA [10]	EPRI [11]	LBNL [12]	WCDSR [13]	LBNL [14]
SHELL MEASURES						
Roof	✔			✔		
Wall				✔		
Windows		✔				✔
SYSTEM						
Multizone	✔					
Duct CV	✔					
Duct VAV		✔	✔			
Fan-Coil	✔	✔	✔			
Hydronic	✔					
Water HP		✔	✔			
Unitary			✔			
SYSTEM CONVERSION						
Multizone to VAV				✔	✔	
UTILIZATION						
Controls		✔	✔		✔	
Economizer		✔	✔	✔		
Cool Storage		✔		✔		
PLANT						
Electric Resistance			✔			
Electric Furnace	✔					
Electric Boiler	✔		✔			
Gas Furnace	✔		✔			
Gas Boiler	✔		✔			
Oil Furnace	✔					
Oil Boiler	✔		✔			
Electric Package Unit	✔					
Air-Source Heat Pump	✔		✔		✔	
Duel-Fuel Heat Pump						
Water-Loop Heat Pump	✔		✔			
Gas Package Unit	✔		✔			
Electric Chiller	✔		✔	✔		
Gas Chiller			✔			
Window/Wall Unit	✔					

Table 6.2. Shell Efficiency Data (U.S. Average) (a)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Cooling Slope for Roof_R (kBtu/ft2-R)	0.03	0.03	0.02	0.07	0.02	0.00	0.06	0.08	0.01	0.03	0.00	-0.02
Heating Slope for Roof_R (kBtu/ft2-R)	-0.15	-0.02	-0.29	-0.11	-0.08	-0.05	-0.03	-0.27	-0.24	-0.42	-0.45	-0.08
Cooling Slope for Wall R-Value (kBtu/ft2-R)	0.24	0.19	0.19	0.17	0.40	0.20	0.57	0.67	0.13	0.46	0.34	0.00
Heating Slope for Wall R-Value (kBtu/ft2-R)	-1.29	-0.47	-0.75	-0.23	-1.00	-0.55	-0.54	-1.07	-1.46	-1.39	-1.65	-0.21
Cooling Slope for Window R-Value (kBtu/ft2-R)	1.36	2.08	1.21	0.92	2.08	1.90	2.25	1.03	0.74	2.00	0.88	0.05
Heating Slope for Window R-Value (kBtu/ft2-R)	-2.62	-2.98	-3.17	-0.94	-2.19	-2.59	-2.67	-2.02	-3.30	-8.42	-2.95	-0.44
Cooling Slope for Window Shading Coeff. (kBtu/ft2)	15.61	12.37	14.91	7.56	20.93	18.14	17.83	10.97	5.00	32.85	12.48	1.62
Heating Slope for Window Shading Coeff. (kBtu/ft2)	-5.24	-2.96	-7.30	-1.53	-4.70	-4.18	-2.43	-3.36	-5.18	-16.29	-5.53	-1.27
Cooling Slope for Window/Wall Ratio (kBtu/ft2)	49.75	13.26	67.87	26.56	52.71	32.52	19.99	48.21	10.54	73.03	41.21	21.75
Heating Slope for Window/Wall Ratio (kBtu/ft2)	1.95	5.80	7.89	4.48	1.07	7.68	4.90	0.46	3.53	8.01	4.28	-1.79
Cooling Slope for Infiltration (kBtu/ft2-air change per hour)	-4.05	-10.46	-4.66	-10.74	-3.99	-4.38	0.00	-3.65	-1.86	-1.90	-1.77	-0.22
Heating Slope for Infiltration (kBtu/ft2-air change per hour)	6.65	3.36	11.98	9.32	3.42	9.14	0.00	5.68	12.19	4.22	4.46	1.95

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Cooling Slope for Roof_R (kBtu/ft2-R)	0.01	0.02	0.02	0.07	0.02	0.00	0.04	0.14	0.01	0.02	0.00	-0.02
Heating Slope for Roof_R (kBtu/ft2-R)	-0.16	-0.03	-0.27	-0.09	-0.08	-0.03	-0.01	-0.14	-0.22	-0.23	-0.27	-0.08
Cooling Slope for Wall R-Value (kBtu/ft2-R)	0.13	0.14	0.16	0.18	0.34	0.18	0.61	0.79	0.14	0.52	0.37	-0.01
Heating Slope for Wall R-Value (kBtu/ft2-R)	-1.26	-0.40	-0.64	-0.19	-1.00	-0.48	-0.42	-0.66	-1.72	-0.88	-1.00	-0.23
Cooling Slope for Window R-Value (kBtu/ft2-R)	0.76	1.98	1.10	1.02	1.73	2.13	2.53	1.55	0.54	1.27	0.77	0.02
Heating Slope for Window R-Value (kBtu/ft2-R)	-1.85	-3.08	-2.66	-0.78	-1.84	-2.94	-1.95	-1.11	-2.75	-3.67	-1.30	-0.21
Cooling Slope for Window Shading Coeff. (kBtu/ft2)	10.60	13.60	13.65	8.19	18.65	21.22	18.32	13.35	4.19	23.89	10.80	0.81
Heating Slope for Window Shading Coeff. (kBtu/ft2)	-4.03	-3.02	-5.99	-1.14	-3.69	-3.79	-1.74	-1.61	-4.41	-9.00	-2.86	-0.67
Cooling Slope for Window/Wall Ratio (kBtu/ft2)	42.16	11.21	59.16	25.83	50.18	30.64	18.42	49.00	10.38	84.60	47.70	23.74
Heating Slope for Window/Wall Ratio (kBtu/ft2)	0.88	5.62	6.24	4.20	1.54	6.46	4.68	5.15	4.45	3.49	2.59	-2.84
Cooling Slope for Infiltration (kBtu/ft2-air change per hour)	-3.40	-9.92	-4.82	-8.70	-4.01	-4.69	0.00	-5.72	-1.96	-2.35	-2.21	-0.23
Heating Slope for Infiltration (kBtu/ft2-air change per hour)	7.01	3.46	11.32	5.57	3.40	8.77	0.00	2.94	11.47	2.44	2.75	1.93

(a) The cooling slope for roof_r, for example, stands for the change in cooling load in kBtu/ft2 per a change of one unit in r-value. A negative number indicates that the cooling or heating load decreases as a result of a one-unit change in the building characteristic; a positive number indicates an increase.

6.1.2. Window Technologies

COMMEND can accept window costs as a function of the R-value of the window and shading coefficient. **Table 6.3** presents WAPA's [10] estimates of the incremental costs of window technologies compared to the cost of clear insulating glass.

Table 6.3. Incremental Cost of Various Glass Features[a]

Feature	Cost/ft² of window area (1991$)
Tinting	0.50-1.00
Reflective coating	3.00-4.00
Low-E coating on glass	2.75
Triple glazing	3.30
Gas fill	1.0
Low-E on suspended film	3.50-4.50

Source: WAPA [10]

[a]Compared to the cost of clear insulating glass.

As indicated in **Table 6.4**, LBNL [14] includes more detailed information on the window frame and reports cost figures similar to WAPA's [10].

Table 6.4. Window Measure Costs (in 1991$)

Feature[a]	Cost/ft² of window area	R-value	Shading Coefficient
Single glaze, aluminum frame	6.43	0.79	0.90
Single glaze, aluminum frame, gray tint	7.72	0.80	0.71
Single glaze, aluminum frame, reflective coating	9.00	0.97	0.33
Double glaze, aluminum frame	9.62	1.25	0.79
Double glaze, wood frame	16.85	2.08	0.66
Double glaze, aluminum frame, low-e	11.64	1.56	0.71
Double glaze, aluminum frame, spectrally selective	18.00	3.33	0.52
Double glaze, aluminum frame, selective tint, selective coating	20.00	3.45	0.38
Double glaze, wood frame, low-e	18.87	2.78	0.59
Heat mirror, wood frame	22.37	3.45	0.39
Double glaze, wood frame, argon fill	17.48	2.17	0.66
Double glaze, wood frame, argon fill, low-e	19.50	3.33	0.59
Super window(2 low-e coatings on 2 suspended plastic films)	32.39	5.00	0.51
Retrofit film on single pane	1.70	1.45	0.43

Source: LBNL [14]

[a]Assumes 3 ft x 4 ft window

Equation 1 describes the incremental cost of a window per square foot of glazing area compared to a single-glazed, aluminum-frame window as a function of the changes in R-value (ΔR) and shading coefficient (ΔSC). Equation 1 is based on a linear regression of the data in Table 6.4 with an R^2 of 0.94 [14]:

$$\text{Cost } (\$/\text{ft}^2) = 6.43 + 5.50\ \Delta R - 2.31\ \Delta SC \quad (1)$$

[14] Because there is wide scatter in the points used for the regression, the equation does not exactly reproduce the costs in Table 6.4 as a function of ΔR value and ΔSC.

The efficiency of window technologies is a function of building type, climate, and building vintage. Simulation results using the prototypes are averaged over the U.S. to come up with overall impacts of window technologies in the U.S. These values are input to COMMEND in the form of heating and cooling slopes that indicate changes in heating and cooling requirements for a given building type as a result of changes in window R-value and shading coefficient. These heating and cooling slopes are presented in Table 6.2. In Table A.5, Appendix A, the data are presented by region.

6.2 HVAC Technologies

An HVAC system is defined to be a system that distributes the heat or coolth generated by HVAC plant, but does not include the plant. HVAC plant is where the heat and coolth are actually generated (e.g., chillers and boilers). There are also plant auxiliaries – equipment, such as a cooling tower, that is used to improve the performance of the HVAC plant but has nothing to do with the distribution of heat or coolth. In our compilation of data, we consider auxiliaries as part of the plant and factor them into both the cost and efficiency values for the plant.

6.2.1. HVAC Systems

Means [8], WAPA [10], and EPRI [11] provide overall HVAC costs, including both the cost of the complete HVAC system and plant. **Table 6.5** summarizes the total HVAC costs from these sources. With the exception of WAPA [10], these documents also report plant costs. Because COMMEND 4.0 requires system and plant costs separately, we estimate the system costs by subtracting plant costs from the overall HVAC costs. To make this cost estimation, the components of the overall system and the components related to the plant are determined for each capacity level. **Table 6.6** shows costs after the plant and auxiliary equipment costs are deducted from the total.

Generally, we recommend Means data as the primary source (in a piece-wise linear functional form) to COMMEND. Where Means data are not available, other sources can be used. Because Means does not provide cost data on ducted VAV systems, we used the EPRI estimates in our implementation.

The efficiency of an HVAC system depends on how much energy it requires for its pumps and fans, and also how much of the heat generated by these pumps and fans ends up as an additional heating or cooling load. These values are very building-specific and were developed for our analysis based on prototype simulations. **Table 6.7** presents the system multipliers for correcting the building heating and cooling loads for the effect of the particular system; in Table A.6, Appendix A, the data are presented by region. **Table 6.8** presents the electricity use of specific systems; in Table A.7, Appendix A, the data are presented by region.

Table 6.5. Total HVAC Costs Per Unit of Capacity[a]

SYSTEM	Means 1992 [8, 9]			EPRI 1988 [11] for 400 ton cooling capacity, 1986$/ton	WAPA 1991 [10] for 100 ton cooling capacity, 1991$/ton
	Capacity	1992$ per unit of capacity[b]	Notes		
Multizone[c]	9.5 ton	5021			
	32 ton	3705			
	79 ton	2870			
Ducted CV[c]	1.58 ton	3047			
	3 ton	2078			
	9.5 ton	1986			
	32 ton	1996			
Ducted VAV				1720[d,e]	1830[d,g]
				1245[f]	
Fan-Coil	12.66 ton	2890		1600[h]	
	19 ton	2542	g, h	1950[i]	2130[g,i]
	32 ton	1914	g, h		
	127 ton	1774	g, h		
	13 ton	2891	e, h		
	32 ton	2030	e, h		
	190 ton	2400	e, h		
Hydronic[j]	61-410 MBH	205/MBH			
	510-12000 MBH	69/MBH			
Water Loop HP				1400	1500
Unitary				1390	

[a] Total HVAC Costs = System Costs + Plant Costs
[b] 1 ton = 12 kBtu/hour; MBH = kBtu/hour
[c] Rooftop Unit
[d] Central 2-pipe VAV
[e] Reciprocating Water-cooled Chiller
[f] Multiple Unitary VAV
[g] Reciprocating Air-cooled Chiller
[h] Central 2-pipe Fan-Coil
[i] Central 4-pipe Fan-Coil
[j] Electric Boiler

Table 6.6. HVAC System Costs Per Unit of Capacity[a]

SYSTEM	Means 1992 [8, 9]			EPRI 1988 [11] for 400 ton cooling capacity, 1986$/ton	WAPA 1991 [10] for 100 ton cooling capacity, 1991$/ton
	Capacity	1992$ per unit of capacity[b]	Notes		
Multizone[c]	9.5 ton 32 ton 79 ton	2268 1630 1732			
Ducted CV[c]	3 ton 9.5 ton 32 ton	669 1040 942			
Ducted VAV				1444[d] 656[e]	1180[d]
Fan-Coil	19 ton 32 ton 127 ton	1573 1132 1150	f f f	1325[f] 1557[g]	1480[g]
Hydronic(8)	410 MBH 6148 MBH	190/MBH 61/MBH			
Water Loop HP				0[h]	0[h]
Unitary				0	

[a] System Costs = Total HVAC Costs - Plant Costs
[b] 1 ton = 12 kBtu/hour; MBH = kBtu/hour
[c] Rooftop Unit
[d] Central 2-pipe VAV
[e] Multiple Unitary VAV
[f] Central 2-pipe Fan-Coil
[g] Central 4-pipe Fan-Coil
[h] The costs for the water loop are included in the plant costs.

Table 6.7. System Load Multipliers (U.S. Average) (a)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Plant Heating Multiplier-Hydronic System	1.24	1.18	1.03	1.34	1.51	1.34	0.88	0.81	1.01	1.65	1.56	0.91
Plant Heating Multiplier-Ducted CV System	0.86	3.59	0.83	3.08	3.74	3.95	9.50	4.27	1.86	0.89	0.86	2.00
Plant Heating Multiplier-Multizone System	2.13	2.41	1.54	2.18	2.94	2.87	6.63	3.14	1.34	2.11	2.02	1.41
Plant Heating Multiplier-Ducted VAV System	1.78	1.92	1.60	1.84	2.27	2.08	1.00	1.56	1.71	1.21	1.11	1.67
Plant Heating Multiplier-Fan Coil System	1.08	1.07	1.02	1.02	1.77	1.49	1.26	0.99	1.04	1.10	1.09	0.91
Plant Cooling Multiplier-Ducted CV System	1.43	2.20	1.44	2.13	4.20	2.60	2.05	3.50	5.85	1.81	1.77	4.96
Plant Cooling Multiplier-Multizone System	2.45	1.86	2.47	1.84	3.65	2.20	1.82	3.00	4.03	3.01	2.90	3.74
Plant Cooling Multiplier-Ducted VAV System	1.97	1.62	2.30	1.64	2.59	1.71	1.33	2.16	4.96	2.01	1.95	3.49
Plant Cooling Multiplier-Fan Coil System	1.08	1.09	1.11	1.08	1.21	1.10	1.09	1.16	1.13	1.21	1.25	0.89

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Plant Heating Multiplier-Hydronic System	1.27	1.20	1.04	1.64	1.48	1.37	0.77	0.63	1.01	2.10	2.01	0.91
Plant Heating Multiplier-Ducted CV System	0.93	3.53	0.84	4.43	3.67	4.49	11.01	9.16	1.90	0.90	0.82	1.92
Plant Heating Multiplier-Multizone System	1.94	2.42	1.59	3.17	2.94	3.25	7.68	6.65	1.37	2.73	3.04	1.37
Plant Heating Multiplier-Ducted VAV System	1.75	1.91	1.54	2.17	2.23	2.14	0.83	0.79	1.71	1.15	1.04	1.63
Plant Heating Multiplier-Fan Coil System	1.10	1.10	1.02	1.03	1.81	1.56	1.28	1.01	1.05	1.08	1.05	0.91
Plant Cooling Multiplier-Ducted CV System	1.45	2.34	1.44	2.16	4.06	2.51	1.78	2.70	5.73	1.88	1.84	4.48
Plant Cooling Multiplier-Multizone System	2.59	1.96	2.39	1.91	3.57	2.16	1.62	2.41	4.01	2.76	2.73	3.50
Plant Cooling Multiplier-Ducted VAV System	2.17	1.69	2.21	1.64	2.56	1.67	1.30	1.64	4.85	1.98	1.98	3.05
Plant Cooling Multiplier-Fan Coil System	1.09	1.11	1.12	1.11	1.23	1.12	1.09	1.15	1.17	1.30	1.33	0.90

(a) The building loads are multiplied by these factors to account for the heating/cooling loads added to the building loads by the particular distribution system. The load obtained by the above multiplication is what the heating/cooling plant has to satisfy.

Table 6.8. System Energy Use Data (kWh/ft2 of conditioned floor area) (U.S. Average) (a)

STOCK VINTAGE	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
System Energy Use- Hydronic System	0.06	0.04	0.09	0.04	0.05	0.06	0.03	0.06	0.21	0.28	0.19	0.02
System Energy Use- Ducted CV System	3.16	3.68	3.41	3.03	5.90	4.31	11.67	11.50	3.68	11.63	8.61	1.12
System Energy Use- Multizone System	3.60	3.22	3.95	2.73	5.33	3.91	10.47	10.34	3.31	13.40	9.83	1.00
System Energy Use- Ducted VAV System	2.42	2.35	3.01	2.17	3.48	2.73	6.98	6.71	3.06	8.40	6.11	0.76
System Energy Use- Fan Coil System	0.40	0.46	0.43	0.33	0.70	0.63	1.48	1.35	0.44	1.67	1.30	0.10

NEW VINTAGE	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
System Energy Use- Hydronic System	0.06	0.04	0.08	0.04	0.04	0.05	0.02	0.01	0.19	0.17	0.10	0.02
System Energy Use- Ducted CV System	2.38	3.24	2.99	3.40	5.06	4.37	11.44	10.18	3.42	10.70	8.20	0.93
System Energy Use- Multizone System	2.71	2.84	3.47	3.07	4.58	3.97	10.27	9.15	3.08	11.30	9.19	0.83
System Energy Use- Ducted VAV System	1.86	2.06	2.67	2.37	3.02	2.78	7.52	5.78	2.85	7.15	5.87	0.58
System Energy Use- Fan Coil System	0.30	0.41	0.39	0.37	0.63	0.65	1.48	1.25	0.42	1.59	1.33	0.08

(a) System Energy Use stands for the electricity used by the distribution system, mostly for its pumps and fans. System Energy Use is obtained from the simulation results.

6.2.2. System Conversion[15]

A common system conversion option is from multizone to VAV. For retrofit situations, the cost of a VAV system includes changing the supply terminals to VAV terminals and adding a main-fan variable-flow device. Retrofitting dual-duct systems is less expensive because the supply terminals can easily be modified to VAV terminals. Retrofitting main-fan control devices can be difficult for some buildings. **Table 6.9** summarizes cost information. The costs are expressed in dollars per cubic foot per minute ($/cfm) of air flow. Typical flow-to-area ratios are 0.7 to 2.0 cfm/ft^2 for office buildings.

Table 6.9. Variable-Air-Volume Fan Control Retrofit Costs

Option	Converted from Dual-Duct (1985$/cfm)[a]	Converted from Other (1985$/cfm)
Discharge Dampers	0.20 - 0.50	0.60 - 1.10
Inlet Vanes	0.24 - 0.56	0.65 - 1.15
Variable-Speed Drives	0.40 - 0.90	0.83 - 1.47
Variable-Pitch Fans	0.48 - 1.28	0.93 - 1.83

Source: LBNL [12]
[a] cfm = cubic feet per minute

6.2.3. HVAC Plant

Plant cost data are presented in **Tables 6.10, 6.11, and 6.12**. Table 6.10 presents heating plant options, Table 6.11 presents combined plant options, and Table 6.12 presents cooling plant options. Cost is a function of size as well as the efficiency of the equipment; these tables present cost as a function of size. For some equipment classes, more than one level of efficiency is defined. In the case of gas furnaces, for example, both standard and efficient design options are presented.

Again, we recommend entering Means data to COMMEND in a piece-wise-linear functional form. EPRI data are also useful where Means data are not available for certain plant types.

Seasonal plant heating and cooling efficiencies are presented in **Table 6.13**. Efficiencies were developed both for stock and new equipment. For combined plants, secondary heating efficiencies were also developed.

[15] COMMEND allows system and plant conversion modeling. The data in this section can be used to model conversions from non-VAV systems to VAV systems.

Table 6.10. Heating Plant Costs Per MBH[a]

Plant Type	Means 1992 [8, 9]			EPRI 1988 [11]		
	Capacity (MBH)	Cost 1992$/MBH	Notes	Capacity (MBH)	Cost 1986$/MBH	Notes
Electric Resistance				14 15-170	18.50 13.00	
Electric Furnace	30 91 141	17.00 11.50 8.50				
Electric Boiler	41 103 410 6,143 12,300	88.00 38.00 15.00 7.50 5.75		1000 6000	10.00 6.00	
Gas Furnace, Typical	42 105 400	14.50 7.50 7.50	b, c b, c b, c	100-350 350 900	7.50 7.50 6.00	
Gas Furnace, Efficient	55 72	22.00 17.00	b, d b, d			
Gas Boiler, Typical	100 400 6,100	21.50 13.00 9.50		1000 4000 6000	10.00 7.00 8.50	
Gas Boiler, Efficient			e			e
Oil Furnace	55 125 400	18.00 9.80 7.00	f f f			
Oil Boiler	109 480 3,820 6,100 7,000	23.80 13.75 7.00 9.30 9.76		1000 4000 6000	10.00 7.00 8.50	

[a] MBH = kBtu/hour
[b] Not including gas/oil and flue piping.
[c] Direct drive.
[d] Pulse combustion.
[e] The cost of an efficient gas boiler is approximately 30% higher than the cost of a regular gas boiler.
[f] Atomizing gun type burner.

Table 6.11. Combined Plant Costs Per Unit of Capacity[a]

Plant Type	Means 1992 [3,4]				EPRI TAG 1988 [6]			WCDSR 1990 [8]		
	Capacity tons	Capacity MBH	Cost 1992$/ton	Notes	Capacity	Cost 1986$/ton	Notes	Capacity	Cost 1990$/ton	Notes
Electric Packaged	1 3 4	14 35 54	805 742 750							
Air-source HP[b]	1.5 5 10 30	5 27 45 163	1616 960 1170 1173		1.5 ton 5 ton 10 ton 20 ton 30 ton	1000 800 750 770 900		2 ton 40 ton	930 790	
Efficient Air-source HP				c			c			c
Water-loop HP (w/o water-loop)[b]	1 5 10 20	13 29 50 100	1250 555 872 585		1 ton 5 ton 10 ton 20 ton	1000 880 840 890				
Dual-fuel HP				d			d			d
Gas Package	5 10 25 100	112 200 450 1350	1045 1040 1040 1160		<5 ton 10 ton 30 ton 60 ton	550 700 870 780				

[a] 1 ton = 12 kBtu/hour; MBH = kBtu / hour
[b] Heating capacity quoted is for the auxiliary resistance heating only.
[c] A 5-ton efficient air-source HP with an EER of 11 is 5% more expensive than an air-source HP of similar size with an EER of 10 [15].
[d] Dual-fuel HPs include two complete heating units and are thus more expensive than ordinary HPs. Dual-fuel heat pumps are used for peak reduction purposes.

Table 6.12. Cooling Plant Costs Per Ton[a]

Plant Type	Means 1992 [8, 9]		EPRI 1988 [11]			LBNL 1985 [12]
	Capacity (tons)	Cost 1992$/ton	Capacity (tons)	Cost 1986$/ton	Notes	Cost 1985$/ton
Chiller-Centrifugal	200 400 1000	540 375 257	200 400 1000	460 450 400		350 - 600 + 10% for installation
Chiller-Reciprocating	20 100 160	870 650 480	20 200	500 500		200 - 500 + 10 % for installation
Chiller-Screw			180 400 700	500 420 450		
Gas Chiller			15 - 500 tons	8.00 - 11.00/ft^2	b	
Window/Wall Unit	0.5 1	450 625				

[a] 1 ton = 12 kBtu/hour; MBH = kBtu / hour
[b] Source: EPRI [16] (1992$)

Table 6.13. Seasonal Heating and Cooling-Plant Efficiency Data (*)

Plant Type	Seasonal Heating Plant Efficiency (BTU out/BTU in) Average (stock)	Marginal (new const.)	Footnotes
HEATING			
Electric Resistance	1.0	1.0	1
Electric Furnace	0.93	0.96	2
Electric Boiler	0.94	0.94	3
Gas Furnace, Typical	0.63	0.76	4
Gas Furnace Efficient	0.85	0.89	5
Gas Boiler, Typical	0.6	0.65	6
Gas Boiler Efficient	0.85	0.9	7
Oil Furnace	0.68	0.77	8
Oil Boiler	0.6	0.68	9

Plant Type	Seasonal Plant Efficiency or COP (BTU out/BTU in)						
	Primary Heating		Secondary Heating		Cooling		
	Average (stock)	Marginal (new const.)	Average (stock)	Marginal (new const.)	Average (stock)	Marginal (new const.)	Footnotes
COMBINED							
Electric Packaged	0.93	0.96	n.a.	n.a.	2.2	2.7	10
Air-Source HP, Std.	2.4	3	0.93	0.96	2.2	2.7	11
Air-Source HP, Effic.	2.8	3.2	0.93	0.96	2.5	3	12
Dual-Fuel HP	2.8	3.2	0.63	0.76	2.5	3	13
Water-Loop HP	3.5	4	n.a.	n.a.	2.6	3.5	14
Gas Packaged	0.7	0.8	n.a.	n.a.	2.2	2.7	15

Plant Type	Seasonal Cooling Plant COP (BTU out/BTU in) Average (stock)	Marginal (new const.)	Footnotes
COOLING			
Centrifugal Chillers:			
w/tower	3.5	4.5	16
w/evap. condenser	3.8	4.8	17
Reciprocating Chillers:			
w/air-cooled cond.	2.3	3	18
w/tower	3.4	4	19
w/evap. condenser	3.7	4.4	20
Screw Chillers:			
w/tower	3.7	3.9	21
w/evap. condenser	4	4.2	22
Gas Chiller	0.5	0.9	23
Window/Wall Unit	2.2	2.7	24

Sources:

[12] LBL, 1985: "Commercial-Sector Conservation Technologies", Usibelli et al., LBL #18543.
[16] EPRI, 1992: "TAG Technical Assessment Guide", Volume 2, Part 2 (Commercial Electricity End-Use), CU-7222s, V2, P2.
[17] EPRI, 1989: "Handbook of High-Efficiency Electric Equipment and Cogeneration System Options for Commercial Buildings", CU-6661.
[18] Boiler Efficiency Institute, 1988: "Boiler Efficiency Improvement", Dyer and Maples, Boiler Efficiency Institute, Auburn Alabama.
[19] E-Source, 1992: "Space Cooling and Air Handling", E-Source, Boulder, CO.

Notes:

(*) Table reflects the effects of EPACT Standards which affect gas furnaces and boilers, packaged units and heat pumps.

1. Assumes that resistance heater and electrical wiring are in space to be heated, so all heat beyond electric meter is useful.
2. Average assumes 2% loss from furnace housing and 5% duct leakage to/from unheated space. Marginal assumes 1% and 3%.
3. Assumes 2% of rated input is lost through boiler shell; average boiler load is 33%.
4. Average assumes 70% seasonal burner efficiency, less 1% each for pilot lights and shell losses and 5% for duct losses; marginal assumes 80%, no pilot, 1% shell, and 3% duct loss.
5. Average assumes 90% Calif. Seasonal Efficiency (rather than AFUE, since CSE accounts for fan energy) less 5% duct losses; marginal same except 92% CA Seasonal Effic., 3% duct loss.
6. Average assumes boiler at 80% new steady-state efficiency degraded by 5% due to water and fire-side rust, scale, and soot; 2% of input rating lost through boiler casing, 3% through stack; two boilers kept hot all year, average boiler load is 33% of one boiler. Marginal same except no rust, soot, or scale.
7. Average assumes condensing boiler used, but heat exchangers not large enough to lower return water to condensing temperature. Marginal assumes condensing boiler used, heat exchangers allow condensing.
8. Average assumes 5% better than gas furnace (due to powered burner with controlled excess air and off-cycle air); marginal 1% more efficient than marginal gas (both have power burner or induced draft).
9. Average assumed same as gas. Marginal assumes 83% efficiency with the reductions which apply to marginal gas. Oil boilers have more efficiency degradation due to soot, but all have forced or induced draft; effects are assumed to cancel.
10. Electric packaged means direct expansion air conditioner with air-cooled condenser and resistance heat. Heating efficiency assumed same as electric furnace. Cooling: Average from [17], [16], and [12]; marginal assumed 0.5 COP point (absolute) higher.
11. Primary heating from [17] and [16]; secondary same as electric furnace. Cooling same as electric packaged.
12. Primary heating from [17] and [16]; secondary same as electric furnace. Cooling from [17].
13. Dual fuel HP means direct expansion cooling and heating with refrigerant-to-air outdoor coil; gas backup. Heat pump COPs assumed same as effic. air-source; gas effic. assumed same as std. gas furnace.
14. Numbers are from [17] and [16]; averaged assumed to be at lower end of range of most-common COPs; marginal at upper end.
15. From [17]: cooling same as electric packaged; heating at lower end of range of conventional and effic. units to account for seasonal effect
16. From EPRI and [19]. Approx. 0.1 points of COP reduction for tower fan and condensing water pump; degradation from fouling approx. balances improved efficiency at part load. Marginal assumes mid-range of high-effic. equip.
17. Same as with tower except about 0.3 point of COP increase for the evaporative condenser. Based on [19].
18. From [17] and [16]. Average assumes COP of 3.3 less 0.8 for fans and 0.2 for wear and fouling degradation. Marginal assumes 0.5 above average (approx. diff. between conventional and high efficiency).
19. From EPRI and [12]. Assumed 0.1 points of COP reduction (for tower and pump) in mid-range conventional COP for average; same for high-efficiency for marginal.
20. Assumes 10% COP improvement for evaporative condenser.
21. From [17], using upper end of ranges of conv. and high-effic. less 0.1% for tower and pump.
22. Same as screw with tower except 10% COP improvement with evap. condenser.
23. Average assumes 0.6 COP (single-effect); marginal assumes 1.0 COP (double-effect); discounted for tower and pump usage.
24. Assumed same as electric packaged unit. While window/wall units are smaller, they borrow from the more efficient residential technology.

6.2.4. Utilization Systems

Costs for multi-function controls and economizers are presented in **Table 6.14**. Efficiency characteristics of these utilization system options are building-specific and are developed in this report based on prototype simulations. The effect of economizers on building loads is shown for different building types in **Table 6.15**; in Table A.9, Appendix A, the data are presented by region.

Table 6.14. Utilization System Costs

System	EPRI 1988 [11]		WAPA 1991 [10]		LBNL 1985 [12]	
	Capacity (tons)	Cost 1986$/ton	Capacity (tons)	Cost 1991$/ton	Capacity (tons)	Cost 1985$/ton
Multi-Function Controls				0.27/ft^2 (for 30,000 ft^2)		
Economizers	10 75 100	140 48 48	5-10 15-20 <100 ton	125 62.50 35	5-10 15-20 25-100	75-175 50-75 25-50

Due to the complex nature of EMCS and custom design features for each installation, it is difficult to obtain average costs for them. Based on our experience, we assumed that energy savings of 10% could be achieved at a cost of 20¢/ft^2 (1995$).

COMMEND 4.0 can also model thermal energy storage systems (TES). TES systems generally do not save energy but are implemented to shift load to off-peak hours. This project does not elaborate on peak issues and therefore TES-related parameters have not been developed.

Table 6.15. Effect of Economizers on Load (U.S. Average) (a)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
% Reduction in Clg. in Ducted CV system	22%	34%	13%	33%	24%	26%	37%	30%	44%	26%	25%	28%
% Reduction in Clg. in Multizone system	25%	33%	22%	30%	21%	24%	38%	31%	37%	31%	28%	23%
% Reduction in Clg. in Ducted VAV system	26%	31%	29%	27%	12%	20%	30%	24%	55%	11%	8%	39%
% Reduction in Heating in Ducted CV system	0%	-21%	0%	-23%	-13%	-15%	-38%	-20%	-10%	0%	0%	-9%
% Reduction in Heating in Multizone system	-58%	-69%	-49%	-69%	-40%	-49%	-87%	-53%	-43%	-36%	-31%	-40%
% Reduction in Heating in Ducted VAV system	-7%	-15%	11%	2%	-21%	-11%	-244%	-17%	24%	-10%	-6%	23%

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
% Reduction in Clg. in Ducted CV system	19%	32%	13%	30%	19%	22%	34%	26%	40%	21%	21%	21%
% Reduction in Clg. in Multizone system	23%	30%	23%	28%	16%	21%	36%	28%	34%	21%	20%	18%
% Reduction in Clg. in Ducted VAV system	26%	28%	28%	25%	7%	16%	31%	14%	52%	4%	3%	30%
% Reduction in Heating in Ducted CV system	0%	-20%	0%	-28%	-13%	-15%	-47%	-30%	-10%	0%	0%	-9%
% Reduction in Heating in Multizone system	-53%	-63%	-48%	-74%	-37%	-48%	-101%	-66%	-42%	-35%	-35%	-38%
% Reduction in Heating in Ducted VAV system	-7%	-13%	7%	-1%	-19%	-18%	-336%	-191%	23%	-17%	-20%	24%

(a) Negative reductions indicate that the load increases.

7. *SERVICE DEMAND*

In this section, we discuss our characterization of HVAC service demand and the sensitivity of this demand to factors external to the HVAC system. Service demand is characterized by the base-case heating and cooling loads, base-case peak-heating and -cooling requirements, and sensitivity of heating and cooling loads to environmental factors including changes in weather conditions, occupation patterns, and the efficiency of other end uses.

Average building heating and cooling loads by building type were developed using the prototype simulations and the U.S. averages are presented in **Table 7.1**. COMMEND utilizes these parameters at the core of its energy equations for calculating energy consumption. These loads, which were developed for the base year, were modified for the forecast years using the slope parameters to calculate new building loads that reflect the introduction of conservation measures. The slope parameters were developed using simulation results.

Average peak-heating and -cooling requirements were also developed from the simulation outputs, and are presented in **Table 7.2**. In Table A.8, Appendix A, the data are presented by region. These parameters were used for sizing HVAC equipment (the size affects its cost).

Sensitivity of the building heating and cooling loads to exogenous variables such as occupancy level and changes in weather were also developed using prototype simulations. Table 5.1 presents the baseline values for occupancy and heating/cooling degree days; in Table A.2, Appendix A, the data are presented by region. **Table 7.3** presents the average sensitivities of loads to changes in these parameters for the U.S. commercial floorstock. In Table A.3, Appendix A, the data are presented by region.

Weather sensitivity was determined by comparing base-case simulations for a fixed building type and vintage to simulation results for different weather data for the similar prototype class (North or South). For example, for new small offices, the sensitivity of building loads to weather in the north (Zones 1, 2, and 3-N) is determined using the base-case simulations for new small offices in Zones 1 and 3-N and the associated variation in HDD and CDD between Zones 1 and 3-N.

There are conservation measures for other end uses such as lighting and office equipment that interact with HVAC service requirements. One good example is lighting/HVAC interactions: improved lighting efficiency can decrease cooling requirements and/or increase heating requirements [20]. To account for such interactions, coincidence factors are defined in COMMEND. We developed coincidence factors for lighting and equipment interactions by building type using prototype simulations. Average coincidence factors for the different building types are given in **Table 7.4**. In Table A.4, Appendix A, the data are presented by region.

The heating coincidence factor for lighting represents the number of units of extra heating energy required annually if lighting energy use is reduced by one unit. Typically, there are times when buildings are lit and the HVAC equipment is not operating; consequently, the sum of the heating and cooling coincidence factors is less than 100%. For lighting coincidence factors, we assumed that all energy generated by the lighting equipment ends up in the space. Lighting/HVAC interactions are different from equipment/HVAC interactions because the schedules for each are different.

Table 7.1. Heating and Cooling Loads (U.S. Average) (a)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Heating Load (kBtu/ft2)	10.31	5.76	21.53	6.20	8.95	7.00	5.47	15.92	28.69	40.90	29.10	6.88
Cooling Load (kBtu/ft2)	20.18	26.61	22.46	23.99	19.75	25.52	92.83	49.44	8.59	59.60	46.60	3.18

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Heating Load (kBtu/ft2)	9.51	5.36	16.91	3.92	7.27	5.69	3.40	4.27	24.67	19.00	12.50	6.16
Cooling Load (kBtu/ft2)	13.97	21.76	20.56	26.76	18.31	27.61	108.35	59.89	8.21	65.60	55.80	3.02

(a) The Heating and Cooling Loads are annual heating and cooling loads in kBtu per ft2 of floor area.

Table 7.2. System Sizing Requirements (U.S. Average) (a)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Heating Equipment Sizing Requirement (Btu/hr-ft2)	14.75	8.61	39.19	20.10	29.92	11.54	5.56	21.03	42.14	43.40	34.17	7.82
Cooling Equipment Sizing Requirement (Btu/hr-ft2)	19.16	15.44	21.96	15.07	21.64	11.83	25.54	24.64	18.50	40.20	31.19	3.35

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Heating Equipment Sizing Requirement (Btu/hr-ft2)	12.23	7.42	34.96	14.65	26.16	11.15	4.37	10.87	39.78	30.51	24.01	7.04
Cooling Equipment Sizing Requirement (Btu/hr-ft2)	14.60	13.36	20.09	11.67	19.14	11.89	27.09	22.60	17.11	35.38	29.52	2.88

(a) The System Sizing Requirement indicates the capacity needed in Btu/hr per ft2 of building floor area.

Table 7.3. Building Response to Exogenous Variables (U.S. Average) (a)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Cooling Slope for HDD (kBtu/ft2-degree days) (a)	-2.6E-03	-2.3E-03	-3.1E-03	-2.9E-03	-2.5E-03	-2.7E-03	-5.7E-03	-5.3E-03	-1.6E-03	-7.2E-03	-5.9E-03	-7.4E-04
Heating Slope for HDD (kBtu/ft2-degree days) (a)	4.9E-03	2.3E-03	7.2E-03	2.1E-03	4.7E-03	2.5E-03	2.4E-03	6.5E-03	7.1E-03	1.2E-02	9.1E-03	2.1E-03
Cooling Slope for CDD (kBtu/ft2-degree days) (a)	1.0E-02	9.2E-03	1.3E-02	1.2E-02	9.9E-03	1.1E-02	2.8E-02	2.4E-02	6.3E-03	3.1E-02	2.6E-02	2.8E-03
Heating Slope for CDD (kBtu/ft2-degree days) (a)	-2.1E-02	-1.1E-02	-3.3E-02	-1.1E-02	-2.1E-02	-1.2E-02	-1.3E-02	-3.3E-02	-3.3E-02	-5.8E-02	-4.4E-02	-1.0E-02
Cooling Slope for Occupancy (kBtu/ft2-person/1000ft2) (b)	0.29	0.11	0.54	0.56	0.02	0.28	-0.17	0.62	0.10	0.34	0.24	0.41
Heating Slope for Occupancy (kBtu/ft2-person/1000ft2) (b)	0.30	0.24	0.39	0.39	-0.01	0.19	0.44	2.87	0.51	2.19	1.43	0.43

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Cooling Slope for HDD (kBtu/ft2-degree days) (a)	-2.0E-03	-2.1E-03	-2.8E-03	-3.2E-03	-2.5E-03	-3.0E-03	-6.7E-03	-6.2E-03	-1.5E-03	-8.7E-03	-7.4E-03	-7.6E-04
Heating Slope for HDD (kBtu/ft2-degree days) (a)	4.7E-03	2.3E-03	6.2E-03	1.7E-03	4.1E-03	2.0E-03	1.6E-03	3.1E-03	6.6E-03	1.1E-02	7.8E-03	2.0E-03
Cooling Slope for CDD (kBtu/ft2-degree days) (a)	7.8E-03	8.4E-03	1.2E-02	1.2E-02	9.4E-03	1.2E-02	3.1E-02	2.5E-02	5.8E-03	3.1E-02	2.6E-02	2.6E-03
Heating Slope for CDD (kBtu/ft2-degree days) (a)	-1.9E-02	-1.0E-02	-2.7E-02	-8.3E-03	-1.7E-02	-9.3E-03	-8.1E-03	-1.5E-02	-2.9E-02	-3.9E-02	-2.9E-02	-8.9E-03
Cooling Slope for Occupancy (kBtu/ft2-person/1000ft2) (b)	0.30	0.11	0.53	0.72	0.02	0.31	-0.27	0.29	0.11	0.50	0.33	0.47
Heating Slope for Occupancy (kBtu/ft2-person/1000ft2) (b)	0.27	0.25	0.36	0.41	-0.01	0.18	0.38	1.73	0.47	1.28	0.81	0.42

(a) The values in this table indicate the expected change in building loads in kBtu/ft2 of floor area per heating/cooling degree days if and when there is a shift in the average heating/cooling degree days for the building stock. Such a shift may be due to geographically-uneven expansion of the building stock. A negative number indicates a load reduction; a positive number indicates a load increase.

(b) The increase in load in kBtu/ft2 as the result of a one-unit increase in the occupancy characteristic (in this case, person/1000 ft2).

Table 7.4. Coincidence Factors (U.S. Average) (a)

STOCK VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Cooling Coincidence Factor for Lighting	0.48	0.70	0.45	0.62	0.43	0.66	0.87	0.57	0.40	0.59	0.54	0.22
Heating Coincidence Factor for Lighting	-0.28	-0.16	-0.39	-0.29	-0.20	-0.16	-0.10	-0.30	-0.48	-0.33	-0.39	-0.24
Cooling Coincidence Factor for Equipment	0.56	0.77	0.54	0.73	0.47	0.66	0.96	0.79	0.54	0.74	0.77	0.15
Heating Coincidence Factor for Equipment	-0.23	-0.12	-0.34	-0.20	-0.18	-0.26	-0.03	-0.12	-0.36	-0.21	-0.18	-0.18

NEW VINTAGE

	S_OFF	L_OFF	S_RET	L_RET	S_HOTEL	L_HOTEL	HOSPTL	S_MARKET	SCHOOL	FASTFD	SITDOWN	WARE_H
Cooling Concidence Factor for Lighting	0.46	0.70	0.46	0.72	0.45	0.69	0.91	0.73	0.42	0.71	0.66	0.23
Heating Concidence Factor for Lighting	-0.29	-0.15	-0.36	-0.23	-0.19	-0.12	-0.06	-0.16	-0.44	-0.21	-0.26	-0.25
Cooling Concidence Factor for Equipment	0.53	0.77	0.54	0.81	0.49	0.69	0.97	0.89	0.55	0.88	0.89	0.16
Heating Concidence Factor for Equipment	-0.25	-0.13	-0.31	-0.15	-0.17	-0.23	-0.02	-0.04	-0.32	-0.07	-0.08	-0.18

(a) Coincidence Factors are an indication of the interaction between space conditioning and the other end uses.
A reduction in lighting energy, for example, may significantly reduce the need to cool a building.
Coincidence factors quantify the reduction in the heating/cooling load per unit of reduction in the energy use of other end uses.

8. CONCLUSIONS AND FUTURE DIRECTIONS

Because energy consumption is increasing so rapidly in the commercial sector, it is important for energy analysts to have access to commercial energy end-use forecasting models that disaggregate energy consumption not only by fuel type, end use, and building type, but also by specific technology. In this report, we describe our development and refinement of a base-year data set characterizing space conditioning technologies in commercial buildings.[16] Although this highly detailed data set was developed specifically for EPRI's COMMEND 4.0 forecasting model, it will also be useful for other COMMEND users, forecasters using other commercial-sector models, and researchers and practitioners involved in policy analysis. Using the data set that we created for COMMEND 4.0, analysts will be able to evaluate both regional and national commercial-sector, energy-related policies and programs at the technology level.

In order to produce technology and service demand input data for COMMEND 4.0, we relied on data characterizing commercial buildings and HVAC systems, previous LBNL work, and engineering judgement. To develop service demand and efficiency data, we also used regional weather data, generated DOE-2 prototypes, and ran DOE-2 simulations. The set of DOE-2 prototypes that we developed for this project represent the commercial building stock in the U.S. and can be used to answer a wide range of policy questions. These prototypes can be used to generate data that may be required for future versions of COMMEND and can also be used for policy analysis that is independent of COMMEND.

The data presented in this report will be refined and improved as more commercial-sector data become available. Although there is little information now available regarding the market shares of specific technologies, we expect future commercial-sector surveys to respond to this lack by including questions that will allow the better characterization of the commercial sector.

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[16] In addition to developing a data set for HVAC technologies, we have developed data sets characterizing lighting, refrigeration, office equipment, and water heating technologies. These characterization studies are published as LBNL reports [21, 22, 23, 24].

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APPENDICES

Appendix A	COMMEND Data Related to Prototypes and Simulation Results
Appendix B	Commercial Building Data from CBECS
Appendix C	Commercial Building Prototype Characteristics
Appendix D	Technology Data Sheets
Appendix E	COMMEND End-Use Planning System
Appendix F	Sources of Cost Data

Appendix A - COMMEND Data Related to Prototypes and Simulation Results

Data by climate zone.

Table A.1a Weights for Averaging Regional Data

Floor Area (million ft2) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S -(1)-	Zone 4	Zone 5 -(1)-
Small Office	250.6	804.9	338.8	299.5	1036.8	783.4
Large Office	396.8	2107.7	1681.7	819.4	2503.6	864.9
Small Retail	663.0	1526.9	946.6	714.0	1285.2	1392.3
Large Retail	685.2	1859.6	559.2	431.2	1201.2	1139.6
Small Hotel	107.7	191.5	215.5	0.0	299.3	383.0
Large Hotel	134.9	708.1	134.9	0.0	286.6	421.5
Hospital	98.2	474.4	670.8	0.0	180.0	212.7
Supermarket	95.3	174.7	262.0	0.0	87.3	174.7
School	702.8	2872.1	1495.4	876.5	1075.7	1115.5
Fastfood Restaurant	88.0	205.2	64.4	0.0	123.0	105.4
Sit-Down Restaurant	88.0	205.2	64.4	0.0	123.0	105.4
Warehouse	796.9	2416.2	1391.6	617.0	1918.4	2169.0

Floor Area (million ft2) (NEW)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S -(1)-	Zone 4	Zone 5 -(1)-
Small Office	40.2	218.6	39.6	102.4	362.8	182.1
Large Office	101.6	642.8	563.0	234.1	966.1	356.4
Small Retail	137.8	318.3	149.8	102.8	260.3	315.1
Large Retail	54.4	342.6	99.7	87.2	189.0	407.1
Small Hotel	36.2	9.6	36.2	0.0	41.0	118.1
Large Hotel	85.0	141.6	4.7	0.0	33.0	207.7
Hospital	10.5	62.7	69.0	0.0	18.8	48.1
Supermarket	0.0	35.9	39.3	0.0	34.2	61.6
School	90.9	183.3	25.8	8.7	104.2	182.3
Fastfood Restaurant	5.2	9.0	1.9	0.0	22.0	52.9
Sit-Down Restaurant	5.2	9.0	1.9	0.0	22.0	52.9
Warehouse	248.1	413.0	235.1	247.1	343.3	741.4

(1) For some building types, entries of zero under the Zone 3-S column appear because separate prototypes were not developed for the South and the North.

Table A.1b Conditioned Area-Cooling (%) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	82%	82%	82%	86%	86%	86%
Large Office	79%	79%	79%	87%	87%	87%
Small Retail	41%	41%	41%	49%	49%	49%
Large Retail	60%	60%	60%	65%	65%	65%
Small Hotel	69%	69%	69%	69%	69%	69%
Large Hotel	70%	70%	70%	70%	70%	70%
Hospital	86%	86%	86%	86%	86%	86%
Supermarket	70%	70%	70%	70%	70%	70%
School	31%	31%	31%	73%	73%	73%
Fastfood Restaurant	74%	74%	74%	74%	74%	74%
Sit-Down Restaurant	74%	74%	74%	74%	74%	74%
Warehouse	13%	13%	13%	23%	23%	23%

Conditioned Area-Cooling (%) (NEW)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	89%	89%	89%	87%	87%	87%
Large Office	93%	93%	93%	88%	88%	88%
Small Retail	54%	54%	54%	45%	45%	45%
Large Retail	73%	73%	73%	74%	74%	74%
Small Hotel	82%	82%	82%	82%	82%	82%
Large Hotel	93%	93%	93%	93%	93%	93%
Hospital	97%	97%	97%	97%	97%	97%
Supermarket	75%	75%	75%	75%	75%	75%
School	60%	60%	60%	85%	85%	85%
Fastfood Restaurant	84%	84%	84%	84%	84%	84%
Sit-Down Restaurant	84%	84%	84%	84%	84%	84%
Warehouse	8%	8%	8%	40%	40%	40%

Table A.1c Conditioned Area-Heating (%) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	95%	95%	95%	88%	88%	88%
Large Office	97%	97%	97%	90%	90%	90%
Small Retail	89%	89%	89%	75%	75%	75%
Large Retail	95%	95%	95%	84%	84%	84%
Small Hotel	86%	86%	86%	86%	86%	86%
Large Hotel	94%	94%	94%	94%	94%	94%
Hospital	90%	90%	90%	90%	90%	90%
Supermarket	79%	79%	79%	79%	79%	79%
School	99%	99%	99%	95%	95%	95%
Fastfood Restaurant	86%	86%	86%	86%	86%	86%
Sit-Down Restaurant	86%	86%	86%	86%	86%	86%
Warehouse	47%	47%	47%	29%	29%	29%

Conditioned Area-Heating (%) (NEW)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	98%	98%	98%	87%	87%	87%
Large Office	97%	97%	97%	88%	88%	88%
Small Retail	89%	89%	89%	91%	91%	91%
Large Retail	97%	97%	97%	83%	83%	83%
Small Hotel	86%	86%	86%	86%	86%	86%
Large Hotel	89%	89%	89%	89%	89%	89%
Hospital	100%	100%	100%	100%	100%	100%
Supermarket	66%	66%	66%	66%	66%	66%
School	97%	97%	97%	94%	94%	94%
Fastfood Restaurant	86%	86%	86%	86%	86%	86%
Sit-Down Restaurant	86%	86%	86%	86%	86%	86%
Warehouse	45%	45%	45%	28%	28%	28%

Table A.2a Characterization of buildings and their environment

Roof R-Value (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	12.0	12.0	12.0	11.3	11.3	11.3
Large Office	9.5	9.5	9.5	11.6	11.6	11.6
Small Retail	10.1	10.1	10.1	9.5	9.5	9.5
Large Retail	10.6	10.6	10.6	11.5	11.5	11.5
Small Hotel	10.5	10.5	10.5	10.5	10.5	10.5
Large Hotel	12.3	12.3	12.3	12.3	12.3	12.3
Hospital	12.2	12.2	12.2	12.2	12.2	12.2
Supermarket	6.8	6.8	6.8	6.8	6.8	6.8
School	11.1	11.1	11.1	10.5	10.5	10.5
Fastfood Restaurant	11.2	11.2	11.2	11.2	11.2	11.2
Sit Down Restaurant	11.2	11.2	11.2	11.2	11.2	11.2
Warehouse	7.8	7.8	7.8	7.6	7.6	7.6

Roof R-Value (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	13.3	13.3	13.3	12.6	12.6	12.6
Large Office	9.1	9.1	9.1	12.6	12.6	12.6
Small Retail	13.2	13.2	13.2	12.2	12.2	12.2
Large Retail	14.0	14.0	14.0	12.0	12.0	12.0
Small Hotel	13.2	13.2	13.2	13.2	13.2	13.2
Large Hotel	14.0	14.0	14.0	14.0	14.0	14.0
Hospital	11.5	11.5	11.5	11.5	11.5	11.5
Supermarket	11.8	11.8	11.8	11.8	11.8	11.8
School	12.6	12.6	12.6	13.3	13.3	13.3
Fastfood Restaurant	13.2	13.2	13.2	13.2	13.2	13.2
Sit Down Restaurant	13.2	13.2	13.2	13.2	13.2	13.2
Warehouse	10.1	10.1	10.1	10.6	10.6	10.6

Table A.2b Characterization of buildings and their environment

Wall R-Value (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	5.3	5.3	5.3	4.3	4.3	4.3
Large Office	3.2	3.2	3.2	3.6	3.6	3.6
Small Retail	3.4	3.4	3.4	2.5	2.5	2.5
Large Retail	3.1	3.1	3.1	3.3	3.3	3.3
Small Hotel	3.8	3.8	3.8	3.8	3.8	3.8
Large Hotel	4.3	4.3	4.3	4.3	4.3	4.3
Hospital	4.6	4.6	4.6	4.6	4.6	4.6
Supermarket	3.9	3.9	3.9	3.9	3.9	3.9
School	2.8	2.8	2.8	3.6	3.6	3.6
Fastfood Restaurant	3.6	3.6	3.6	3.6	3.6	3.6
Sit Down Restaurant	3.6	3.6	3.6	3.6	3.6	3.6
Warehouse	3.2	3.2	3.2	2.4	2.4	2.4

Wall R-Value (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	6.3	6.3	6.3	5.6	5.6	5.6
Large Office	4.6	4.6	4.6	6.0	6.0	6.0
Small Retail	6.6	6.6	6.6	4.4	4.4	4.4
Large Retail	6.4	6.4	6.4	4.8	4.8	4.8
Small Hotel	5.3	5.3	5.3	5.3	5.3	5.3
Large Hotel	6.2	6.2	6.2	6.2	6.2	6.2
Hospital	6.9	6.9	6.9	6.9	6.9	6.9
Supermarket	5.8	5.8	5.8	5.8	5.8	5.8
School	5.3	5.3	5.3	5.7	5.7	5.7
Fastfood Restaurant	4.9	4.9	4.9	4.9	4.9	4.9
Sit Down Restaurant	4.9	4.9	4.9	4.9	4.9	4.9
Warehouse	4.6	4.6	4.6	4.0	4.0	4.0

Table A.2c Characterization of buildings and their environment

Window R-Value (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.80	1.80	1.80	1.40	1.40	1.40
Large Office	1.60	1.60	1.60	1.50	1.50	1.50
Small Retail	1.50	1.50	1.50	1.20	1.20	1.20
Large Retail	1.50	1.50	1.50	1.50	1.50	1.50
Small Hotel	1.50	1.50	1.50	1.50	1.50	1.50
Large Hotel	1.40	1.40	1.40	1.40	1.40	1.40
Hospital	1.80	1.80	1.80	1.80	1.80	1.80
Supermarket	1.52	1.52	1.52	1.52	1.52	1.52
School	1.60	1.60	1.60	1.40	1.40	1.40
Fastfood Restaurant	1.53	1.53	1.53	1.53	1.53	1.53
Sit Down Restaurant	1.53	1.53	1.53	1.53	1.53	1.53
Warehouse	1.40	1.40	1.40	1.40	1.40	1.40

Window R-Value (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	2.00	2.00	2.00	1.58	1.58	1.58
Large Office	1.70	1.70	1.70	1.70	1.70	1.70
Small Retail	1.70	1.70	1.70	1.30	1.30	1.30
Large Retail	1.70	1.70	1.70	1.50	1.50	1.50
Small Hotel	1.70	1.70	1.70	1.70	1.70	1.70
Large Hotel	1.70	1.70	1.70	1.70	1.70	1.70
Hospital	2.00	2.00	2.00	2.00	2.00	2.00
Supermarket	1.60	1.60	1.60	1.60	1.60	1.60
School	1.70	1.70	1.70	1.70	1.70	1.70
Fastfood Restaurant	1.53	1.53	1.53	1.53	1.53	1.53
Sit Down Restaurant	1.53	1.53	1.53	1.53	1.53	1.53
Warehouse	1.70	1.70	1.70	1.70	1.70	1.70

Table A.2d Characterization of buildings and their environment

Window Shading Coefficient (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.79	0.79	0.79	0.82	0.82	0.82
Large Office	0.80	0.80	0.80	0.77	0.77	0.77
Small Retail	0.83	0.83	0.83	0.84	0.84	0.84
Large Retail	0.79	0.79	0.79	0.79	0.79	0.79
Small Hotel	0.81	0.81	0.81	0.81	0.81	0.81
Large Hotel	0.80	0.80	0.80	0.80	0.80	0.80
Hospital	0.71	0.71	0.71	0.71	0.71	0.71
Supermarket	0.82	0.82	0.82	0.82	0.82	0.82
School	0.79	0.79	0.79	0.82	0.82	0.82
Fastfood Restaurant	0.80	0.80	0.80	0.80	0.80	0.80
Sit Down Restaurant	0.80	0.80	0.80	0.80	0.80	0.80
Warehouse	0.83	0.83	0.83	0.85	0.85	0.85

Window Shading Coefficient (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.71	0.71	0.71	0.75	0.75	0.75
Large Office	0.69	0.69	0.69	0.71	0.71	0.71
Small Retail	0.78	0.78	0.78	0.83	0.83	0.83
Large Retail	0.74	0.74	0.74	0.76	0.76	0.76
Small Hotel	0.76	0.76	0.76	0.76	0.76	0.76
Large Hotel	0.74	0.74	0.74	0.74	0.74	0.74
Hospital	0.66	0.66	0.66	0.66	0.66	0.66
Supermarket	0.79	0.79	0.79	0.79	0.79	0.79
School	0.71	0.71	0.71	0.73	0.73	0.73
Fastfood Restaurant	0.80	0.80	0.80	0.80	0.80	0.80
Sit Down Restaurant	0.80	0.80	0.80	0.80	0.80	0.80
Warehouse	0.80	0.80	0.80	0.82	0.82	0.82

Table A.2e Characterization of buildings and their environment

Window/Wall Ratio (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.20	0.20	0.20	0.20	0.20	0.20
Large Office	0.45	0.45	0.45	0.45	0.45	0.45
Small Retail	0.15	0.15	0.15	0.15	0.15	0.15
Large Retail	0.15	0.15	0.15	0.15	0.15	0.15
Small Hotel	0.24	0.24	0.24	0.24	0.24	0.24
Large Hotel	0.30	0.30	0.30	0.30	0.30	0.30
Hospital	0.25	0.25	0.25	0.25	0.25	0.25
Supermarket	0.15	0.15	0.15	0.15	0.15	0.15
School	0.27	0.27	0.27	0.27	0.27	0.27
Fastfood Restaurant	0.30	0.30	0.30	0.30	0.30	0.30
Sit Down Restaurant	0.20	0.20	0.20	0.20	0.20	0.20
Warehouse	0.06	0.06	0.06	0.06	0.06	0.06

Window/Wall Ratio (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.15	0.15	0.15	0.15	0.15	0.15
Large Office	0.50	0.50	0.50	0.50	0.50	0.50
Small Retail	0.15	0.15	0.15	0.15	0.15	0.15
Large Retail	0.15	0.15	0.15	0.15	0.15	0.15
Small Hotel	0.21	0.21	0.21	0.21	0.21	0.21
Large Hotel	0.35	0.35	0.35	0.35	0.35	0.35
Hospital	0.25	0.25	0.25	0.25	0.25	0.25
Supermarket	0.15	0.15	0.15	0.15	0.15	0.15
School	0.18	0.18	0.18	0.18	0.18	0.18
Fastfood Restaurant	0.20	0.20	0.20	0.20	0.20	0.20
Sit Down Restaurant	0.15	0.15	0.15	0.15	0.15	0.15
Warehouse	0.03	0.03	0.03	0.03	0.03	0.03

Table A.2f Characterization of buildings and their environment

Air Change (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.40	0.40	0.40	0.40	0.40	0.40
Large Office	0.30	0.30	0.30	0.30	0.30	0.30
Small Retail	0.30	0.30	0.30	0.30	0.30	0.30
Large Retail	0.30	0.30	0.30	0.30	0.30	0.30
Small Hotel	0.25	0.25	0.25	0.25	0.25	0.25
Large Hotel	0.25	0.25	0.25	0.25	0.25	0.25
Hospital	0.20	0.20	0.20	0.20	0.20	0.20
Supermarket	0.30	0.30	0.30	0.30	0.30	0.30
School (1)	0.80	0.80	0.80	0.80	0.80	0.80
Fastfood Restaurant	0.25	0.25	0.25	0.25	0.25	0.25
Sit Down Restaurant	0.25	0.25	0.25	0.25	0.25	0.25
Warehouse	0.25	0.25	0.25	0.25	0.25	0.25

Air Change (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.40	0.40	0.40	0.40	0.40	0.40
Large Office	0.30	0.30	0.30	0.30	0.30	0.30
Small Retail	0.30	0.30	0.30	0.30	0.30	0.30
Large Retail	0.30	0.30	0.30	0.30	0.30	0.30
Small Hotel	0.25	0.25	0.25	0.25	0.25	0.25
Large Hotel	0.25	0.25	0.25	0.25	0.25	0.25
Hospital	0.25	0.25	0.25	0.25	0.25	0.25
Supermarket	0.30	0.30	0.30	0.30	0.30	0.30
School (1)	0.80	0.80	0.80	0.80	0.80	0.80
Fastfood Restaurant	0.25	0.25	0.25	0.25	0.25	0.25
Sit Down Restaurant	0.25	0.25	0.25	0.25	0.25	0.25
Warehouse	0.25	0.25	0.25	0.25	0.25	0.25

(1) Schools have high infiltration rates because of the high surface to volume, and window to wall ratios in these buildings.

Table A.2g Characterization of buildings and their environment

Occupancy -sq.ft./person (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	440	440	440	440	440	440
Large Office	430	430	430	430	430	430
Small Retail	180	180	180	180	180	180
Large Retail	360	360	360	360	360	360
Small Hotel	120	120	120	120	120	120
Large Hotel	210	210	210	210	210	210
Hospital	90	90	90	90	90	90
Supermarket	227	227	227	227	227	227
School	105	105	105	105	105	105
Fastfood Restaurant	65	65	65	65	65	65
Sit Down Restaurant	50	50	50	50	50	50
Warehouse	2085	2085	2085	2085	2085	2085

Occupancy - sq.ft./person (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	470	470	470	470	470	470
Large Office	390	390	390	390	390	390
Small Retail	180	180	180	180	180	180
Large Retail	360	360	360	360	360	360
Small Hotel	120	120	120	120	120	120
Large Hotel	210	210	210	210	210	210
Hospital	190	190	190	190	190	190
Supermarket	227	227	227	227	227	227
School	105	105	105	105	105	105
Fastfood Restaurant	65	65	65	65	65	65
Sit Down Restaurant	50	50	50	50	50	50
Warehouse	1635	1635	1635	1635	1635	1635

Table A.2h Characterization of buildings and their environment

Heating Degree Day - 65 F (STOCK)

Building Type	Zone 1	Zone 2	Zone 3N	Zone 3S	Zone 4	Zone 5
Small Office	8070	6194	4236	4236	1670	2193
Large Office	8070	6194	4236	4236	1670	2193
Small Retail	8070	6194	4236	4236	1670	2193
Large Retail	8070	6194	4236	4236	1670	2193
Small Hotel	8070	6194	4236	4236	1670	2193
Large Hotel	8070	6194	4236	4236	1670	2193
Hospital	8070	6194	4236	4236	1670	2193
Supermarket	8070	6194	4236	4236	1670	2193
School	8070	6194	4236	4236	1670	2193
Fastfood Restaurant	8070	6194	4236	4236	1670	2193
Sit Down Restaurant	8070	6194	4236	4236	1670	2193
Warehouse	8070	6194	4236	4236	1670	2193

Heating Degree Day - 65 F (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	8070	6194	4236	4236	1670	2193
Large Office	8070	6194	4236	4236	1670	2193
Small Retail	8070	6194	4236	4236	1670	2193
Large Retail	8070	6194	4236	4236	1670	2193
Small Hotel	8070	6194	4236	4236	1670	2193
Large Hotel	8070	6194	4236	4236	1670	2193
Hospital	8070	6194	4236	4236	1670	2193
Supermarket	8070	6194	4236	4236	1670	2193
School	8070	6194	4236	4236	1670	2193
Fastfood Restaurant	8070	6194	4236	4236	1670	2193
Sit Down Restaurant	8070	6194	4236	4236	1670	2193
Warehouse	8070	6194	4236	4236	1670	2193

Table A.2i Characterization of buildings and their environment

Cooling Degree Day - 65 F (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	750	998	1425	1425	1053	2047
Large Office	750	998	1425	1425	1053	2047
Small Retail	750	998	1425	1425	1053	2047
Large Retail	750	998	1425	1425	1053	2047
Small Hotel	750	998	1425	1425	1053	2047
Large Hotel	750	998	1425	1425	1053	2047
Hospital	750	998	1425	1425	1053	2047
Supermarket	750	998	1425	1425	1053	2047
School	750	998	1425	1425	1053	2047
Fastfood Restaurant	750	998	1425	1425	1053	2047
Sit Down Restaurant	750	998	1425	1425	1053	2047
Warehouse	750	998	1425	1425	1053	2047

Cooling Degree Day - 65 F (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	750	998	1425	1425	1053	2047
Large Office	750	998	1425	1425	1053	2047
Small Retail	750	998	1425	1425	1053	2047
Large Retail	750	998	1425	1425	1053	2047
Small Hotel	750	998	1425	1425	1053	2047
Large Hotel	750	998	1425	1425	1053	2047
Hospital	750	998	1425	1425	1053	2047
Supermarket	750	998	1425	1425	1053	2047
School	750	998	1425	1425	1053	2047
Fastfood Restaurant	750	998	1425	1425	1053	2047
Sit Down Restaurant	750	998	1425	1425	1053	2047
Warehouse	750	998	1425	1425	1053	2047

Table A.2j Characterization of buildings and their environment

Cooling Load (STOCK) (kBtu/ft2)

Building Type	Zone 1	Zone 2	Zone 3N	Zone 3S	Zone 4	Zone 5
Small Office	15.84	18.67	22.50	17.04	20.07	23.35
Large Office	20.45	22.94	26.49	25.64	28.98	31.55
Small Retail	14.00	17.21	22.19	21.37	24.65	29.36
Large Retail	15.60	18.50	22.50	23.01	30.49	31.10
Small Hotel	11.37	13.89	17.65	17.65	22.40	24.14
Large Hotel	17.58	20.38	24.17	24.17	32.54	32.36
Hospital	74.02	81.80	92.69	92.69	112.83	109.62
Supermarket	33.08	39.47	48.89	48.89	58.04	64.87
School	4.51	5.77	8.13	8.26	9.29	12.63
Fastfood Restaurant	40.32	47.90	59.85	59.85	74.12	81.22
Sit Down Restaurant	31.48	37.79	48.07	48.07	55.55	64.97
Warehouse	0.96	1.60	2.73	2.87	3.41	4.68

Cooling Load (NEW) (kBtu/ft2)

Building Type	Zone 1	Zone 2	Zone 3N	Zone 3S	Zone 4	Zone 5
Small Office	10.79	13.01	16.11	12.56	13.38	17.34
Large Office	15.60	17.82	20.96	21.27	24.00	26.70
Small Retail	13.35	16.28	20.79	19.80	23.39	27.31
Large Retail	17.00	20.04	24.10	23.97	31.99	32.43
Small Hotel	9.76	12.15	15.67	15.67	19.73	21.75
Large Hotel	18.95	21.82	25.50	25.50	35.10	33.97
Hospital	85.25	93.89	106.79	106.79	132.70	124.95
Supermarket	37.90	44.59	53.57	53.57	65.72	69.61
School	4.20	5.39	7.54	7.51	8.54	11.54
Fastfood Restaurant	35.27	42.47	53.87	53.87	64.97	73.30
Sit Down Restaurant	30.28	36.53	46.57	46.57	53.53	62.95
Warehouse	0.65	1.16	2.22	2.25	2.59	3.89

Table A.2k Characterization of buildings and their environment

Heating Load (STOCK) (kBtu/ft2)

Building Type	Zone 1	Zone 2	Zone 3N	Zone 3S	Zone 4	Zone 5
Small Office	27.65	18.37	10.14	15.70	1.47	5.12
Large Office	15.50	10.52	5.84	6.38	0.79	2.15
Small Retail	49.95	35.27	21.27	20.62	1.95	6.35
Large Retail	15.98	10.34	4.78	2.83	0.03	0.48
Small Hotel	30.90	20.38	11.30	11.30	0.41	2.42
Large Hotel	16.59	11.03	6.45	6.45	0.41	1.81
Hospital	14.61	8.88	4.47	4.47	0.20	1.23
Supermarket	41.51	26.22	13.25	13.25	0.41	3.41
School	50.90	37.79	25.33	28.95	9.22	12.94
Fastfood Restaurant	84.50	58.75	36.43	36.43	5.74	13.25
Sit Down Restaurant	62.13	42.54	25.43	25.43	2.66	8.54
Warehouse	14.48	10.00	6.08	6.45	1.67	2.29

Heating Load (NEW) (kBtu/ft2)

Building Type	Zone 1	Zone 2	Zone 3N	Zone 3S	Zone 4	Zone 5
Small Office	26.39	17.96	10.28	15.64	1.84	5.53
Large Office	15.26	10.45	6.01	6.69	0.89	2.29
Small Retail	42.47	30.08	17.96	17.41	1.43	5.12
Large Retail	13.28	8.43	3.55	2.29	0.00	0.31
Small Hotel	27.72	18.03	9.66	9.66	0.24	1.84
Large Hotel	13.59	8.74	4.98	4.98	0.20	1.26
Hospital	9.66	6.21	2.70	2.70	0.03	0.68
Supermarket	22.26	12.77	5.33	5.33	0.03	0.99
School	47.42	35.20	23.49	25.81	8.33	11.51
Fastfood Restaurant	77.33	53.84	33.39	33.39	5.70	12.36
Sit Down Restaurant	57.05	38.78	22.91	22.91	2.15	7.48
Warehouse	13.42	9.25	5.60	5.80	1.57	2.01

Table A.3a Building Response to Exogenous Variables

Cooling Slope for HDD (kBtu/sq.ft.-degree days) (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-1.7E-03	-1.7E-03	-1.7E-03	-3.1E-03	-3.1E-03	-3.1E-03
Large Office	-1.6E-03	-1.6E-03	-1.6E-03	-2.9E-03	-2.9E-03	-2.9E-03
Small Retail	-2.1E-03	-2.1E-03	-2.1E-03	-3.9E-03	-3.9E-03	-3.9E-03
Large Retail	-1.8E-03	-1.8E-03	-1.8E-03	-4.0E-03	-4.0E-03	-4.0E-03
Small Hotel	-1.6E-03	-1.6E-03	-1.6E-03	-3.2E-03	-3.2E-03	-3.2E-03
Large Hotel	-1.7E-03	-1.7E-03	-1.7E-03	-4.0E-03	-4.0E-03	-4.0E-03
Hospital	-4.9E-03	-4.9E-03	-4.9E-03	-8.3E-03	-8.3E-03	-8.3E-03
Supermarket	-4.1E-03	-4.1E-03	-4.1E-03	-7.8E-03	-7.8E-03	-7.8E-03
School	-9.4E-04	-9.4E-04	-9.4E-04	-2.1E-03	-2.1E-03	-2.1E-03
Fastfood Restaurant	-5.1E-03	-5.1E-03	-5.1E-03	-1.0E-02	-1.0E-02	-1.0E-02
Sit Down Restaurant	-4.3E-03	-4.3E-03	-4.3E-03	-8.3E-03	-8.3E-03	-8.3E-03
Warehouse	-4.6E-04	-4.6E-04	-4.6E-04	-8.9E-04	-8.9E-04	-8.9E-04

Cooling Slope for HDD (kBtu/sq.ft.-degree days) (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-1.4E-03	-1.4E-03	-1.4E-03	-2.3E-03	-2.3E-03	-2.3E-03
Large Office	-1.4E-03	-1.4E-03	-1.4E-03	-2.7E-03	-2.7E-03	-2.7E-03
Small Retail	-1.9E-03	-1.9E-03	-1.9E-03	-3.7E-03	-3.7E-03	-3.7E-03
Large Retail	-1.9E-03	-1.9E-03	-1.9E-03	-4.1E-03	-4.1E-03	-4.1E-03
Small Hotel	-1.5E-03	-1.5E-03	-1.5E-03	-3.0E-03	-3.0E-03	-3.0E-03
Large Hotel	-1.7E-03	-1.7E-03	-1.7E-03	-4.1E-03	-4.1E-03	-4.1E-03
Hospital	-5.6E-03	-5.6E-03	-5.6E-03	-8.9E-03	-8.9E-03	-8.9E-03
Supermarket	-4.1E-03	-4.1E-03	-4.1E-03	-7.9E-03	-7.9E-03	-7.9E-03
School	-8.7E-04	-8.7E-04	-8.7E-04	-2.0E-03	-2.0E-03	-2.0E-03
Fastfood Restaurant	-4.9E-03	-4.9E-03	-4.9E-03	-9.5E-03	-9.5E-03	-9.5E-03
Sit Down Restaurant	-4.2E-03	-4.2E-03	-4.2E-03	-8.0E-03	-8.0E-03	-8.0E-03
Warehouse	-4.1E-04	-4.1E-04	-4.1E-04	-8.0E-04	-8.0E-04	-8.0E-04

(1) The values in this table indicate the expected change in building loads in kBtu per ft2 of floor area per unit change in heating/cooling degree days if and when there is a shift in the average heating/cooling degree days for the building stock. Such a shift may be due to geographically-uneven expansion of the building stock.

Table A.3b Building Response to Exogenous Variables

Cooling Slope for CDD (kBtu/sq.ft.-degree days) (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	9.9E-03	9.9E-03	9.9E-03	1.0E-02	1.0E-02	1.0E-02
Large Office	9.0E-03	9.0E-03	9.0E-03	9.5E-03	9.5E-03	9.5E-03
Small Retail	1.2E-02	1.2E-02	1.2E-02	1.3E-02	1.3E-02	1.3E-02
Large Retail	1.0E-02	1.0E-02	1.0E-02	1.3E-02	1.3E-02	1.3E-02
Small Hotel	9.3E-03	9.3E-03	9.3E-03	1.0E-02	1.0E-02	1.0E-02
Large Hotel	9.8E-03	9.8E-03	9.8E-03	1.3E-02	1.3E-02	1.3E-02
Hospital	2.8E-02	2.8E-02	2.8E-02	2.7E-02	2.7E-02	2.7E-02
Supermarket	2.3E-02	2.3E-02	2.3E-02	2.6E-02	2.6E-02	2.6E-02
School	5.4E-03	5.4E-03	5.4E-03	7.0E-03	7.0E-03	7.0E-03
Fastfood Restaurant	2.9E-02	2.9E-02	2.9E-02	3.4E-02	3.4E-02	3.4E-02
Sit Down Restaurant	2.5E-02	2.5E-02	2.5E-02	2.7E-02	2.7E-02	2.7E-02
Warehouse	2.6E-03	2.6E-03	2.6E-03	2.9E-03	2.9E-03	2.9E-03

Cooling Slope for CDD (kBtu/sq.ft.-degree days) (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	7.9E-03	7.9E-03	7.9E-03	7.7E-03	7.7E-03	7.7E-03
Large Office	7.9E-03	7.9E-03	7.9E-03	8.7E-03	8.7E-03	8.7E-03
Small Retail	1.1E-02	1.1E-02	1.1E-02	1.2E-02	1.2E-02	1.2E-02
Large Retail	1.1E-02	1.1E-02	1.1E-02	1.4E-02	1.4E-02	1.4E-02
Small Hotel	8.7E-03	8.7E-03	8.7E-03	9.8E-03	9.8E-03	9.8E-03
Large Hotel	9.7E-03	9.7E-03	9.7E-03	1.4E-02	1.4E-02	1.4E-02
Hospital	3.2E-02	3.2E-02	3.2E-02	2.9E-02	2.9E-02	2.9E-02
Supermarket	2.3E-02	2.3E-02	2.3E-02	2.6E-02	2.6E-02	2.6E-02
School	5.0E-03	5.0E-03	5.0E-03	6.5E-03	6.5E-03	6.5E-03
Fastfood Restaurant	2.8E-02	2.8E-02	2.8E-02	3.1E-02	3.1E-02	3.1E-02
Sit Down Restaurant	2.4E-02	2.4E-02	2.4E-02	2.6E-02	2.6E-02	2.6E-02
Warehouse	2.3E-03	2.3E-03	2.3E-03	2.6E-03	2.6E-03	2.6E-03

(1) The values in this table indicate the expected change in building loads in kBtu per ft2 of floor area per unit change in heating/cooling degree days if and when there is a shift in the average heating/cooling degree days for the building stock. Such a shift may be due to geographically-uneven expansion of the building stock.

Table A.3c Building Response to Exogenous Variables

Heating Slope for HDD (kBtu/sq.ft.-degree days) (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	4.6E-03	4.6E-03	4.6E-03	5.2E-03	5.2E-03	5.2E-03
Large Office	2.5E-03	2.5E-03	2.5E-03	2.1E-03	2.1E-03	2.1E-03
Small Retail	7.5E-03	7.5E-03	7.5E-03	7.0E-03	7.0E-03	7.0E-03
Large Retail	2.9E-03	2.9E-03	2.9E-03	1.2E-03	1.2E-03	1.2E-03
Small Hotel	5.1E-03	5.1E-03	5.1E-03	4.3E-03	4.3E-03	4.3E-03
Large Hotel	2.6E-03	2.6E-03	2.6E-03	2.3E-03	2.3E-03	2.3E-03
Hospital	2.6E-03	2.6E-03	2.6E-03	1.6E-03	1.6E-03	1.6E-03
Supermarket	7.4E-03	7.4E-03	7.4E-03	4.8E-03	4.8E-03	4.8E-03
School	6.7E-03	6.7E-03	6.7E-03	7.8E-03	7.8E-03	7.8E-03
Fastfood Restaurant	1.3E-02	1.3E-02	1.3E-02	1.1E-02	1.1E-02	1.1E-02
Sit Down Restaurant	9.6E-03	9.6E-03	9.6E-03	8.3E-03	8.3E-03	8.3E-03
Warehouse	2.2E-03	2.2E-03	2.2E-03	2.0E-03	2.0E-03	2.0E-03

Heating Slope for HDD (kBtu/sq.ft.-degree days) (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	4.2E-03	4.2E-03	4.2E-03	4.9E-03	4.9E-03	4.9E-03
Large Office	2.4E-03	2.4E-03	2.4E-03	2.2E-03	2.2E-03	2.2E-03
Small Retail	6.4E-03	6.4E-03	6.4E-03	6.0E-03	6.0E-03	6.0E-03
Large Retail	2.5E-03	2.5E-03	2.5E-03	9.7E-04	9.7E-04	9.7E-04
Small Hotel	4.7E-03	4.7E-03	4.7E-03	3.8E-03	3.8E-03	3.8E-03
Large Hotel	2.2E-03	2.2E-03	2.2E-03	1.8E-03	1.8E-03	1.8E-03
Hospital	1.8E-03	1.8E-03	1.8E-03	9.9E-04	9.9E-04	9.9E-04
Supermarket	4.4E-03	4.4E-03	4.4E-03	2.1E-03	2.1E-03	2.1E-03
School	6.2E-03	6.2E-03	6.2E-03	7.0E-03	7.0E-03	7.0E-03
Fastfood Restaurant	1.1E-02	1.1E-02	1.1E-02	1.0E-02	1.0E-02	1.0E-02
Sit Down Restaurant	8.9E-03	8.9E-03	8.9E-03	7.6E-03	7.6E-03	7.6E-03
Warehouse	2.0E-03	2.0E-03	2.0E-03	1.9E-03	1.9E-03	1.9E-03

(1) The values in this table indicate the expected change in building loads in kBtu per ft2 of floor area per unit change in heating/cooling degree days if and when there is a shift in the average heating/cooling degree days for the building stock. Such a shift may be due to geographically-uneven expansion of the building stock.

Table A.3d Building Response to Exogenous Variables

Heating Slope for CDD (kBtu/sq.ft.-degree days) (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-2.6E-02	-2.6E-02	-2.6E-02	-1.7E-02	-1.7E-02	-1.7E-02
Large Office	-1.4E-02	-1.4E-02	-1.4E-02	-6.8E-03	-6.8E-03	-6.8E-03
Small Retail	-4.2E-02	-4.2E-02	-4.2E-02	-2.3E-02	-2.3E-02	-2.3E-02
Large Retail	-1.7E-02	-1.7E-02	-1.7E-02	-3.8E-03	-3.8E-03	-3.8E-03
Small Hotel	-2.9E-02	-2.9E-02	-2.9E-02	-1.4E-02	-1.4E-02	-1.4E-02
Large Hotel	-1.5E-02	-1.5E-02	-1.5E-02	-7.5E-03	-7.5E-03	-7.5E-03
Hospital	-1.5E-02	-1.5E-02	-1.5E-02	-5.2E-03	-5.2E-03	-5.2E-03
Supermarket	-4.2E-02	-4.2E-02	-4.2E-02	-1.6E-02	-1.6E-02	-1.6E-02
School	-3.8E-02	-3.8E-02	-3.8E-02	-2.6E-02	-2.6E-02	-2.6E-02
Fastfood Restaurant	-7.1E-02	-7.1E-02	-7.1E-02	-3.7E-02	-3.7E-02	-3.7E-02
Sit Down Restaurant	-5.4E-02	-5.4E-02	-5.4E-02	-2.7E-02	-2.7E-02	-2.7E-02
Warehouse	-1.2E-02	-1.2E-02	-1.2E-02	-6.7E-03	-6.7E-03	-6.7E-03

Heating Slope for CDD (kBtu/sq.ft.-degree days) (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-2.4E-02	-2.4E-02	-2.4E-02	-1.6E-02	-1.6E-02	-1.6E-02
Large Office	-1.4E-02	-1.4E-02	-1.4E-02	-7.1E-03	-7.1E-03	-7.1E-03
Small Retail	-3.6E-02	-3.6E-02	-3.6E-02	-2.0E-02	-2.0E-02	-2.0E-02
Large Retail	-1.4E-02	-1.4E-02	-1.4E-02	-3.2E-03	-3.2E-03	-3.2E-03
Small Hotel	-2.7E-02	-2.7E-02	-2.7E-02	-1.3E-02	-1.3E-02	-1.3E-02
Large Hotel	-1.3E-02	-1.3E-02	-1.3E-02	-6.0E-03	-6.0E-03	-6.0E-03
Hospital	-1.0E-02	-1.0E-02	-1.0E-02	-3.2E-03	-3.2E-03	-3.2E-03
Supermarket	-2.5E-02	-2.5E-02	-2.5E-02	-7.0E-03	-7.0E-03	-7.0E-03
School	-3.5E-02	-3.5E-02	-3.5E-02	-2.3E-02	-2.3E-02	-2.3E-02
Fastfood Restaurant	-6.5E-02	-6.5E-02	-6.5E-02	-3.4E-02	-3.4E-02	-3.4E-02
Sit Down Restaurant	-5.1E-02	-5.1E-02	-5.1E-02	-2.5E-02	-2.5E-02	-2.5E-02
Warehouse	-1.2E-02	-1.2E-02	-1.2E-02	-6.1E-03	-6.1E-03	-6.1E-03

(1) The values in this table indicate the expected change in building loads in kBtu per ft2 of floor area per unit change in heating/cooling degree days if and when there is a shift in the average heating/cooling degree days for the building stock. Such a shift may be due to geographically-uneven expansion of the building stock.

Table A.3e Building Response to Exogenous Variables

Cooling Slope for Occupancy (kBtu/sq.ft. Person/1000 sq.ft.) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.15	0.20	0.25	0.29	0.30	0.44
Large Office	-0.26	-0.10	0.08	0.10	0.23	0.45
Small Retail	0.33	0.40	0.50	0.50	0.62	0.72
Large Retail	0.35	0.43	0.54	0.52	0.65	0.78
Small Hotel	0.01	0.01	0.01	0.01	0.02	0.02
Large Hotel	0.18	0.24	0.34	0.34	0.09	0.47
Hospital	-0.77	-0.47	-0.13	-0.13	-0.01	0.49
Supermarket	0.31	0.42	0.77	0.77	-0.05	1.10
School	0.04	0.06	0.09	0.09	0.09	0.18
Fastfood Restaurant	0.24	0.31	0.48	0.48	0.12	0.67
Sit Down Restaurant	0.17	0.22	0.33	0.33	0.09	0.47
Warehouse	0.14	0.28	0.35	0.35	0.43	0.57

Cooling Slope for Occupancy (kBtu/sq.ft. Person/1000 sq.ft.) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.17	0.21	0.29	0.29	0.31	0.43
Large Office	-0.20	-0.10	0.07	0.08	0.22	0.41
Small Retail	0.34	0.41	0.50	0.51	0.62	0.74
Large Retail	0.41	0.51	0.66	0.66	0.75	0.95
Small Hotel	0.01	0.01	0.01	0.01	0.02	0.02
Large Hotel	0.16	0.22	0.32	0.32	0.09	0.47
Hospital	-0.97	-0.66	-0.32	-0.32	-0.07	0.40
Supermarket	0.01	0.10	0.41	0.41	-0.47	0.74
School	0.04	0.06	0.09	0.08	0.09	0.18
Fastfood Restaurant	0.25	0.33	0.48	0.48	0.17	0.68
Sit Down Restaurant	0.16	0.21	0.32	0.32	0.09	0.46
Warehouse	0.17	0.28	0.34	0.39	0.45	0.56

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.3f Building Response to Exogenous Variables

Heating Slope for Occupancy (kBtu/sq.ft. Person/1000 sq.ft.) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.83	0.54	0.35	0.35	0.06	0.14
Large Office	0.63	0.42	0.26	0.27	0.05	0.10
Small Retail	0.88	0.61	0.38	0.38	0.08	0.12
Large Retail	0.92	0.61	0.35	0.32	0.00	0.08
Small Hotel	-0.01	-0.01	-0.01	-0.01	0.00	0.00
Large Hotel	0.51	0.31	0.15	0.15	-0.01	0.02
Hospital	0.97	0.69	0.38	0.38	0.02	0.18
Supermarket	5.74	4.22	2.86	2.86	0.41	1.21
School	0.93	0.71	0.47	0.47	0.12	0.18
Fastfood Restaurant	3.98	3.03	2.09	2.09	0.60	0.95
Sit Down Restaurant	2.62	1.99	1.37	1.37	0.38	0.62
Warehouse	0.85	0.64	0.43	0.43	0.07	0.14

Heating Slope for Occupancy (kBtu/sq.ft. Person/1000 sq.ft.) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.82	0.53	0.36	0.32	0.08	0.12
Large Office	0.70	0.46	0.27	0.29	0.06	0.11
Small Retail	0.87	0.62	0.38	0.38	0.07	0.12
Large Retail	1.15	0.78	0.41	0.41	0.02	0.09
Small Hotel	-0.01	-0.01	-0.01	-0.01	0.00	0.00
Large Hotel	0.47	0.28	0.15	0.15	0.00	0.02
Hospital	0.98	0.58	0.38	0.38	0.00	0.14
Supermarket	5.42	3.89	2.47	2.47	0.13	0.88
School	0.93	0.70	0.47	0.47	0.12	0.18
Fastfood Restaurant	3.97	3.03	2.08	2.08	0.64	0.95
Sit Down Restaurant	2.56	1.94	1.33	1.33	0.37	0.60
Warehouse	0.90	0.62	0.39	0.39	0.06	0.17

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.4a Coincidence Factors

Cooling Coincidence Factor for Lighting (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.35	0.40	0.46	0.38	0.58	0.52
Large Office	0.59	0.63	0.67	0.65	0.79	0.74
Small Retail	0.30	0.34	0.40	0.40	0.60	0.54
Large Retail	0.40	0.47	0.53	0.57	0.88	0.77
Small Hotel	0.27	0.31	0.37	0.37	0.53	0.50
Large Hotel	0.45	0.52	0.59	0.59	0.93	0.81
Hospital	0.76	0.81	0.88	0.88	0.99	0.96
Supermarket	0.40	0.47	0.54	0.54	0.78	0.72
School	0.23	0.27	0.36	0.35	0.52	0.54
Fastfood Restaurant	0.41	0.48	0.56	0.56	0.80	0.75
Sit Down Restaurant	0.38	0.44	0.51	0.51	0.72	0.69
Warehouse	0.10	0.14	0.18	0.20	0.28	0.26

Cooling Coincidence Factor for Lighting (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.33	0.38	0.43	0.37	0.53	0.49
Large Office	0.58	0.63	0.67	0.64	0.79	0.74
Small Retail	0.31	0.35	0.42	0.41	0.64	0.56
Large Retail	0.46	0.53	0.61	0.62	0.94	0.84
Small Hotel	0.27	0.31	0.37	0.37	0.55	0.51
Large Hotel	0.47	0.54	0.62	0.62	0.95	0.84
Hospital	0.80	0.85	0.92	0.92	0.99	0.97
Supermarket	0.48	0.55	0.63	0.63	0.87	0.81
School	0.23	0.28	0.36	0.36	0.53	0.54
Fastfood Restaurant	0.41	0.48	0.57	0.57	0.79	0.75
Sit Down Restaurant	0.38	0.44	0.52	0.52	0.72	0.70
Warehouse	0.09	0.13	0.18	0.18	0.25	0.26

(1) Coincidence Factors are an indication of the interaction between space conditioning and the other end uses. A reduction in lighting energy, for example, may significantly reduce the cooling in a building. Coincidence factors quantify the reduction in the heating/cooling load per unit of reduction in the energy use of other end uses.

Table A.4b Coincidence Factors

Heating Coincidence Factor for Lighting (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-0.46	-0.39	-0.32	-0.37	-0.14	-0.21
Large Office	-0.28	-0.23	-0.18	-0.19	-0.07	-0.09
Small Retail	-0.57	-0.51	-0.44	-0.44	-0.18	-0.26
Large Retail	-0.50	-0.42	-0.35	-0.32	-0.03	-0.12
Small Hotel	-0.42	-0.36	-0.30	-0.30	-0.05	-0.13
Large Hotel	-0.53	-0.20	-0.15	-0.15	-0.04	-0.07
Hospital	-0.25	-0.16	-0.08	-0.08	-0.01	-0.03
Supermarket	-0.50	-0.42	-0.34	-0.34	-0.06	-0.15
School	-0.64	-0.59	-0.49	-0.49	-0.27	-0.30
Fastfood Restaurant	-0.53	-0.46	-0.36	-0.36	-0.11	-0.17
Sit Down Restaurant	-0.57	-0.50	-0.42	-0.42	-0.18	-0.23
Warehouse	-0.34	-0.30	-0.25	-0.25	-0.15	-0.16

Heating Coincidence Factor for Lighting (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-0.48	-0.41	-0.34	-0.37	-0.18	-0.24
Large Office	-0.29	-0.23	-0.18	-0.20	-0.06	-0.10
Small Retail	-0.56	-0.50	-0.43	-0.43	-0.16	-0.25
Large Retail	-0.47	-0.40	-0.31	-0.30	-0.01	-0.09
Small Hotel	-0.42	-0.37	-0.31	-0.31	-0.05	-0.12
Large Hotel	-0.23	-0.19	-0.12	-0.12	-0.03	-0.05
Hospital	-0.17	-0.09	-0.05	-0.05	0.00	-0.02
Supermarket	-0.42	-0.34	-0.24	-0.24	-0.01	-0.09
School	-0.65	-0.57	-0.49	-0.50	-0.27	-0.29
Fastfood Restaurant	-0.53	-0.45	-0.35	-0.35	-0.12	-0.17
Sit Down Restaurant	-0.57	-0.50	-0.41	-0.41	-0.17	-0.23
Warehouse	-0.37	-0.31	-0.25	-0.25	-0.16	-0.17

(1) Coincidence Factors are an indication of the interaction between space conditioning and the other end uses. A reduction in lighting energy, for example, may significantly reduce the cooling in a building. Coincidence factors quantify the reduction in the heating/cooling load per unit of reduction in the energy use of other end uses.

Table A.4c Coincidence Factors

Cooling Coincidence Factor for Equipment (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.40	0.46	0.52	0.43	0.69	0.60
Large Office	0.66	0.70	0.75	0.73	0.86	0.84
Small Retail	0.35	0.40	0.46	0.46	0.74	0.64
Large Retail	0.50	0.58	0.68	0.74	0.94	0.90
Small Hotel	0.29	0.33	0.39	0.39	0.57	0.54
Large Hotel	0.46	0.52	0.60	0.60	0.90	0.80
Hospital	0.90	0.93	0.96	0.96	1.00	0.99
Supermarket	0.66	0.73	0.79	0.79	0.90	0.89
School	0.39	0.44	0.51	0.49	0.65	0.65
Fastfood Restaurant	0.52	0.61	0.73	0.73	0.96	0.91
Sit Down Restaurant	0.58	0.66	0.79	0.79	0.96	0.92
Warehouse	0.07	0.10	0.13	0.13	0.18	0.18

Cooling Coincidence Factor for Equipment (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.38	0.43	0.48	0.41	0.63	0.56
Large Office	0.64	0.69	0.73	0.71	0.85	0.82
Small Retail	0.36	0.42	0.47	0.47	0.77	0.66
Large Retail	0.56	0.64	0.75	0.78	0.97	0.94
Small Hotel	0.29	0.34	0.40	0.40	0.59	0.55
Large Hotel	0.48	0.56	0.63	0.63	0.93	0.84
Hospital	0.94	0.95	0.97	0.97	1.00	0.99
Supermarket	0.77	0.81	0.86	0.86	0.95	0.93
School	0.39	0.44	0.52	0.51	0.65	0.65
Fastfood Restaurant	0.54	0.63	0.76	0.76	0.97	0.93
Sit Down Restaurant	0.60	0.69	0.81	0.81	0.96	0.93
Warehouse	0.06	0.09	0.13	0.13	0.18	0.18

(1) Coincidence Factors are an indication of the interaction between space conditioning and the other end uses. A reduction in lighting energy, for example, may significantly reduce the cooling in a building. Coincidence factors quantify the reduction in the heating/cooling load per unit of reduction in the energy use of other end uses.

Table A.4d Coincidence Factors

Heating Coincidence Factor for Equipment (STOCK) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-0.43	-0.36	-0.28	-0.34	-0.08	-0.17
Large Office	-0.24	-0.19	-0.14	-0.15	-0.04	-0.06
Small Retail	-0.54	-0.47	-0.40	-0.40	-0.09	-0.19
Large Retail	-0.41	-0.33	-0.22	-0.17	0.00	-0.03
Small Hotel	-0.40	-0.35	-0.28	-0.28	-0.04	-0.10
Large Hotel	-0.52	-0.39	-0.25	-0.25	-0.05	-0.11
Hospital	-0.09	-0.03	-0.02	-0.02	0.00	-0.01
Supermarket	-0.27	-0.19	-0.12	-0.12	-0.01	-0.04
School	-0.49	-0.44	-0.37	-0.38	-0.20	-0.21
Fastfood Restaurant	-0.43	-0.33	-0.20	-0.20	0.00	-0.04
Sit Down Restaurant	-0.37	-0.28	-0.16	-0.16	-0.01	-0.05
Warehouse	-0.26	-0.21	-0.17	-0.17	-0.11	-0.11

Heating Coincidence Factor for Equipment (NEW) (1)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-0.46	-0.38	-0.31	-0.36	-0.12	-0.20
Large Office	-0.25	-0.20	-0.16	-0.17	-0.04	-0.07
Small Retail	-0.53	-0.46	-0.39	-0.39	-0.08	-0.18
Large Retail	-0.38	-0.30	-0.18	-0.15	0.00	-0.02
Small Hotel	-0.41	-0.35	-0.28	-0.28	-0.03	-0.10
Large Hotel	-0.50	-0.33	-0.22	-0.22	-0.03	-0.09
Hospital	-0.04	-0.03	-0.02	-0.02	0.00	-0.01
Supermarket	-0.16	-0.10	-0.06	-0.06	0.00	-0.01
School	-0.48	-0.42	-0.35	-0.37	-0.20	-0.21
Fastfood Restaurant	-0.40	-0.31	-0.17	-0.17	0.00	-0.03
Sit Down Restaurant	-0.35	-0.26	-0.14	-0.14	-0.01	-0.04
Warehouse	-0.27	-0.23	-0.18	-0.17	-0.11	-0.11

(1) Coincidence Factors are an indication of the interaction between space conditioning and the other end uses. A reduction in lighting energy, for example, may significantly reduce the cooling in a building. Coincidence factors quantify the reduction in the heating/cooling load per unit of reduction in the energy use of other end uses.

Table A.5a Shell Efficiency Data

Cooling Slope for Roof R-Value (kBtu/sq.ft. R) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.04	0.03	0.02	-0.01	0.08	-0.01
Large Office	0.03	0.03	0.03	0.03	0.04	0.02
Small Retail	0.02	0.01	-0.01	-0.01	0.09	0.00
Large Retail	0.06	0.06	0.07	0.07	0.10	0.06
Small Hotel	0.02	0.02	0.01	0.01	0.05	0.01
Large Hotel	0.01	0.00	0.00	0.00	0.01	0.00
Hospital	0.08	0.07	0.05	0.05	0.04	0.03
Supermarket	0.09	0.09	0.06	0.06	0.14	0.05
School	0.01	0.01	0.00	0.00	0.01	0.00
Fastfood Restaurant	0.02	0.02	0.00	0.00	0.07	0.00
Sit Down Restaurant	0.01	0.00	-0.03	-0.03	0.05	-0.03
Warehouse	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03

Cooling Slope for Roof R-Value (kBtu/sq.ft. R) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.02	0.02	0.01	-0.03	0.04	-0.03
Large Office	0.02	0.02	0.02	0.02	0.03	0.02
Small Retail	0.02	0.01	-0.01	-0.01	0.10	0.00
Large Retail	0.07	0.07	0.08	0.07	0.10	0.06
Small Hotel	0.02	0.02	0.01	0.01	0.05	0.01
Large Hotel	0.00	0.00	0.00	0.00	0.01	0.00
Hospital	0.06	0.05	0.04	0.04	0.03	0.02
Supermarket	0.15	0.15	0.13	0.13	0.20	0.11
School	0.01	0.01	0.00	0.00	0.02	0.00
Fastfood Restaurant	0.02	0.03	0.01	0.01	0.07	0.00
Sit Down Restaurant	0.01	0.01	-0.03	-0.03	0.05	-0.03
Warehouse	-0.01	-0.01	-0.02	-0.02	-0.02	-0.03

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5b Shell Efficiency Data

Heating Slope for Roof R-Value (kBtu/sq.ft. R) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-0.26	-0.19	-0.13	-0.29	-0.06	-0.13
Large Office	-0.07	-0.04	-0.02	-0.03	0.00	-0.01
Small Retail	-0.57	-0.43	-0.30	-0.30	-0.06	-0.13
Large Retail	-0.25	-0.18	-0.10	-0.10	0.00	-0.03
Small Hotel	-0.21	-0.16	-0.11	-0.11	-0.01	-0.04
Large Hotel	-0.09	-0.07	-0.05	-0.05	-0.01	-0.02
Hospital	-0.06	-0.04	-0.03	-0.03	0.00	-0.01
Supermarket	-0.59	-0.42	-0.26	-0.26	-0.02	-0.09
School	-0.40	-0.31	-0.22	-0.22	-0.09	-0.11
Fastfood Restaurant	-0.79	-0.60	-0.40	-0.40	-0.10	-0.17
Sit Down Restaurant	-0.81	-0.62	-0.44	-0.44	-0.12	-0.20
Warehouse	-0.15	-0.11	-0.08	-0.08	-0.03	-0.04

Heating Slope for Roof R-Value (kBtu/sq.ft. R) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-0.28	-0.20	-0.14	-0.30	-0.08	-0.14
Large Office	-0.07	-0.05	-0.03	-0.04	0.00	-0.01
Small Retail	-0.57	-0.43	-0.30	-0.30	-0.06	-0.13
Large Retail	-0.26	-0.18	-0.10	-0.10	0.00	-0.03
Small Hotel	-0.22	-0.17	-0.11	-0.11	-0.01	-0.04
Large Hotel	-0.05	-0.04	-0.03	-0.03	-0.01	-0.01
Hospital	-0.03	-0.02	-0.01	-0.01	0.00	0.00
Supermarket	-0.51	-0.35	-0.19	-0.19	-0.01	-0.06
School	-0.40	-0.31	-0.22	-0.22	-0.09	-0.11
Fastfood Restaurant	-0.79	-0.59	-0.40	-0.40	-0.11	-0.17
Sit Down Restaurant	-0.81	-0.62	-0.44	-0.44	-0.12	-0.20
Warehouse	-0.15	-0.12	-0.08	-0.08	-0.03	-0.04

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5c Shell Efficiency Data

Cooling Slope for Wall R-Value (kBtu/sq.ft. R) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.32	0.31	0.23	0.05	0.33	0.09
Large Office	0.15	0.16	0.13	0.12	0.30	0.15
Small Retail	0.12	0.12	0.10	0.10	0.41	0.16
Large Retail	0.11	0.12	0.13	0.16	0.26	0.19
Small Hotel	0.30	0.29	0.25	0.25	0.64	0.37
Large Hotel	0.16	0.17	0.12	0.12	0.37	0.17
Hospital	0.66	0.62	0.56	0.56	0.61	0.44
Supermarket	0.60	0.65	0.61	0.61	1.03	0.66
School	0.09	0.09	0.11	0.11	0.18	0.16
Fastfood Restaurant	0.32	0.36	0.36	0.36	0.78	0.46
Sit Down Restaurant	0.25	0.28	0.25	0.25	0.62	0.30
Warehouse	-0.01	-0.01	-0.01	-0.01	0.02	-0.01

Cooling Slope for Wall R-Value (kBtu/sq.ft. R) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.20	0.17	0.11	0.00	0.21	0.01
Large Office	0.10	0.10	0.08	0.09	0.24	0.11
Small Retail	0.11	0.11	0.08	0.09	0.37	0.14
Large Retail	0.13	0.14	0.14	0.16	0.27	0.19
Small Hotel	0.25	0.25	0.22	0.22	0.58	0.33
Large Hotel	0.16	0.17	0.14	0.14	0.35	0.17
Hospital	0.73	0.67	0.62	0.62	0.62	0.46
Supermarket	0.68	0.72	0.69	0.69	1.10	0.72
School	0.10	0.11	0.11	0.12	0.19	0.16
Fastfood Restaurant	0.32	0.36	0.36	0.36	0.80	0.46
Sit Down Restaurant	0.25	0.28	0.25	0.25	0.64	0.30
Warehouse	-0.01	-0.01	-0.01	-0.02	0.02	-0.01

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5d Shell Efficiency Data

Heating Slope for Wall R-Value (kBtu/sq.ft. R) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-3.29	-2.43	-1.62	-1.19	-0.31	-0.53
Large Office	-1.00	-0.75	-0.51	-0.52	-0.16	-0.24
Small Retail	-1.49	-1.13	-0.80	-0.79	-0.16	-0.34
Large Retail	-0.49	-0.36	-0.22	-0.20	-0.01	-0.04
Small Hotel	-2.57	-1.95	-1.37	-1.37	-0.18	-0.51
Large Hotel	-1.30	-0.80	-0.55	-0.55	-0.10	-0.22
Hospital	-1.25	-0.86	-0.47	-0.47	-0.05	-0.15
Supermarket	-2.38	-1.68	-1.01	-1.01	-0.06	-0.32
School	-2.29	-1.78	-1.28	-1.71	-0.69	-0.89
Fastfood Restaurant	-2.67	-2.02	-1.32	-1.32	-0.22	-0.48
Sit Down Restaurant	-3.01	-2.31	-1.59	-1.59	-0.40	-0.71
Warehouse	-0.37	-0.29	-0.20	-0.21	-0.09	-0.11

Heating Slope for Wall R-Value (kBtu/sq.ft. R) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-3.41	-2.55	-1.74	-1.26	-0.39	-0.60
Large Office	-0.84	-0.64	-0.44	-0.50	-0.17	-0.24
Small Retail	-1.35	-1.02	-0.72	-0.71	-0.15	-0.31
Large Retail	-0.51	-0.38	-0.23	-0.21	0.00	-0.04
Small Hotel	-2.69	-2.04	-1.43	-1.43	-0.20	-0.53
Large Hotel	-0.95	-0.71	-0.48	-0.48	-0.08	-0.19
Hospital	-1.06	-0.72	-0.38	-0.38	-0.03	-0.12
Supermarket	-2.29	-1.60	-0.94	-0.94	-0.04	-0.28
School	-2.93	-2.28	-1.64	-1.99	-0.80	-1.03
Fastfood Restaurant	-3.10	-2.35	-1.56	-1.56	-0.33	-0.61
Sit Down Restaurant	-3.17	-2.44	-1.68	-1.68	-0.43	-0.75
Warehouse	-0.40	-0.31	-0.21	-0.23	-0.10	-0.12

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5e Shell Efficiency Data

Cooling Slope for Window R-Value (kBtu/sq.ft. R) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	1.47	1.55	1.47	0.64	1.75	0.84
Large Office	1.55	1.65	1.55	1.55	3.05	1.87
Small Retail	0.78	0.82	0.80	0.84	2.31	1.12
Large Retail	0.62	0.70	0.72	0.90	1.41	1.00
Small Hotel	1.39	1.49	1.51	1.51	3.23	1.99
Large Hotel	1.51	1.63	1.49	1.49	3.09	1.81
Hospital	2.01	2.15	2.19	2.19	3.09	2.07
Supermarket	0.78	0.88	0.82	0.82	1.99	1.12
School	0.40	0.46	0.56	0.66	1.10	0.92
Fastfood Restaurant	1.45	1.53	1.39	1.39	3.68	1.79
Sit Down Restaurant	0.60	0.64	0.58	0.58	1.67	0.82
Warehouse	0.02	0.02	0.02	0.04	0.12	0.04

Cooling Slope for Window R-Value (kBtu/sq.ft. R) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	0.80	0.86	0.80	0.34	0.98	0.42
Large Office	1.29	1.35	1.25	1.51	3.11	1.85
Small Retail	0.74	0.78	0.74	0.80	2.21	1.06
Large Retail	0.74	0.82	0.88	0.96	1.45	1.06
Small Hotel	1.14	1.25	1.27	1.27	2.81	1.71
Large Hotel	1.83	1.97	1.79	1.79	3.57	2.15
Hospital	2.41	2.53	2.55	2.55	3.21	2.25
Supermarket	1.10	1.23	1.33	1.33	2.27	1.49
School	0.28	0.34	0.44	0.48	0.78	0.64
Fastfood Restaurant	0.78	0.82	0.76	0.76	2.17	1.04
Sit Down Restaurant	0.44	0.48	0.44	0.44	1.29	0.64
Warehouse	0.02	0.02	0.00	0.00	0.04	0.02

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5f Shell Efficiency Data

Heating Slope for Window R-Value (kBtu/sq.ft. R) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-6.67	-5.00	-3.29	-2.51	-0.52	-1.08
Large Office	-6.51	-4.92	-3.31	-3.33	-0.78	-1.45
Small Retail	-6.17	-4.82	-3.33	-3.29	-0.68	-1.43
Large Retail	-2.03	-1.51	-0.92	-0.78	-0.02	-0.18
Small Hotel	-5.84	-4.50	-3.09	-3.09	-0.26	-1.00
Large Hotel	-5.08	-3.94	-2.71	-2.71	-0.34	-1.00
Hospital	-5.94	-4.18	-2.35	-2.35	-0.26	-0.84
Supermarket	-3.94	-3.05	-2.09	-2.09	-0.18	-0.76
School	-5.20	-4.18	-2.95	-3.59	-1.43	-1.79
Fastfood Restaurant	-14.18	-11.51	-8.37	-8.37	-2.83	-4.16
Sit Down Restaurant	-5.12	-4.12	-2.97	-2.97	-0.78	-1.39
Warehouse	-0.76	-0.60	-0.40	-0.44	-0.18	-0.22

Heating Slope for Window R-Value (kBtu/sq.ft. R) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-4.94	-3.76	-2.55	-1.93	-0.54	-0.88
Large Office	-6.71	-5.16	-3.53	-4.00	-1.08	-1.81
Small Retail	-5.54	-4.32	-3.01	-2.95	-0.56	-1.27
Large Retail	-2.05	-1.53	-0.90	-0.80	0.00	-0.16
Small Hotel	-5.26	-4.08	-2.77	-2.77	-0.20	-0.88
Large Hotel	-5.82	-4.46	-3.05	-3.05	-0.36	-1.12
Hospital	-4.72	-3.21	-1.79	-1.79	-0.14	-0.62
Supermarket	-3.61	-2.71	-1.61	-1.61	-0.04	-0.46
School	-4.64	-3.74	-2.67	-3.11	-1.29	-1.59
Fastfood Restaurant	-9.62	-7.85	-5.72	-5.72	-2.13	-2.93
Sit Down Restaurant	-3.84	-3.09	-2.23	-2.23	-0.56	-1.02
Warehouse	-0.38	-0.28	-0.20	-0.22	-0.10	-0.10

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5g Shell Efficiency Data

Cooling Slope for Window Shading Coefficient (kBtu/sq.ft.) (STOCK

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	14.91	16.39	17.30	10.01	18.21	13.09
Large Office	8.99	9.67	10.70	10.81	15.93	13.88
Small Retail	10.36	11.27	12.29	12.40	22.53	15.82
Large Retail	5.46	5.92	6.26	6.71	11.04	8.42
Small Hotel	13.77	15.02	16.50	16.50	29.59	21.62
Large Hotel	13.88	15.02	15.48	15.48	26.63	19.80
Hospital	14.79	15.93	16.84	16.84	25.83	19.80
Supermarket	8.42	9.33	9.67	9.67	17.41	12.75
School	2.62	3.07	4.21	4.78	6.37	7.06
Fastfood Restaurant	24.47	26.40	28.22	28.22	48.48	36.99
Sit Down Restaurant	9.10	9.90	10.58	10.58	18.89	14.00
Warehouse	0.68	1.02	1.25	1.37	2.28	1.82

Cooling Slope for Window Shading Coefficient (kBtu/sq.ft.) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	10.13	11.04	11.72	6.83	12.18	8.88
Large Office	8.88	9.67	10.58	12.40	18.21	15.82
Small Retail	9.90	10.70	11.61	11.38	21.17	14.91
Large Retail	6.03	6.49	6.94	7.17	11.49	8.88
Small Hotel	12.18	13.43	14.68	14.68	26.74	19.46
Large Hotel	17.07	18.55	18.89	18.89	31.07	23.22
Hospital	15.59	16.50	17.30	17.30	25.61	19.91
Supermarket	9.45	10.36	11.04	11.04	18.21	13.88
School	2.05	2.50	3.53	3.76	5.12	5.69
Fastfood Restaurant	15.36	16.50	18.09	18.09	30.27	23.56
Sit Down Restaurant	6.83	7.28	7.97	7.97	14.23	10.47
Warehouse	0.34	0.46	0.57	0.68	1.14	0.80

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5h Shell Efficiency Data

Heating Slope for Window Shading Coefficient (kBtu/sq.ft.) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-10.36	-8.54	-6.15	-5.58	-2.28	-3.19
Large Office	-5.12	-4.21	-3.30	-3.53	-1.37	-1.93
Small Retail	-11.04	-9.90	-7.85	-7.85	-3.30	-4.78
Large Retail	-2.96	-2.50	-1.71	-1.37	0.00	-0.34
Small Hotel	-10.81	-9.22	-6.94	-6.94	-0.80	-2.50
Large Hotel	-7.06	-6.03	-4.55	-4.55	-1.02	-2.16
Hospital	-5.23	-3.64	-2.28	-2.28	-0.23	-0.80
Supermarket	-5.69	-4.89	-3.76	-3.76	-0.34	-1.48
School	-6.15	-5.69	-4.67	-5.69	-4.67	-3.98
Fastfood Restaurant	-22.65	-20.71	-16.50	-16.50	-9.56	-10.13
Sit Down Restaurant	-8.19	-7.40	-5.80	-5.80	-2.39	-3.19
Warehouse	-1.82	-1.48	-1.14	-1.25	-1.02	-0.91

Heating Slope for Window Shading Coefficient (kBtu/sq.ft.) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-7.97	-6.60	-4.89	-4.21	-2.28	-2.73
Large Office	-5.23	-4.21	-3.53	-3.98	-1.59	-2.28
Small Retail	-9.56	-8.54	-6.94	-6.94	-2.62	-3.98
Large Retail	-2.73	-2.28	-1.37	-1.14	0.00	-0.23
Small Hotel	-9.56	-8.08	-6.03	-6.03	-0.46	-1.93
Large Hotel	-6.94	-5.69	-4.21	-4.21	-0.57	-1.71
Hospital	-3.64	-2.96	-1.59	-1.59	-0.11	-0.57
Supermarket	-4.67	-3.87	-2.39	-2.39	0.00	-0.68
School	-5.46	-5.12	-4.10	-4.89	-3.98	-3.41
Fastfood Restaurant	-16.16	-14.91	-11.72	-11.72	-7.97	-7.62
Sit Down Restaurant	-6.15	-5.58	-4.44	-4.44	-1.71	-2.50
Warehouse	-0.91	-0.80	-0.68	-0.68	-0.57	-0.46

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5i Shell Efficiency Data

Cooling Slope for Window/Wall Ratio (kBtu/sq.ft.) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	47.23	51.55	55.19	33.80	55.88	44.50
Large Office	10.38	11.33	13.18	12.36	14.54	16.05
Small Retail	49.84	54.28	58.95	57.01	93.20	74.77
Large Retail	19.92	21.62	22.87	23.10	36.87	29.82
Small Hotel	35.68	39.00	42.68	42.68	71.10	55.65
Large Hotel	25.35	27.48	29.19	29.19	43.87	36.62
Hospital	16.25	17.62	18.98	18.98	27.72	23.62
Supermarket	37.96	41.10	43.29	43.29	71.15	56.81
School	6.23	7.43	9.73	10.24	11.95	14.42
Fastfood Restaurant	55.31	59.50	65.26	65.26	102.13	84.96
Sit Down Restaurant	31.02	33.46	36.29	36.29	58.62	47.50
Warehouse	10.96	13.66	16.53	18.33	29.65	24.98

Cooling Slope for Window/Wall Ratio (kBtu/sq.ft.) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	39.03	42.56	45.75	29.13	47.57	38.12
Large Office	7.44	8.19	9.70	11.54	13.18	15.09
Small Retail	43.24	47.00	50.75	51.89	85.01	68.05
Large Retail	20.03	21.74	22.87	22.99	29.82	29.47
Small Hotel	33.71	37.13	40.71	40.71	67.77	53.09
Large Hotel	24.32	26.37	27.82	27.82	41.48	34.48
Hospital	15.02	16.25	17.21	17.21	24.58	21.30
Supermarket	35.64	38.37	40.83	40.83	63.36	52.44
School	5.80	7.08	9.22	9.90	11.52	13.83
Fastfood Restaurant	55.40	59.60	65.35	65.35	102.13	85.15
Sit Down Restaurant	31.12	33.55	36.38	36.38	58.43	47.70
Warehouse	10.96	13.66	16.17	18.15	30.01	25.16

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5j Shell Efficiency Data

Heating Slope for Window/Wall Ratio (kBtu/sq.ft.) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	11.61	5.46	2.16	3.30	-1.82	-0.91
Large Office	13.45	9.63	5.80	7.24	1.57	2.80
Small Retail	23.56	11.84	4.10	12.75	-0.68	2.39
Large Retail	10.70	6.71	3.87	4.32	0.11	1.14
Small Hotel	6.74	2.82	0.51	0.51	-0.09	-0.17
Large Hotel	16.90	11.78	7.51	7.51	0.94	2.48
Hospital	9.01	6.55	4.92	4.92	1.09	2.46
Supermarket	4.37	1.09	-0.55	-0.55	0.00	-0.55
School	7.77	5.12	2.30	5.12	-0.60	0.94
Fastfood Restaurant	24.19	13.36	7.12	7.12	-5.07	-0.10
Sit Down Restaurant	12.10	6.44	3.22	3.22	-0.88	0.20
Warehouse	1.26	-0.72	-1.26	-2.52	-5.21	-2.87

Heating Slope for Window/Wall Ratio (kBtu/sq.ft.) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	10.36	4.78	1.71	2.73	-2.39	-1.48
Large Office	13.45	9.76	6.08	7.85	1.78	3.07
Small Retail	19.80	9.90	3.53	10.47	-0.34	2.16
Large Retail	11.38	7.40	4.44	5.58	0.11	1.48
Small Hotel	7.17	3.24	1.19	1.19	0.17	0.26
Large Hotel	14.17	9.82	6.32	6.32	0.60	1.96
Hospital	9.42	6.69	4.92	4.92	0.55	2.32
Supermarket	19.12	12.43	7.37	7.37	0.27	2.18
School	10.92	7.68	4.18	4.35	-0.60	0.68
Fastfood Restaurant	28.97	17.07	9.95	9.95	-3.80	1.46
Sit Down Restaurant	15.22	9.07	5.07	5.07	-0.10	1.27
Warehouse	-1.44	-2.52	-2.52	-3.23	-4.67	-3.05

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.

Table A.5k Shell Efficiency Data

Cooling Slope for Air Change (Infiltration) (kBtu/sq.ft. Air Change per Hour) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-3.41	-3.69	-3.62	-2.18	-5.74	-3.28
Large Office	-12.38	-11.52	-10.24	-9.82	-10.33	-8.71
Small Retail	-3.00	-3.21	-3.35	-3.28	-8.26	-4.78
Large Retail	-6.83	-7.51	-8.02	-9.73	-17.16	-12.63
Small Hotel	-2.45	-2.62	-2.85	-2.85	-6.03	-4.15
Large Hotel	-3.24	-3.41	-2.90	-2.90	-8.14	-4.27
Hospital (1)	0.00	0.00	0.00	0.00	0.00	0.00
Supermarket	-2.63	-3.02	-3.22	-3.22	-6.05	-4.29
School	-1.15	-1.30	-1.63	-1.61	-2.55	-2.34
Fastfood Restaurant	-1.25	-1.42	-1.59	-1.59	-3.13	-2.11
Sit Down Restaurant	-1.19	-1.31	-1.42	-1.42	-3.02	-1.93
Warehouse	-0.06	-0.06	-0.06	-0.11	-0.46	-0.23

Cooling Slope for Air Change (Infiltration) (kBtu/sq.ft. Air Change per Hour) (NEW) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	-2.73	-3.00	-2.87	-1.78	-4.64	-2.59
Large Office	-11.44	-10.92	-9.64	-8.88	-10.16	-8.02
Small Retail	-3.21	-3.48	-3.48	-3.41	-9.01	-5.05
Large Retail	-5.89	-6.49	-7.00	-7.43	-12.89	-9.64
Small Hotel	-2.39	-2.67	-2.85	-2.85	-6.20	-4.21
Large Hotel	-3.76	-4.04	-3.53	-3.53	-8.82	-4.89
Hospital (1)	0.00	0.00	0.00	0.00	0.00	0.00
Supermarket	-4.00	-4.49	-4.88	-4.88	-7.90	-5.76
School	-1.20	-1.35	-1.66	-1.61	-2.65	-2.32
Fastfood Restaurant	-1.31	-1.48	-1.71	-1.71	-3.19	-2.28
Sit Down Restaurant	-1.31	-1.42	-1.48	-1.48	-3.19	-2.05
Warehouse	-0.06	-0.06	-0.06	-0.06	-0.46	-0.23

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.
(1) Air infiltration occurs only when the building is not pressurized, i.e. system is not on.
Hospitals operate 24-hours, therefore slopes are zero here.

Table A.5l Shell Efficiency Data

Heating Slope for Air Change (Infiltration) (kBtu/sq.ft. Air Change per Hour) (STOCK) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	15.16	11.06	7.31	8.54	1.98	3.96
Large Office	8.36	5.63	3.50	3.76	0.85	1.54
Small Retail	23.69	17.55	11.95	11.81	3.55	6.01
Large Retail	19.63	14.51	9.47	8.54	0.34	2.39
Small Hotel	8.48	6.49	4.78	4.78	0.63	1.88
Large Hotel	18.21	13.49	9.16	9.16	1.71	3.98
Hospital (1)	0.00	0.00	0.00	0.00	0.00	0.00
Supermarket	11.80	8.58	5.56	5.56	0.59	2.15
School	20.71	15.87	11.29	11.29	4.59	5.99
Fastfood Restaurant	7.68	5.80	4.10	4.10	1.08	1.99
Sit Down Restaurant	7.85	6.03	4.38	4.38	1.37	2.22
Warehouse	3.58	2.67	1.71	1.76	0.85	0.97

Heating Slope for Air Change (Infiltration) (kBtu/sq.ft. Air Change per Hour) (New) (a)

Building Type	Zone 1	Zone 2	Zone 3-N	Zone 3-S	Zone 4	Zone 5
Small Office	16.32	12.15	8.26	9.49	2.73	4.57
Large Office	9.30	6.23	3.84	4.27	0.94	1.79
Small Retail	23.62	17.48	12.02	11.88	3.41	6.01
Large Retail	14.08	10.33	6.57	6.32	0.17	1.62
Small Hotel	8.99	6.88	5.06	5.06	0.57	1.88
Large Hotel	17.70	12.92	8.65	8.65	1.31	3.47
Hospital (1)	0.00	0.00	0.00	0.00	0.00	0.00
Supermarket	10.24	6.93	4.00	4.00	0.20	1.46
School	20.76	15.95	11.36	11.36	4.59	6.01
Fastfood Restaurant	7.57	5.75	3.98	3.98	1.08	1.88
Sit Down Restaurant	7.80	5.97	4.32	4.32	1.37	2.22
Warehouse	3.58	2.67	1.71	1.76	0.91	1.02

(a) The increase in load in kBtu/ft2 as a result of one-unit increase in the building characteristic.
(1) Air infiltration occurs only when the building is not pressurized, i.e. system is not on.
Hospitals operate 24-hours, therefore slopes are zero here.

Table A.6a System Load Multiplier Data

Heating Load Multiplier- Hydronic System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.16	1.20	1.29	1.24	1.60	1.33
Large Office	1.13	1.16	1.20	1.20	1.43	1.29
Small Retail	1.02	1.03	1.03	1.02	1.35	1.09
Large Retail	1.24	1.30	1.51	1.77	[1]	2.86
Small Hotel	1.35	1.41	1.53	1.53	[1]	2.14
Large Hotel	1.35	1.38	1.25	1.25	[1]	1.06
Hospital	0.91	0.96	0.79	0.79	[1]	0.53
Supermarket	0.86	0.83	0.76	0.76	[1]	0.59
School	1.02	1.02	1.01	1.01	0.98	1.01
Fastfood Restaurant	1.40	1.54	1.74	1.74	4.46	2.42
Sit Down Restaurant	1.33	1.45	1.63	1.63	5.77	2.30
Warehouse	0.94	0.93	0.91	0.91	0.63	0.79

Heating Load Multiplier- Hydronic System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.19	1.23	1.32	1.27	1.59	1.33
Large Office	1.14	1.17	1.21	1.22	1.42	1.30
Small Retail	1.02	1.03	1.03	1.03	1.45	1.11
Large Retail	1.40	1.49	1.85	2.24	[1]	4.78
Small Hotel	1.32	1.38	1.51	1.51	[1]	2.13
Large Hotel	1.39	1.43	1.26	1.26	[1]	1.03
Hospital	0.88	0.85	0.62	0.62	[1]	0.30
Supermarket	0.77	0.71	0.56	0.56	[1]	0.28
School	1.02	1.02	1.02	1.01	0.98	1.01
Fastfood Restaurant	1.43	1.59	1.79	1.79	4.40	2.48
Sit Down Restaurant	1.36	1.49	1.69	1.69	6.71	2.45
Warehouse	0.95	0.93	0.91	0.91	0.65	0.76

[1] Very small building heating load.

Table A.6b System Load Multiplier Data

Heating Load Multiplier- Ducted-CV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.88	0.87	0.85	0.90	0.70	0.83
Large Office	2.18	2.75	3.64	3.49	15.74	6.49
Small Retail	0.88	0.85	0.80	0.79	0.51	0.68
Large Retail	2.15	2.67	4.09	5.84	[1]	17.79
Small Hotel	2.17	2.56	3.45	3.45	[1]	9.31
Large Hotel	2.75	3.26	4.29	4.29	[1]	9.45
Hospital	4.88	7.23	11.33	11.33	[1]	29.53
Supermarket	2.28	3.24	5.28	5.28	[1]	13.92
School	1.70	1.70	1.87	1.86	3.02	2.66
Fastfood Restaurant	0.92	0.86	0.80	0.80	1.31	0.95
Sit Down Restaurant	0.93	0.85	0.76	0.76	0.85	0.78
Warehouse	1.61	1.65	2.06	2.05	5.20	4.00

Heating Load Multiplier- Ducted-CV System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.95	0.96	0.94	0.95	0.70	0.87
Large Office	2.05	2.55	3.27	3.34	14.00	6.18
Small Retail	0.89	0.86	0.81	0.79	0.50	0.68
Large Retail	2.46	3.18	5.41	7.96	[1]	32.11
Small Hotel	2.07	2.45	3.38	3.38	[1]	9.85
Large Hotel	3.02	3.76	5.14	5.14	[1]	12.78
Hospital	5.65	7.99	13.70	13.70	[1]	36.60
Supermarket	2.84	4.37	8.71	8.71	[1]	32.79
School	1.68	1.68	1.88	1.86	2.93	2.64
Fastfood Restaurant	0.93	0.87	0.79	0.79	1.07	0.89
Sit Down Restaurant	0.92	0.84	0.74	0.74	0.79	0.74
Warehouse	1.57	1.60	1.89	1.87	4.48	3.71

[1] Very small building heating load.

Table A.6c System Load Multiplier Data

Heating Load Multiplier- Multizone System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.43	1.75	2.29	1.73	8.26	2.95
Large Office	1.54	1.90	2.50	2.40	9.43	4.35
Small Retail	1.19	1.32	1.53	1.59	7.79	2.91
Large Retail	1.54	1.88	2.86	4.11	[1]	12.57
Small Hotel	1.82	2.09	2.73	2.73	[1]	6.99
Large Hotel	2.09	2.43	3.05	3.05	[1]	6.43
Hospital	3.51	5.10	7.88	7.88	[1]	20.00
Supermarket	1.79	2.43	3.82	3.82	[1]	9.76
School	1.27	1.26	1.35	1.31	1.96	1.75
Fastfood Restaurant	1.53	1.84	2.30	2.30	8.25	4.16
Sit Down Restaurant	1.45	1.71	2.16	2.16	12.47	4.38
Warehouse	1.16	1.18	1.45	1.43	3.55	2.75

Heating Load Multiplier- Multizone System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.31	1.55	1.97	1.53	5.85	2.39
Large Office	1.48	1.80	2.28	2.33	8.65	4.21
Small Retail	1.18	1.31	1.52	1.61	8.76	3.05
Large Retail	1.79	2.28	3.85	5.66	[1]	22.78
Small Hotel	1.78	2.04	2.71	2.71	[1]	7.52
Large Hotel	2.30	2.79	3.64	3.64	[1]	8.62
Hospital	4.10	5.66	9.53	9.53	[1]	24.65
Supermarket	2.23	3.30	6.32	6.32	[1]	23.07
School	1.26	1.25	1.35	1.32	1.92	1.75
Fastfood Restaurant	1.43	1.67	2.07	2.07	6.64	3.63
Sit Down Restaurant	1.41	1.65	2.11	2.11	13.56	4.35
Warehouse	1.14	1.15	1.35	1.33	3.09	2.58

[1] Very small building heating load.

Table A.6d System Load Multiplier Data

Heating Load Multiplier- Ducted-VAV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.64	1.72	1.85	1.65	2.58	2.08
Large Office	1.76	1.83	1.98	1.94	2.74	2.35
Small Retail	1.54	1.52	1.57	1.70	2.30	2.20
Large Retail	1.81	1.78	2.00	2.47	[1]	2.71
Small Hotel	1.90	2.03	2.23	2.23	[1]	3.85
Large Hotel	2.05	2.07	1.97	1.97	[1]	2.34
Hospital	1.15	1.08	0.86	0.86	[1]	0.58
Supermarket	1.67	1.58	1.47	1.47	[1]	1.16
School	1.65	1.65	1.69	1.70	1.95	2.14
Fastfood Restaurant	1.24	1.21	1.17	1.17	1.10	1.19
Sit Down Restaurant	1.17	1.12	1.01	1.01	1.06	0.94
Warehouse	1.59	1.63	1.70	1.70	1.96	2.09

Heating Load Multiplier- Ducted-VAV System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.60	1.67	1.78	1.59	2.54	1.99
Large Office	1.73	1.80	1.92	1.91	2.77	2.34
Small Retail	1.48	1.45	1.49	1.64	2.14	2.14
Large Retail	2.07	2.03	2.36	3.34	[1]	4.00
Small Hotel	1.84	1.95	2.15	2.15	[1]	3.91
Large Hotel	2.09	2.13	1.97	1.97	[1]	2.38
Hospital	1.06	0.91	0.61	0.61	[1]	0.40
Supermarket	1.18	0.95	0.51	0.51	[1]	0.52
School	1.63	1.63	1.67	1.67	1.93	2.10
Fastfood Restaurant	1.19	1.17	1.13	1.13	1.19	1.11
Sit Down Restaurant	1.14	1.08	0.96	0.96	1.10	0.95
Warehouse	1.55	1.58	1.63	1.63	1.89	2.02

[1] Very small building heating load.

Table A.6e System Load Multiplier Data

Heating Load Multiplier- Fan Coil System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.04	1.07	1.10	1.11	1.21	1.15
Large Office	1.05	1.06	1.07	1.08	1.13	1.10
Small Retail	1.02	1.02	1.01	1.01	1.00	0.99
Large Retail	1.03	1.02	1.02	1.00	[1]	1.00
Small Hotel	1.53	1.61	1.78	1.78	[1]	2.70
Large Hotel	1.50	1.52	1.38	1.38	[1]	1.26
Hospital	1.21	1.31	1.22	1.22	[1]	1.19
Supermarket	1.01	1.00	0.97	0.97	[1]	0.94
School	1.06	1.05	1.03	1.01	1.03	1.01
Fastfood Restaurant	1.12	1.11	1.08	1.08	0.95	1.04
Sit Down Restaurant	1.13	1.09	1.02	1.02	1.00	0.96
Warehouse	0.91	0.90	0.93	0.92	0.94	0.94

Heating Load Multiplier- Fan Coil System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.06	1.09	1.14	1.12	1.19	1.14
Large Office	1.07	1.09	1.10	1.12	1.19	1.13
Small Retail	1.03	1.03	1.02	1.00	1.00	0.99
Large Retail	1.03	1.04	1.03	1.00	[1]	0.89
Small Hotel	1.54	1.63	1.82	1.82	[1]	2.91
Large Hotel	1.57	1.61	1.41	1.41	[1]	1.27
Hospital	1.30	1.31	1.22	1.22	[1]	1.20
Supermarket	1.04	1.03	0.99	0.99	[1]	0.93
School	1.07	1.05	1.04	1.02	1.03	1.03
Fastfood Restaurant	1.14	1.12	1.09	1.09	0.97	1.03
Sit Down Restaurant	1.13	1.08	1.01	1.01	1.03	0.96
Warehouse	0.91	0.90	0.91	0.91	0.91	0.93

[1] Very small building heating load.

Table A.6f System Load Multiplier Data

Cooling Load Multiplier - Ducted-CV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.38	1.39	1.38	1.40	1.50	1.42
Large Office	2.66	2.53	2.22	2.27	2.01	2.00
Small Retail	1.45	1.43	1.42	1.44	1.42	1.49
Large Retail	3.02	2.68	2.30	2.23	1.65	1.80
Small Hotel	5.91	5.02	4.42	4.42	3.79	3.95
Large Hotel	3.37	2.97	2.76	2.76	2.09	2.37
Hospital	2.38	2.25	2.07	2.07	1.71	1.87
Supermarket	4.44	4.10	3.65	3.65	2.74	3.03
School	13.04	8.50	5.90	6.50	4.36	4.55
Fastfood Restaurant	1.80	1.80	1.89	1.89	1.64	1.98
Sit Down Restaurant	1.75	1.74	1.84	1.84	1.59	1.96
Warehouse	17.11	8.43	5.33	5.30	4.62	3.78

Cooling Load Multiplier - Ducted-CV System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.37	1.39	1.38	1.40	1.52	1.42
Large Office	2.86	2.69	2.34	2.46	2.16	2.14
Small Retail	1.44	1.42	1.41	1.45	1.41	1.50
Large Retail	3.03	2.70	2.36	2.41	1.76	1.93
Small Hotel	5.68	4.83	4.33	4.33	3.59	3.89
Large Hotel	3.15	2.83	2.67	2.67	2.01	2.31
Hospital	2.04	1.96	1.80	1.80	1.49	1.66
Supermarket	3.48	3.22	3.00	3.00	2.21	2.61
School	12.82	8.32	5.99	6.49	4.20	4.57
Fastfood Restaurant	1.79	1.78	1.88	1.88	1.60	2.00
Sit Down Restaurant	1.74	1.72	1.83	1.83	1.58	1.96
Warehouse	21.79	9.97	5.37	5.38	4.82	3.80

Table A.6g System Load Multiplier Data

Cooling Load Multiplier - Multizone System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	2.86	2.68	2.35	2.58	2.43	2.21
Large Office	2.08	2.05	1.90	1.93	1.72	1.78
Small Retail	3.03	2.80	2.41	2.55	2.38	2.26
Large Retail	2.32	2.16	1.96	1.95	1.54	1.66
Small Hotel	4.69	4.11	3.76	3.76	3.37	3.53
Large Hotel	2.63	2.41	2.32	2.32	1.87	2.10
Hospital	2.04	1.96	1.84	1.84	1.56	1.71
Supermarket	3.66	3.42	3.13	3.13	2.42	2.69
School	7.76	5.35	4.06	4.41	3.15	3.44
Fastfood Restaurant	3.54	3.42	3.18	3.18	2.45	2.86
Sit Down Restaurant	3.28	3.15	3.00	3.00	2.50	2.83
Warehouse	10.07	5.40	3.86	3.83	3.71	3.09

Cooling Load Multiplier - Multizone System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	2.93	2.74	2.42	2.60	2.70	2.26
Large Office	2.21	2.16	1.99	2.07	1.83	1.89
Small Retail	2.81	2.60	2.29	2.49	2.28	2.22
Large Retail	2.42	2.24	2.05	2.11	1.63	1.77
Small Hotel	4.55	3.99	3.71	3.71	3.22	3.50
Large Hotel	2.51	2.34	2.28	2.28	1.80	2.06
Hospital	1.81	1.75	1.64	1.64	1.39	1.55
Supermarket	2.98	2.79	2.65	2.65	2.00	2.36
School	7.72	5.26	4.15	4.43	3.06	3.49
Fastfood Restaurant	3.35	3.21	3.06	3.06	2.38	2.82
Sit Down Restaurant	3.15	3.02	2.93	2.93	2.42	2.78
Warehouse	12.63	6.29	3.88	3.88	3.86	3.11

Table A.6h System Load Multiplier Data

Cooling Load Multiplier - Ducted-VAV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	2.98	2.38	1.92	2.26	1.61	1.80
Large Office	2.17	1.89	1.66	1.68	1.39	1.52
Small Retail	4.34	3.03	2.30	2.48	1.64	1.96
Large Retail	2.52	1.99	1.69	1.65	1.29	1.43
Small Hotel	4.52	3.53	2.87	2.87	1.77	2.55
Large Hotel	2.28	1.92	1.77	1.77	1.28	1.68
Hospital	1.36	1.32	1.34	1.34	1.25	1.37
Supermarket	3.31	2.53	2.14	2.14	1.51	1.92
School	12.15	7.95	5.03	5.64	2.97	3.81
Fastfood Restaurant	2.50	2.18	2.08	2.08	1.55	2.08
Sit Down Restaurant	2.25	2.01	2.00	2.00	1.58	2.11
Warehouse	16.71	8.32	4.15	4.18	2.35	2.36

Cooling Load Multiplier - Ducted-VAV System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	3.50	2.67	2.09	2.47	1.84	1.94
Large Office	2.37	2.02	1.75	1.78	1.45	1.60
Small Retail	3.73	2.71	2.14	2.36	1.58	1.91
Large Retail	2.57	2.01	1.72	1.77	1.33	1.50
Small Hotel	4.38	3.37	2.78	2.78	1.68	2.50
Large Hotel	2.03	1.76	1.68	1.68	1.25	1.62
Hospital	1.29	1.28	1.30	1.30	1.23	1.34
Supermarket	2.03	1.75	1.68	1.68	1.40	1.71
School	11.89	7.72	5.00	5.50	2.90	3.79
Fastfood Restaurant	2.35	2.06	2.03	2.03	1.58	2.11
Sit Down Restaurant	2.13	1.93	1.97	1.97	1.58	2.12
Warehouse	21.32	9.85	4.42	4.47	2.54	2.45

Table A.6i System Load Multiplier Data

Cooling Load Multiplier - Fan Coil System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.07	1.08	1.09	1.10	1.06	1.11
Large Office	1.09	1.10	1.11	1.11	1.06	1.13
Small Retail	1.09	1.10	1.13	1.13	1.05	1.16
Large Retail	1.07	1.07	1.09	1.10	1.04	1.11
Small Hotel	1.20	1.21	1.27	1.27	1.08	1.28
Large Hotel	1.06	1.07	1.14	1.14	0.99	1.19
Hospital	1.08	1.09	1.10	1.10	1.04	1.12
Supermarket	1.13	1.14	1.18	1.18	1.04	1.20
School	1.10	1.12	1.15	1.15	1.01	1.21
Fastfood Restaurant	1.17	1.19	1.27	1.27	1.08	1.35
Sit Down Restaurant	1.21	1.22	1.33	1.33	1.10	1.41
Warehouse	0.89	0.87	0.89	0.88	0.87	0.91

Cooling Load Multiplier - Fan Coil System (kBtu/sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	1.08	1.09	1.11	1.10	1.06	1.12
Large Office	1.10	1.11	1.14	1.13	1.06	1.15
Small Retail	1.09	1.11	1.14	1.14	1.05	1.18
Large Retail	1.08	1.09	1.12	1.12	1.05	1.14
Small Hotel	1.19	1.20	1.27	1.27	1.06	1.29
Large Hotel	1.06	1.07	1.14	1.14	0.99	1.18
Hospital	1.08	1.08	1.10	1.10	1.04	1.12
Supermarket	1.14	1.13	1.17	1.17	1.04	1.20
School	1.11	1.13	1.17	1.17	1.02	1.25
Fastfood Restaurant	1.19	1.21	1.30	1.30	1.09	1.39
Sit Down Restaurant	1.22	1.23	1.34	1.34	1.10	1.43
Warehouse	0.89	0.88	0.89	0.89	0.86	0.91

Table A.7a System Electricity Use Data

Hydronic System (kWh/sq.ft.) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.15	0.11	0.07	0.08	0.01	0.03
Large Office	0.10	0.07	0.04	0.04	0.01	0.02
Small Retail	0.21	0.15	0.10	0.09	0.01	0.03
Large Retail	0.07	0.06	0.04	0.03	0.00	0.01
Small Hotel	0.15	0.10	0.07	0.07	0.01	0.03
Large Hotel	0.13	0.09	0.06	0.06	0.00	0.02
Hospital	0.06	0.05	0.02	0.02	0.00	0.00
Supermarket	0.16	0.10	0.05	0.05	0.00	0.01
School	0.31	0.26	0.20	0.21	0.09	0.13
Fastfood Restaurant	0.49	0.37	0.27	0.27	0.09	0.14
Sit Down Restaurant	0.35	0.26	0.17	0.17	0.06	0.08
Warehouse	0.05	0.03	0.02	0.02	0.00	0.01

Hydronic System (kWh/sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.14	0.11	0.07	0.08	0.01	0.04
Large Office	0.11	0.07	0.04	0.05	0.01	0.02
Small Retail	0.17	0.13	0.08	0.08	0.01	0.03
Large Retail	0.08	0.07	0.05	0.03	0.00	0.01
Small Hotel	0.13	0.09	0.06	0.06	0.01	0.02
Large Hotel	0.11	0.08	0.05	0.05	0.00	0.02
Hospital	0.05	0.04	0.02	0.02	0.00	0.00
Supermarket	0.08	0.04	0.01	0.01	0.00	0.00
School	0.30	0.25	0.19	0.20	0.08	0.12
Fastfood Restaurant	0.47	0.35	0.26	0.26	0.09	0.14
Sit Down Restaurant	0.32	0.24	0.16	0.16	0.05	0.08
Warehouse	0.05	0.03	0.02	0.02	0.00	0.01

Table A.7b System Electricity Use Data

Ducted-CV System (kWh/sq.ft.) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	3.55	3.50	3.30	2.94	3.04	2.91
Large Office	3.84	3.87	3.63	3.63	3.57	3.63
Small Retail	3.73	3.63	3.31	3.38	3.22	3.34
Large Retail	3.14	3.13	3.03	3.00	2.89	2.98
Small Hotel	6.24	5.86	5.71	5.71	5.95	5.88
Large Hotel	4.53	4.33	4.26	4.26	4.24	4.26
Hospital	11.74	11.81	11.66	11.66	11.51	11.53
Supermarket	11.59	11.72	11.69	11.69	10.84	11.27
School	5.36	4.22	3.59	4.01	2.76	3.30
Fastfood Restaurant	11.52	11.77	11.66	11.66	11.36	11.74
Sit Down Restaurant	8.47	8.61	8.68	8.68	8.40	8.95
Warehouse	1.34	1.05	1.05	1.10	1.08	1.18

Ducted-CV System (kWh/sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	2.63	2.62	2.49	2.26	2.32	2.21
Large Office	3.25	3.27	3.08	3.32	3.26	3.32
Small Retail	3.18	3.08	2.85	2.97	2.88	2.98
Large Retail	3.42	3.45	3.37	3.44	3.31	3.39
Small Hotel	5.32	5.00	4.94	4.94	4.96	5.06
Large Hotel	4.49	4.36	4.32	4.32	4.35	4.34
Hospital	11.45	11.59	11.43	11.43	11.32	11.32
Supermarket	10.19	10.28	10.35	10.35	9.81	10.21
School	5.01	3.93	3.44	3.69	2.47	3.04
Fastfood Restaurant	9.78	9.96	10.06	10.06	9.72	10.26
Sit Down Restaurant	7.87	8.01	8.16	8.16	7.86	8.40
Warehouse	1.17	0.91	0.86	0.88	0.86	0.97

Table A.7c System Electricity Use Data

Multizone System (kWh/sq.ft.) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	4.15	4.06	3.76	3.38	3.38	3.28
Large Office	3.33	3.36	3.21	3.21	3.12	3.20
Small Retail	4.38	4.24	3.87	3.95	3.65	3.84
Large Retail	2.81	2.80	2.73	2.72	2.60	2.71
Small Hotel	5.66	5.31	5.18	5.18	5.35	5.32
Large Hotel	4.11	3.93	3.87	3.87	3.82	3.87
Hospital	10.53	10.58	10.46	10.46	10.32	10.35
Supermarket	10.45	10.53	10.51	10.51	9.71	10.14
School	4.80	3.80	3.25	3.67	2.45	2.97
Fastfood Restaurant	13.70	13.88	13.56	13.56	12.52	13.13
Sit Down Restaurant	9.97	10.01	9.85	9.85	9.33	9.96
Warehouse	1.19	0.94	0.94	0.98	0.97	1.06

Multizone System (kWh/sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	3.09	3.04	2.85	2.60	2.59	2.51
Large Office	2.84	2.85	2.73	2.94	2.84	2.93
Small Retail	3.73	3.61	3.34	3.48	3.27	3.42
Large Retail	3.08	3.10	3.05	3.11	2.98	3.07
Small Hotel	4.82	4.53	4.47	4.47	4.47	4.59
Large Hotel	4.08	3.96	3.92	3.92	3.93	3.94
Hospital	10.28	10.39	10.26	10.26	10.15	10.16
Supermarket	9.20	9.25	9.31	9.31	8.79	9.19
School	4.49	3.54	3.12	3.33	2.20	2.74
Fastfood Restaurant	11.70	11.80	11.66	11.66	10.70	11.42
Sit Down Restaurant	9.26	9.28	9.25	9.25	8.74	9.35
Warehouse	1.04	0.81	0.77	0.79	0.77	0.87

Table A.7d System Electricity Use Data

Ducted-VAV System (kWh/sq.ft.) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	3.16	2.80	2.56	2.32	2.05	2.28
Large Office	2.78	2.50	2.34	2.33	2.19	2.36
Small Retail	4.52	3.33	2.89	2.97	2.36	2.82
Large Retail	2.43	2.15	2.10	2.09	2.08	2.22
Small Hotel	4.51	3.82	3.39	3.39	3.22	3.28
Large Hotel	2.92	2.69	2.63	2.63	2.74	2.77
Hospital	6.73	6.78	6.96	6.96	7.35	7.31
Supermarket	8.27	6.96	6.52	6.52	5.88	6.32
School	5.01	3.93	2.98	3.40	1.77	2.59
Fastfood Restaurant	9.14	8.61	8.25	8.25	7.78	8.21
Sit Down Restaurant	6.34	6.06	6.08	6.08	5.86	6.33
Warehouse	1.32	1.05	0.74	0.78	0.54	0.65

Ducted-VAV System (kWh/sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	2.67	2.23	1.99	1.86	1.55	1.80
Large Office	2.44	2.15	1.99	2.09	1.96	2.12
Small Retail	3.62	2.80	2.51	2.60	2.15	2.55
Large Retail	2.71	2.34	2.30	2.33	2.26	2.42
Small Hotel	3.91	3.28	2.93	2.93	2.75	2.84
Large Hotel	2.80	2.66	2.65	2.65	2.87	2.84
Hospital	7.01	7.14	7.45	7.45	8.23	7.94
Supermarket	5.98	5.65	5.70	5.70	5.71	5.94
School	4.66	3.63	2.81	3.07	1.62	2.35
Fastfood Restaurant	7.70	7.19	7.06	7.06	6.81	7.24
Sit Down Restaurant	5.78	5.61	5.71	5.71	5.58	6.05
Warehouse	1.15	0.91	0.65	0.67	0.44	0.54

Table A.7e System Electricity Use Data

Fan Coil System (kWh/sq.ft.) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.45	0.45	0.43	0.37	0.37	0.38
Large Office	0.49	0.50	0.47	0.47	0.43	0.46
Small Retail	0.46	0.45	0.43	0.44	0.40	0.44
Large Retail	0.32	0.32	0.33	0.32	0.33	0.35
Small Hotel	0.71	0.68	0.68	0.68	0.68	0.72
Large Hotel	0.61	0.61	0.62	0.62	0.63	0.68
Hospital	1.49	1.49	1.50	1.50	1.36	1.47
Supermarket	1.31	1.33	1.41	1.41	1.17	1.38
School	0.57	0.47	0.43	0.47	0.34	0.45
Fastfood Restaurant	1.62	1.61	1.71	1.71	1.62	1.85
Sit Down Restaurant	1.25	1.23	1.36	1.36	1.25	1.49
Warehouse	0.11	0.09	0.09	0.10	0.09	0.10

Fan Coil System (kWh/sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0.34	0.34	0.33	0.28	0.28	0.28
Large Office	0.41	0.42	0.40	0.43	0.40	0.43
Small Retail	0.40	0.39	0.38	0.39	0.37	0.40
Large Retail	0.35	0.36	0.38	0.36	0.38	0.39
Small Hotel	0.63	0.60	0.62	0.62	0.59	0.64
Large Hotel	0.62	0.62	0.63	0.63	0.64	0.69
Hospital	1.48	1.48	1.50	1.50	1.37	1.48
Supermarket	1.24	1.22	1.31	1.31	1.12	1.31
School	0.54	0.45	0.41	0.43	0.31	0.42
Fastfood Restaurant	1.46	1.43	1.55	1.55	1.45	1.69
Sit Down Restaurant	1.19	1.17	1.31	1.31	1.19	1.43
Warehouse	0.10	0.08	0.08	0.08	0.07	0.08

Table A.8a Equipment Sizing Requirements

Heating Equipment Sizing Requirement (Btu/hr-sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	21.42	17.36	12.99	13.55	7.69	11.11
Large Office	14.21	10.92	7.63	8.41	4	6.6
Small Retail	49.42	44.9	38.34	37.63	16.5	31.75
Large Retail	28.24	24	17.56	16.71	1.13	8.35
Small Hotel	62.31	44.87	29.67	29.67	4.8	19.91
Large Hotel	17.69	13.98	10.6	10.6	1.98	8.02
Hospital	8.25	6.42	4.1	4.1	0.71	2.66
Supermarket	26.47	19.73	13.09	13.09	1.68	9.38
School	50.58	45.12	38.17	39.58	26.08	36.75
Fastfood Restaurant	62.98	49.21	37.18	37.18	16.85	29.56
Sit Down Restaurant	48.84	38.64	28.65	28.65	14.01	23.05
Warehouse	10.27	8.73	7.22	7.38	3.5	5.24

Cooling Equipment Sizing Requirement (Btu/hr-sq.ft.) (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	15.31	15.93	15.24	14.01	14.37	13.48
Large Office	12.62	13.4	12.93	13.8	13.43	13.74
Small Retail	19.35	20.5	20.87	20.07	18.48	20.87
Large Retail	11.61	12.04	11.8	11.53	11	11.68
Small Hotel	17.57	19.66	19.27	19.27	19.11	19.55
Large Hotel	11.99	12.17	11.58	11.58	12.03	11.65
Hospital	26.57	27.14	27.07	27.07	27.86	26.88
Supermarket	21.81	23.32	22.74	22.74	22.04	22.4
School	15.24	15.97	17.75	18.1	16.98	18.55
Fastfood Restaurant	33.58	36.86	34.07	34.07	35.22	35.42
Sit Down Restaurant	27.8	30.61	28.27	28.27	29.51	29.55
Warehouse	1.97	2.26	2.79	2.85	2.73	3.1

Table A.8b Equipment Sizing Requirements

Heating Equipment Sizing Requirement (Btu/hr-sq.ft.) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	24.9	20.32	15.16	15.64	8.55	12.73
Large Office	15.88	11.85	8.92	9.22	4.5	7.22
Small Retail	54.38	48.43	41.39	40.66	19.13	34.58
Large Retail	33.23	28.48	22.27	21.53	2.42	12.6
Small Hotel	70.42	51.28	34.38	34.38	6.25	23.83
Large Hotel	19.05	15.13	11.78	11.78	2.69	9.06
Hospital	10.52	7.77	5.11	5.11	1.29	3.35
Supermarket	37.46	28.05	20.11	20.11	5.92	13.97
School	52.55	46.84	39.79	42.09	27.88	39.77
Fastfood Restaurant	68.53	53.88	41.05	41.05	18.78	32.2
Sit Down Restaurant	53.2	42.3	31.58	31.58	15.84	25.42
Warehouse	11.13	9.51	7.85	8.19	4.02	6

Cooling Equipment Sizing Requirement (Btu/hr-sq.ft.) (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	20.39	21.09	20.09	18.01	18.66	17.63
Large Office	15.14	16.01	15.45	15.43	15.06	15.39
Small Retail	21.18	22.71	22.69	22.01	20.21	22.77
Large Retail	14.69	15.6	16.23	15.54	13.44	15.48
Small Hotel	20.4	22.23	21.79	21.79	21.48	21.72
Large Hotel	11.8	12.08	11.43	11.43	11.79	11.58
Hospital	25.15	25.81	25.43	25.43	25.85	25.22
Supermarket	23.56	25.61	25.08	25.08	23.7	24.09
School	16.27	16.78	18.46	19.38	18.91	19.91
Fastfood Restaurant	38.59	41.88	38.74	38.74	39.73	39.72
Sit Down Restaurant	29.48	32.45	29.9	29.9	31.07	31.12
Warehouse	2.56	2.85	3.36	3.53	3.39	3.75

Table A.9a Effect of Economizers on System Loads

Percent Reduction in Cooling Load due to Economizer- Ducted-CV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	28%	26%	17%	11%	34%	7%
Large Office	52%	48%	34%	34%	29%	10%
Small Retail	15%	14%	6%	7%	28%	5%
Large Retail	51%	47%	34%	34%	27%	11%
Small Hotel	47%	41%	29%	29%	26%	10%
Large Hotel	44%	40%	26%	26%	26%	4%
Hospital	53%	49%	35%	35%	39%	10%
Supermarket	45%	43%	31%	31%	35%	11%
School	71%	64%	48%	49%	38%	16%
Fastfood Restaurant	24%	26%	19%	19%	40%	17%
Sit Down Restaurant	25%	26%	19%	19%	39%	16%
Warehouse	51%	47%	34%	34%	27%	11%

Percent Reduction in Cooling Load due to Economizer- Ducted-CV System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	23%	22%	12%	8%	31%	3%
Large Office	51%	47%	33%	33%	28%	9%
Small Retail	14%	14%	6%	7%	28%	5%
Large Retail	51%	47%	34%	34%	32%	12%
Small Hotel	44%	39%	27%	27%	25%	9%
Large Hotel	45%	40%	25%	25%	27%	4%
Hospital	53%	49%	34%	34%	41%	10%
Supermarket	45%	43%	31%	31%	35%	11%
School	71%	63%	48%	48%	37%	16%
Fastfood Restaurant	22%	23%	17%	17%	38%	15%
Sit Down Restaurant	24%	25%	19%	19%	38%	16%
Warehouse	50%	45%	33%	33%	27%	10%

Table A.9b Effect of Economizers on System Loads

Percent Reduction in Cooling Load due to Economizer- Multizone System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	42%	39%	27%	23%	24%	7%
Large Office	47%	44%	32%	31%	32%	11%
Small Retail	35%	33%	23%	24%	24%	9%
Large Retail	42%	40%	29%	30%	30%	13%
Small Hotel	40%	34%	24%	24%	25%	9%
Large Hotel	39%	34%	22%	22%	31%	6%
Hospital	53%	49%	36%	36%	43%	14%
Supermarket	44%	42%	31%	31%	39%	14%
School	64%	56%	41%	42%	34%	14%
Fastfood Restaurant	41%	39%	30%	30%	31%	17%
Sit Down Restaurant	36%	35%	27%	27%	30%	16%
Warehouse	40%	35%	27%	26%	28%	11%

Percent Reduction in Cooling Load due to Economizer- Multizone System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	38%	36%	24%	20%	23%	5%
Large Office	45%	42%	30%	30%	31%	10%
Small Retail	34%	33%	23%	24%	25%	9%
Large Retail	45%	42%	31%	32%	34%	13%
Small Hotel	38%	33%	22%	22%	25%	8%
Large Hotel	40%	36%	23%	23%	31%	6%
Hospital	53%	50%	36%	36%	45%	14%
Supermarket	45%	43%	32%	32%	39%	14%
School	64%	56%	42%	41%	33%	15%
Fastfood Restaurant	37%	35%	28%	28%	30%	16%
Sit Down Restaurant	34%	33%	26%	26%	29%	15%
Warehouse	40%	34%	25%	25%	28%	10%

Table A.9c Effect of Economizers on System Loads

Percent Reduction in Cooling Load due to Economizer- Ducted-VAV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	52%	43%	28%	30%	15%	10%
Large Office	55%	46%	32%	32%	20%	12%
Small Retail	63%	48%	31%	34%	8%	11%
Large Retail	52%	40%	25%	25%	20%	9%
Small Hotel	49%	39%	19%	19%	-9%	0%
Large Hotel	42%	31%	16%	16%	14%	5%
Hospital	41%	37%	28%	28%	34%	16%
Supermarket	52%	39%	22%	22%	15%	6%
School	81%	74%	58%	59%	33%	34%
Fastfood Restaurant	28%	18%	8%	8%	6%	1%
Sit Down Restaurant	19%	12%	4%	4%	6%	0%
Warehouse	73%	69%	50%	51%	14%	15%

Percent Reduction in Cooling Load due to Economizer- Ducted-VAV System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	52%	43%	28%	31%	16%	11%
Large Office	55%	46%	31%	30%	18%	11%
Small Retail	58%	43%	27%	31%	7%	10%
Large Retail	54%	42%	26%	28%	24%	11%
Small Hotel	47%	35%	15%	15%	-13%	-2%
Large Hotel	38%	29%	14%	14%	15%	4%
Hospital	43%	39%	31%	31%	38%	19%
Supermarket	36%	26%	13%	13%	22%	6%
School	80%	73%	57%	58%	33%	33%
Fastfood Restaurant	22%	14%	5%	5%	9%	1%
Sit Down Restaurant	16%	10%	3%	3%	8%	1%
Warehouse	73%	68%	51%	52%	16%	16%

Table A.9d Effect of Economizers on System Loads

Percent Reduction in Heating Load due to Economizer- Ducted-CV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0%	0%	0%	0%	[1]	1%
Large Office	-18%	-20%	-22%	-21%	[1]	[1]
Small Retail	0%	0%	0%	0%	[1]	1%
Large Retail	-17%	-20%	[1]	[1]	[1]	[1]
Small Hotel	-9%	-10%	-13%	-13%	[1]	[1]
Large Hotel	-13%	-15%	-16%	-16%	[1]	[1]
Hospital	-35%	-36%	[1]	[1]	[1]	[1]
Supermarket	-17%	-19%	-20%	-20%	[1]	[1]
School	-9%	-9%	-9%	-9%	-18%	-8%
Fastfood Restaurant	0%	0%	0%	0%	0%	0%
Sit Down Restaurant	0%	0%	0%	0%	[1]	0%
Warehouse	-8%	-9%	-10%	-10%	[1]	[1]

Percent Reduction in Heating Load due to Economizer- Ducted-CV System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	0%	0%	1%	0%	[1]	1%
Large Office	-16%	-18%	-19%	-19%	[1]	[1]
Small Retail	0%	0%	0%	0%	[1]	1%
Large Retail	-20%	-23%	-27%	[1]	[1]	[1]
Small Hotel	-8%	-9%	-12%	-12%	[1]	[1]
Large Hotel	-14%	-16%	-18%	-18%	[1]	[1]
Hospital	-43%	-44%	[1]	[1]	[1]	[1]
Supermarket	-22%	-25%	[1]	[1]	[1]	[1]
School	-9%	-9%	-9%	-9%	-18%	-8%
Fastfood Restaurant	0%	0%	0%	0%	0%	0%
Sit Down Restaurant	0%	0%	0%	0%	[1]	0%
Warehouse	-8%	-8%	-9%	-9%	[1]	[1]

[1] Small heating load.

Table A.9e Effect of Economizers on System Loads

Percent Reduction in Heating Load due to Economizer- Multizone System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-56%	-60%	-63%	-55%	[1]	-49%
Large Office	-60%	-66%	-69%	-67%	[1]	[1]
Small Retail	-42%	-49%	-54%	-55%	[1]	-49%
Large Retail	-60%	-66%	[1]	[1]	[1]	[1]
Small Hotel	-28%	-32%	-40%	-40%	[1]	[1]
Large Hotel	-44%	-48%	-55%	-55%	[1]	[1]
Hospital	-82%	-84%	[1]	[1]	[1]	[1]
Supermarket	-44%	-51%	-54%	-54%	[1]	[1]
School	-41%	-41%	-43%	-45%	-59%	-41%
Fastfood Restaurant	-28%	-35%	-39%	-39%	-52%	-38%
Sit Down Restaurant	-22%	-29%	-36%	-36%	[1]	-36%
Warehouse	-40%	-40%	-43%	-44%	[1]	[1]

Percent Reduction in Heating Load due to Economizer- Multizone System (NEW)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-48%	-53%	-57%	-51%	[1]	-45%
Large Office	-53%	-59%	-64%	-63%	[1]	[1]
Small Retail	-40%	-47%	-52%	-54%	[1]	-49%
Large Retail	-63%	-69%	-76%	[1]	[1]	[1]
Small Hotel	-24%	-29%	-37%	-37%	[1]	[1]
Large Hotel	-46%	-50%	-56%	-56%	[1]	[1]
Hospital	-92%	-95%	[1]	[1]	[1]	[1]
Supermarket	-50%	-58%	[1]	[1]	[1]	[1]
School	-40%	-40%	-43%	-44%	-57%	-40%
Fastfood Restaurant	-22%	-29%	-35%	-35%	-49%	-35%
Sit Down Restaurant	-20%	-27%	-35%	-35%	[1]	-36%
Warehouse	-37%	-37%	-40%	-40%	[1]	[1]

[1] Small heating load.

Table A.9f Effect of Economizers on System Loads

Percent Reduction in Heating Load due to Economizer- Ducted-VAV System (STOCK)

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-8%	-7%	-7%	-5%	[1]	-6%
Large Office	14%	0%	-18%	-15%	[1]	[1]
Small Retail	24%	15%	6%	10%	[1]	-9%
Large Retail	19%	5%	[1]	[1]	[1]	[1]
Small Hotel	2%	-6%	-26%	-26%	[1]	[1]
Large Hotel	8%	-2%	-24%	-24%	[1]	[1]
Hospital	-89%	-173%	[1]	[1]	[1]	[1]
Supermarket	25%	1%	-48%	-48%	[1]	[1]
School	22%	24%	25%	25%	9%	28%
Fastfood Restaurant	6%	-3%	-18%	-18%	-194%	-58%
Sit Down Restaurant	6%	1%	-12%	-12%	[1]	-64%
Warehouse	29%	32%	21%	21%	[1]	[1]

Percent Reduction in Heating Load due to Economizer- Ducted-VAV System (N

Building Type	Zone 1	Zone 2	Zone 3 N	Zone 3 S	Zone 4	Zone 5
Small Office	-8%	-7%	-6%	-5%	[1]	-5%
Large Office	17%	5%	-10%	-13%	[1]	[1]
Small Retail	22%	13%	3%	7%	[1]	-13%
Large Retail	25%	8%	-19%	[1]	[1]	[1]
Small Hotel	0%	-6%	-27%	-27%	[1]	[1]
Large Hotel	2%	-9%	-40%	-40%	[1]	[1]
Hospital	-119%	-234%	[1]	[1]	[1]	[1]
Supermarket	-4%	-63%	[1]	[1]	[1]	[1]
School	22%	23%	24%	24%	11%	28%
Fastfood Restaurant	6%	2%	-6%	-6%	-85%	-35%
Sit Down Restaurant	5%	1%	-10%	-10%	[1]	-44%
Warehouse	29%	32%	25%	25%	[1]	[1]

[1] Small heating load.

Appendix B - Commercial Building Data from CBECS [2]

Data for the North and the South, and for Stock and New: This section summarizes the characteristics of building types based on the results of CBECS 1989. These data are used to define the parameters of the building prototypes used in this study. The exact parameters utilized in the prototypes are presented in Appendix C. Data are presented for:

Table B.1. Large and Small Offices (north/south and stock/new),

Table B.2. Large and Small Retail Buildings (north/south and stock/new),

Table B.3. Warehouses (north/south and stock/new),

Table B.4. Schools (north/south and stock/new),

Table B.5. Hospitals (stock/new),

Table B.6. Restaurants (stock/new),

Table B.7. Large and Small Lodging (stock/new),

Table B.8. Food Stores (stock/new).

Table B.1. 1989 CBECS Data for Offices
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Large Offices (>= 25,000 ft2)				Small Offices (< 25,000 ft2)			
	Stock		New		Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA								
Total area (million of ft2)	3822	4552	1117	1747	1210	2304	234	711
Percent of total U.S. office area	32	38	9	15	10	19	2	6
CLIMATE WEIGHT FACTORS								
HDD >7000; CDD <2000	8	2	6	2	15	3	4	4
HDD 5500-7000; CDD <2000	48	6	44	9	57	5	79	5
HDD 4000-4999; CDD <2000	44	18	50	13	28	13	17	14
HDD <4000; CDD <2000	0	55	0	55	0	45	0	51
HDD <4000; CDD >2000	0	19	0	20	0	34	0	26
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft2)	111000	93800	137000	90000	5700	6000	6400	6600
Percent heated	97	90	97	88	95	88	98	87
Percent cooled	79	87	93	88	82	86	89	87
Floors	-	-	-	-	2	1	2	1
SHELL								
Percent glass	42	45	50	50	18	18	15	15
Percent storms	58	39	65	60	76	33	95	50
Percent tinted	56	71	95	80	21	47	55	65
Percent shaded	68	59	80	80	41	46	75	45
Percent with wall insul.	45	52	65	85	76	61	90	80
Percent with roof insul	68	83	65	90	86	81	95	90
Wall material	masonry	masonry	masonry	masonry	masonry	masonry	masonry	masonry
Roof material	built-up	built-up	built-up	built-up	built-up	built-up	built-up	built-up
OCCUPANCY								
Occupcy (ft2/pers)	460	400	390	390	434	439	470	470
Weekday hours	12	12	11	12.5	11	11	9.5	10
Saturday hours	7	6	7	7	6	4	4	4
Sunday hours	5	4	5	4	5	4	3	3
LIGHTING								
Percent incand. lit area	26	28	9	9	12	11	9	9
Percent fluor. lit area	90	90	90	90	88	92	90	90
Percent HID lit area	14	12	17	17	2	1	2	1

Table B.2. 1989 CBECS Data for Retail
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Large Retail (>= 25,000 ft2)				Small Retail (< 25,000 ft2)			
	Stock		New		Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA								
Total area (million of ft2)	2796	3080	453	727	2958	3570	599	685
Percent of total U.S. retail area	23	25	4	6	24	29	5	6
CLIMATE WEIGHT FACTORS								
HDD >7000; CDD <2000	19	5	12	0	20	2	23	0
HDD 5500-7000; CDD <2000	61	5	66	6	48	3	52	1
HDD 4000-4999; CDD <2000	20	14	22	12	32	20	25	15
HDD <4000; CDD <2000	0	39	0	26	0	36	0	38
HDD <4000; CDD >2000	0	37	0	56	0	39	0	46
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft2)	80000	79000	77000	81000	5600	5300	7100	5600
Percent heated	95	84	97	83	89	75	89	91
Percent cooled	60	65	73	74	41	49	54	45
Floors	3	2	2	2	2	1	1	1
SHELL								
Percent glass	15	18	16	14	15	15	15	14
Percent storms	51	39	65	39	47	19	72	22
Percent tinted	41	46	57	62	15	23	24	28
Percent shaded	38	42	49	45	34	35	43	38
Percent with wall insul.	51	51	91	69	57	42	94	69
Percent with roof insul	80	83	100	86	76	71	94	86
Wall material	masnry	masonry	masonry	masonry	masonry	masonry	masonry	masonry
Roof material	built-up	built-up	synth-sheeting	built-up	built-up	built-up	metal surfcng	metal surfcng
OCCUPANCY								
Occupcy (ft2/pers)	1000	1060	605	905	930	1020	955	926
Weekday hours	13	13	14	17	11	11	11	11
Saturday hours	11	11	13	16	8	7	8	7
Sunday hours	7	8	9	15	4	4	4	4
LIGHTING								
Percent incand. lit area	37	9	5	5	13	15	19	19
Percent fluor. lit area	81	87	58	82	88	88	88	87
Percent HID lit area	34	10	40	15	5	3	6	7

Table B.3. 1989 CBECS Data for Warehouses
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Warehouses			
	Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA				
Total area (million of ft2)	4489	4820	855	1373
Percent of total U.S. warehouse area	48	52	9	15
CLIMATE WEIGHT FACTORS				
HDD >7000; CDD <2000	17	1	26	2
HDD 5500-7000; CDD <2000	52	2	47	1
HDD 4000-4999; CDD <2000	31	13	28	18
HDD <4000; CDD <2000	0	40	0	25
HDD <4000; CDD >2000	0	45	0	54
FLOOR-AREA WEIGHTED AVERAGES				
Building area (ft2)	16500	13910	15300	13330
Percent Heated	47	29	45	28
Percent Cooled	13	23	8	40
Floors	1	1	1	1
SHELL				
Percent glass	7	5	4	3
Percent storms	32	10	51	15
Percent tinted	19	25	28	41
Percent shaded	16	26	19	47
Percent with wall insul.	46	34	65	57
Percent with roof insul	56	54	72	76
Wall material	masonry	masonry	masonry	masonry
Roof material	metal	metal	metal	metal
OCCUPANCY				
Occupcy (ft2/employee)	2120	2050	1440	1830
Weekday hours	12	12	12	12
Saturday hours	5	5	5	5
Sunday hours	4	3	3	4
LIGHTING				
Percent incand. lit area	26	19	6	19
Percent fluor. lit area	53	69	56	63
Percent HID lit area	23	13	30	22

Table B.4. 1989 CBECS Data for Schools
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Schools			
	Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA				
Total area (million of ft2)	4154	3984	161	434
Percent of total U.S. school area	51	49	2	5
CLIMATE WEIGHT FACTORS				
HDD >7000; CDD <2000	15	2	16	15
HDD 5500-7000; CDD <2000	49	21	68	17
HDD 4000-4999; CDD <2000	36	22	16	2
HDD <4000; CDD <2000	0	27	0	24
HDD <4000; CDD >2000	0	28	0	42
FLOOR-AREA WEIGHTED AVERAGES				
Building area (ft2)	45200	21000	25700	15950
Percent heated	99	95	97	94
Percent cooled	31	73	60	85
Floors	2	1	2	1
SHELL				
Percent glass	29	24	20	15
Percent storms	56	18	90	62
Percent tinted	26	42	58	71
Percent shaded	56	57	87	55
Percent with wall insul.	40	51	75	81
Percent with roof insul	79	75	90	95
Wall material	masonry	masonry	masonry	masonry
Roof material	built-up	built-up	synth-sheeting	built-up
OCCUPANCY				
Occupcy (ft2/employee)	1200	1000	850	1150
Weekday hours	12	11	12	10
Saturday hours	6	3	6	2
Sunday hours	4	3	5	1
LIGHTING				
Percent incand. lit area	39	8	5	15
Percent fluor. lit area	89	91	94	93
Percent HID lit area	18	4	9	5

Table B.5. 1989 CBECS Data for Hospitals
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Hospitals	
	Stock	New
STOCK FLOOR AREA DATA		
Total area (million of ft2)	1636	209
Percent of total U.S. hospital area	100	13
CLIMATE WEIGHT FACTORS		
HDD >7000; CDD <2000	6	5
HDD 5500-7000; CDD <2000	29	30
HDD 4000-4999; CDD <2000	41	33
HDD <4000; CDD <2000	11	9
HDD <4000; CDD >2000	13	23
FLOOR-AREA WEIGHTED AVERAGES		
Building area (ft2)	71500	155800
Percent heated	90	100
Percent Cooled	86	97
Floors	6	18
SHELL		
Percent glass	26	23
Percent storms	79	96
Percent tinted	70	93
Percent shaded	59	49
Percent with wall insul.	66	98
Percent with roof insul	87	82
Wall material	masonry	masonry
Roof material	built-up	built-up
OCCUPANCY		
Occupcy (ft2/employee)	690	830
Weekday hours	24	24
Saturday hours	24	24
Sunday hours	24	24
LIGHTING		
Percent incand. lit area	39	9
Percent fluor. lit area	93	91
Percent HID lit area	23	1

Table B.6. 1989 CBECS Data for Restaurants
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Restaurants	
	Stock	New
STOCK FLOOR AREA DATA		
Total area (million of ft2)	1172	182
Percent of total U.S.restaurant area	100	16
CLIMATE WEIGHT FACTORS		
HDD >7000; CDD <2000	15	8
HDD 5500-7000; CDD <2000	35	14
HDD 4000-4999; CDD <2000	11	3
HDD <4000; CDD <2000	21	34
HDD <4000; CDD >2000	18	41
FLOOR-AREA WEIGHTED AVERAGES		
Building area (ft2)	4870	3870
Percent heated	86	86
Percent cooled	74	84
Floors	2	1
SHELL		
Percent glass	23	18
Percent storms	48	43
Percent tinted	27	34
Percent shaded	57	52
Percent with wall insul.	52	70
Percent with roof insul	80	94
Wall material	masonry	masonry
Roof material	built-up	built-up
OCCUPANCY		
Occupcy (ft2/employee)	600	410
Weekday hours	15	16
Saturday hours	14	15
Sunday hours	11	14
LIGHTING		
Percent incand. lit area	49	30
Percent fluor. lit area	53	72
Percent HID lit area	10	53

Table B.7. 1989 CBECS Data for Lodging
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Lodging			
	Stock		New	
	<= 50000 ft2	> 50000 ft2	<= 50000 ft2	> 50000 ft2
STOCK FLOOR AREA DATA				
Total area (million of ft2)	1197	1686	241	472
Percent of total U.S. lodging area	42	58	8	16
CLIMATE WEIGHT FACTORS				
HDD >7000; CDD <2000	9	8	15	18
HDD 5500-7000; CDD <2000	16	42	4	30
HDD 4000-4999; CDD <2000	18	8	15	1
HDD <4000; CDD <2000	25	17	17	7
HDD <4000; CDD >2000	32	25	49	44
FLOOR-AREA WEIGHTED AVERAGES				
Building area (ft2)	11250	142000	12000	251100
Percent heated	86	94	86	89
Percent cooled	69	70	82	93
Floors	2	-	2	-
SHELL				
Percent glass	24	30	21	35
Percent storms	47	58	80	92
Percent tinted	22	19	31	30
Percent shaded	55	47	39	58
Percent with wall insul.	54	61	76	88
Percent with roof insul	75	88	94	100
Wall material	masonry	masonry	masonry	masonry
Roof material	shingle/siding	built-up	shingle/siding	built-up
OCCUPANCY				
Occupcy (ft2/employee)	1705	1026	1765	579
Weekday hours	24	24	24	24
Saturday hours	24	24	24	24
Sunday hours	24	24	24	24
LIGHTING				
Percent incand. lit area	66	46	62	70
Percent fluor. lit area	38	45	45	31
Percent HID lit area	1	4	2	1

Table B.8. 1989 CBECS Data for Food Stores
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Food Stores	
	Stock	New
STOCK FLOOR AREA DATA		
Total area (millions of ft2)	794	171
Percent of total U.S.food store area	100	22
CLIMATE WEIGHT FACTORS		
HDD >7000; CDD <2000	12	0
HDD 5500-7000; CDD <2000	22	21
HDD 4000-4999; CDD <2000	33	23
HDD <4000; CDD <2000	11	20
HDD <4000; CDD >2000	22	36
FLOOR-AREA WEIGHTED AVERAGES		
Building area (ft2)	7760	5900
Percent heated	79	66
Percent cooled	70	75
Floors	1	1
SHELL		
Percent glass	15	18
Percent storms	47	56
Percent tinted	16	30
Percent shaded	31	29
Percent with wall insul.	55	83
Percent with roof insul	70	84
Wall material	masonry	masonry
Roof material	shingle/siding	shingle/siding
OCCUPANCY		
Occupcy (ft2/employee)	940	622
Weekday hours	17	17
Saturday hours	14	18
Sunday hours	12	17
LIGHTING		
Percent incand. lit area	7	3
Percent fluor. lit area	84	78
Percent HID lit area	11	19

Appendix C - Commercial Building Prototype Characteristics

Parameters for the prototype buildings used in this study are presented in this appendix. Parameters are presented for:

Table C.1. Large and Small Offices (north/south and stock/new),

Table C.2. Large and Small Retail Buildings (north/south and stock/new),

Table C.3. Warehouses (north/south and stock/new),

Table C.4. Schools (north/south and stock/new),

Table C.5. Hospitals (stock/new),

Table C.6. Restaurants (stock/new),

Table C.7. Large and Small Hotels (stock/new),

Table C.8. Food Stores (stock/new).

Table C.1. Office Prototype
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Large Offices (>= 25,000 ft2)				Small Offices (< 25,000 ft2)			
	Stock		New		Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA								
Total area (million of ft2)	3822	4552	1117	1747	1210	2304	234	711
Percent of total U.S office area	32	38	9	15	10	19	2	6
LOCATION WEIGHT FACTORS								
Minneapolis	10	0	9	0	21	0	17	0
Chicago	55	0	58	0	67	0	93	0
Washington DC	41	21	50	13	31	12	17	14
Pasadena	0	55	0	55	0	45	0	51
Charleston	0	19	0	20	0	34	0	26
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft2)	111000	94000	137000	90000	5700	6000	6400	6600
Floors	7	6	7	6	2	1	2	1
SHELL								
Percent glass	45		50		20		15	
Window R-value	1.6	1.5	1.7	1.6	1.8	1.4	2.0	1.6
Window shading coefficient	0.8	0.77	0.69	0.71	0.79	0.82	0.71	0.75
Wall R-value	3.2	3.6	4.6	6.0	5.3	4.3	6.3	5.6
Roof R-value	9.5	11.6	9.1	12.6	12.0	11.3	13.3	12.6
Wall material	masonry				masonry			
Roof material	built-up				built-up			
OCCUPANCY								
Occupcy (ft2/pers)	430		390		440		470	
Weekday hours (hrs/day)	12				11			
Weekend hours (hrs/day)	5				4			
EQUIPMENT								
Power density (W/ft2)	0.75				0.5			
Full equipment hours (hrs/year)	3570				3380			
LIGHTING								
Power density (W/ft2)	1.8		1.3		2.2		1.7	
Full lighting hours (hrs/year)	4190				3340			

Table C.2. Retail Prototype
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Large Retail (>= 25,000 ft2)				Small Retail (< 25,000 ft2)			
	Stock		New		Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA								
Total area (million of ft2)	2796	3080	453	727	2958	3570	599	685
Percent of total U.S retail area	23	25	4	6	24	29	5	6
LOCATION WEIGHT FACTORS								
Minneapolis	25	0	12	0	22	0	23	0
Chicago	67	0	76	0	52	0	53	0
Washington DC	20	14	22	12	32	20	25	15
Pasadena	0	39	0	26	0	36	0	38
Charleston	0	37	0	56	0	39	0	46
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft2)	79000		80000		5200		6400	
Floors	2				1			
SHELL								
Percent glass	15				15			
Window R-value	1.56	1.45	1.69	1.45	1.52	1.27	1.75	1.30
Window shading coefficient	0.78	0.79	0.74	0.76	0.82	0.84	0.78	0.83
Wall R-value	3.6	3.6	6.4	4.8	4.0	2.9	6.6	4.8
Roof R-value	9.1	11.2	9.1	12.6	11.9	10.5	13.3	12.6
Wall material	masonry				masonry			
Roof material	built-up				built-up			
OCCUPANCY								
Occupcy (ft2/pers)	360				180			
Weekday hours (hrs/day)	12		15		11			
Weekend hours (hrs/day)	8		13		6			
EQUIPMENT								
Power density (W/ft2)	0.4				0.4			
Full equipment hours (hrs/year)	4750		5850		4350			
LIGHTING								
Power density (W/ft2)	2.1		1.6		2.0		1.8	
Full lighting hours (hrs/year)	4500		5425		4165			

Table C.3. Warehouse Prototype
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Warehouses			
	Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA				
Total area (million of ft2)	4489	4820	855	1373
Percent of total U.S warehouse area	48	52	9	15
LOCATION WEIGHT FACTORS				
Minneapolis	18	0	29	0
Chicago	54	0	49	0
Washington DC	31	13	28	18
Pasadena	0	40	0	25
Charleston	0	45	0	54
FLOOR-AREA WEIGHTED AVERAGES				
Building area (ft2)	15900	13600	15900	13600
Floors	1	1	1	1
SHELL				
Percent glass	6		3	
Window R-value	1.39	1.39	1.71	1.67
Window shading coefficient	0.83	0.85	0.80	0.82
Wall R-value	3.22	2.38	4.55	3.99
Roof R-value	7.8	7.56	10.08	10.64
Wall material	masonry			
Roof material	metal surfacing			
OCCUPANCY				
Average Occupcy (ft2/pers)	2085		1635	
Weekday hours (hrs/day)	12			
Weekend hours (hrs/day)	4			
EQUIPMENT				
Average Power density (W/ft2)	0.3			
Full equipment hours (hrs/year)	6462			
LIGHTING				
Average Power density (W/ft2)	0.8			
Full lighting hours (hrs/year)	3638			

Table C.4. School Prototype
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Schools			
	Stock		New	
	North U.S.	South U.S.	North U.S.	South U.S.
STOCK FLOOR AREA DATA				
Total area (million of ft2)	4154	3984	161	434
Percent of total U.S school area	51	49	2	5
LOCATION WEIGHT FACTORS				
Minneapolis	17	0	56	0
Chicago	69	0	114	0
Washington DC	36	22	16	2
Pasadena	0	27	0	24
Charleston	0	28	0	42
FLOOR-AREA WEIGHTED AVERAGES				
Building area (ft2)	45000	21000	26000	16000
Floors	2	2	2	2
SHELL				
Percent glass	27		18	
Window R-value	1.60	1.39	1.71	1.67
Window shading coefficient	0.79	0.82	0.71	0.73
Wall R-value	2.8	3.57	5.25	5.67
Roof R-value	11.1	10.5	12.6	13.3
Wall material	masonry			
Roof material	built-up			
OCCUPANCY				
Average Occupcy (ft2/pers)	105			
Weekday hours (hrs/day)	see schedules			
Weekend hours (hrs/day)	see schedules			
EQUIPMENT				
Average Power density (W/ft2)	0.8			
Full equipment hours (hrs/year)	1199			
LIGHTING				
Average Power density (W/ft2)	1.8			
Full lighting hours (hrs/year)	2419			

Table C.5. Hospital Prototype
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Hospitals	
	Stock	New
STOCK FLOOR AREA DATA		
Total area (million of ft2)	1636	209
Percent of total U.S hospital area	100	13
LOCATION WEIGHT FACTORS		
Minneapolis	6	5
Chicago	29	30
Washington DC	41	33
Pasadena	11	9
Charleston	13	23
FLOOR-AREA WEIGHTED AVERAGES		
Building area (ft2)	71500	155800
Floors	6	12
SHELL		
Percent glass	25	
Window R-value	1.81	1.96
Window shading coefficient	0.71	0.66
Wall R-value	4.62	6.9
Roof R-value	12.2	11.5
Wall material	masnry	masnry
Roof material	built-up	built-up
OCCUPANCY		
Average Occupcy (ft2/pers)	190	
Weekday hours (hrs/day)	24	
Weekend hours (hrs/day)	24	
EQUIPMENT		
Average Power density (W/ft2)	2.2	
Full equipment hours (hrs/year)	6962	
LIGHTING		
Average Power density (W/ft2)	2.1	
Full lighting hours (hrs/year)	6624	

Table C.6. Restaurant Prototype
Stock, Climate, Operation, and Lighting Characteristics

	Fast-Food		Sit-Down	
	Stock	New	Stock	New
STOCK FLOOR AREA DATA				
Total area (million of ft2)	586	586	586	586
Percent of total U.S restaurant area	50	50	50	50
LOCATION WEIGHT FACTORS				
Minneapolis	15	8	15	8
Chicago	35	14	35	14
Washington DC	11	3	11	3
Pasadena	21	34	21	34
Charleston	18	41	18	41
FLOOR-AREA WEIGHTED AVERAGES				
Building area (ft2)	2500		5250	
Floors	1		1	
SHELL				
Percent glass	30	20	20	15
Window R-value	1.53	1.53	1.53	1.49
Window shading coefficient	0.80	0.79	0.80	0.80
Wall R-value	3.64	4.9	3.6	4.9
Roof R-value	11.2	13.2	11.2	13.2
Wall material	masonry		masonry	
Roof material	built-up		built-up	
OCCUPANCY				
Average Occupcy (ft2/pers)	65		50	
Weekday hours (hrs/day)	17		17	
Weekend hours (hrs/day)	17		17	
EQUIPMENT				
Average Power density (W/ft2)	2.5		2.0	
Full equipment hours (hrs/year)	2352		2280	
LIGHTING				
Average Power density (W/ft2)	2.1		2.1	
Full lighting hours (hrs/year)	6576		7033	

Table C.7. Lodging Prototype
Stock, Climate, Shell, Operation, and Lighting Characteristics

	Lodging			
	Stock		New	
	Small Hotel	Large Hotel	Small Hotel	Large Hotel
STOCK FLOOR AREA DATA				
Total area (million of ft2)	1197	1686	241	472
Percent of total U.S lodging area	42	58	8	16
LOCATION WEIGHT FACTORS				
Minneapolis	9	8	15	18
Chicago	16	42	4	30
Washington DC	18	8	15	1
Pasadena	25	17	17	7
Charleston	32	25	49	44
FLOOR-AREA WEIGHTED AVERAGES				
Building area (ft2)	11000	142000	12000	250000
Floors	2	6	2	10
SHELL				
Percent glass	24	30	21	35
Window R-value	1.52	1.39	1.71	1.67
Window shading coefficient	0.81	0.80	0.76	0.74
Wall R-value	3.78	4.27	5.32	6.16
Roof R-value	10.5	12.32	13.16	14
Wall material	masonry			
Roof material	shingle/siding	built-up	shingle/siding	built-up
OCCUPANCY				
Average Occupcy (ft2/pers)	120	210	120	210
Weekday hours (hrs/day)	24	24	24	24
Weekend hours (hrs/day)	24	24	24	24
EQUIPMENT				
Average Power density (W/ft2)	0.69	0.72	0.69	0.72
Full equipment hours (hrs/year)	2826	2722	2826	2722
LIGHTING				
Average Power density (W/ft2)	1.06	1.18	1.06	1.18
Full lighting hours (hrs/year)	3443	5157	3443	5157

Table C.8. Food Store Prototype
Stock, Climate, Operation, and Lighting Characteristics

	Supermarket	
	Stock	New
STOCK FLOOR AREA DATA		
Total area (million of ft2)	794	171
Percent of total U.S food store area	100	22
LOCATION WEIGHT FACTORS		
Minneapolis	12	0
Chicago	22	21
Washington DC	33	23
Pasadena	11	20
Charleston	22	36
FLOOR-AREA WEIGHTED AVERAGES		
Building area (ft2)	21300	
Floors	1	
SHELL		
Percent glass	15	15
Window R-value	1.52	1.60
Window shading coefficient	0.82	0.79
Wall R-value	3.9	5.8
Roof R-value	9.8	11.8
Wall material	masnry	
Roof material	shingle/siding	
OCCUPANCY		
Average Occupcy (ft2/pers)	0	
Weekday hours (hrs/day)	18	
Weekend hours (hrs/day)	18	
EQUIPMENT		
Average Power density (W/ft2)	1.2	
Full equipment hours (hrs/year)	5168	
LIGHTING		
Average Power density (W/ft2)	2.4	
Full lighting hours (hrs/year)	7816	

Appendix D - Technology Data Sheets

Constant-Volume Reheat System

Fan Coil System

Hydronic System

Multizone and Dual-Duct Systems

Outside-Air Economizer Cycle

Variable-Air-Volume System

Water-Loop Heat Pump System

Technology Data Sheet:

Constant-Volume Reheat System

General Description: Constant-volume reheat systems provide a high degree of temperature and humidity control. The central heating/cooling unit provides air at a given temperature to all zones served by the system. Each zone is served by a secondary ("terminal") heater which then reheats the air to a temperature compatible with the load requirements of the zone. This system provides a high degree of control, but the simultaneous heating and cooling results in relatively large energy consumption.

Physical Characteristics: Medium to large systems typically use a central preheat coil, a central heating coil, a single supply duct (cool air - typically at 55-60°F) network to all zones, and a reheat coil at each zone. Heating coils are typically served by hot water; cooling coils are typically served by chilled water. Smaller systems may use a direct expansion cooling coil and electric reheat.

Applicability: Any building with multiple zones, though most common in older medium to large office buildings.

Energy Performance: High energy consumption, especially with year-round fixed supply air temperature.

Costs: Medium. Single set of supply and return ducts, single set of pipes (or electricity) for reheating each zone.

Reliability/Lifetime: Due to relative simplicity and use of common components, system reliability is good. Lifetime is dependent on good control maintenance.

Utility System Impacts: High energy use and summer peak demand.

User Impacts: Good temperature and humidity control; high costs for energy and peak power.

Product Availability: Still available, though restricted or prohibited by code in many places.

Comments and Caveats: These systems are sometimes known by the imprecise label "terminal reheat". They offer various retrofit options, including worst-zone reset of supply air temperature and conversion from constant-volume to variable-volume (see VAV System).

Technology Data Sheet:

Fan-Coil System

General Description: Each fan-coil unit consists of a fan and a heating and/or cooling coil. A fan-coil system comprises a fan-coil unit for each zone, controlled to maintain zone temperature. The individual units can be located either in or remote from the zone being served. The use of fan-coil systems results in low energy consumption because the distribution energy use is low and units are directly controlled. Most fan-coil units employ little or no ductwork, and the resulting fan horsepower is low.

Physical Characteristics: The simplest version of a fan-coil system is a unit heater (fan and heating coil hung from the ceiling in the zone being served); the most complex, a single-zone air-handling unit with heating and cooling coils and outside air supply (e.g., a below-window cabinet heater/cooler/ventilator). May be served by one-pipe (steam heating only), two-pipe (heating and/or cooling with seasonal switch over), or four-pipe (heating and cooling with complete zonal control).

Applicability: Perimeter zones, unoccupied zones, or zones with other access to outside air.

Energy Performance: Relatively low energy use. No simultaneous heating and cooling.

Costs: Relatively high for four-pipe configuration; medium to low for two-pipe. Savings on ducts and the space they require can be significant (see *User Impacts*).

Reliability/Lifetime: Higher maintenance than central systems since each zone has a fan.

Utility System Impacts: Low energy and power use.

User Impacts: Energy savings. Possible first-cost savings and/or the ability to build more floors into a given building height.

Product Availability: Widely available.

Comment and Caveats: See *Reliability/Lifetime.*

Technology Data Sheet:

Hydronic Systems

General Description: The hydronic, or water-based, distribution system generally refers to a heating-only system with no fans for recirculation or fresh air distribution.

Physical Characteristics: Hydronic systems usually use a baseboard fin-and-tube heat exchanger ("convector") or an upright radiator. Heat output is controlled by locally varying the hot water flow, centrally varying the water temperature, or some combination. Local control can be with a manual or thermostatic valve.

Applicability: Most applicable to spaces with operable windows for manual control of fresh air. For this reason, it is most commonly found in older office buildings. If space cooling is required, some other system is required in addition (typically window/wall air conditioners). Applicable to all building types, and to new buildings and renovations. Cannot be used in spaces with no access to ventilation air unless the space is unoccupied.

Energy Performance: Since there are no fans in this system, no simultaneous heating and cooling, and often no cooling, it has the lowest energy consumption of any of the common system types.

Costs: Cost per MBH (thousand BTU/hour) of peak heating capacity or square foot of building space decreases quickly with heating system size and building size.

Reliability/Lifetime: Boiler, circulating pump, and control valve are the only moving parts in this system/plant combination. These components are generally highly reliable and have long lifetimes. Manual valves that are left in position for long periods will become stuck.

Utility System Impacts: Energy consumption savings from lack of air-transport system. Overall energy and power impacts depend on whether air-conditioning is used and its COP.

User Impacts: Energy savings. Assuming no cooling, peak power savings and low first cost compared to central air-based system.

Product Availability: Widely available. Many installations have been performed nationwide.

Comment and Caveats: Not suitable for occupied spaces with no access to fresh air. Adding air conditioners to each space may make an inexpensive, efficient HVAC system into an expensive, inefficient one. Manual control valves that become stuck open, or that are difficult to access, often result in occupants controlling the temperature by opening the window, resulting in a large waste of energy.

Technology Data Sheet:

Multizone and Dual-Duct Systems

General Description: Multizone and dual-duct systems are both constant-volume systems which provide heating and cooling to multiple zones by mixing streams of hot and cold air. A multizone system heats and cools several zones (each with different load requirements) from a single, central unit. Dual-duct systems supply hot and cold air in individual ducts to the various zones of the building.

Physical Characteristics: In multizone systems, a thermostat in each zone controls dampers at the central unit that mix the hot and cold air to meet the varying load requirements of the zone involved. The mixed air is supplied from the unit in a single separate duct to each zone. In dual-duct systems, the ducts feed into a mixing box in each zone. By means of dampers, hot and cold air are mixed to achieve the air temperature required to meet the load conditions in the zone involved. Multizone systems typically consist of rooftop units with direct expansion cooling and gas heating, serving up to ten zones; dual duct systems typically have chilled water and hot water coils and serve medium to large buildings with dozens of zones.

Applicability: Any building with multiple zones. Outside air is provided by both systems for ventilation.

Energy Performance: Fair to poor. These systems have constant simultaneous heating and cooling.

Costs: Relatively low for multizone, due to single supply duct to each zone and no piping. Medium for dual-duct (two ducts, but still no piping).

Reliability/Lifetime: Medium for multizone, due to small air-cooled compressors and gas heating. Highly dependent on maintenance. All moving parts are in one location, though. Dual-duct systems are better, due to their relative simplicity and likelihood of larger, better-protected and -maintained units. However, zone dampers and actuators may be difficult and disruptive to access.

Utility System Impacts: High energy use and peak power demand.

User Impacts: High costs for energy and peak power.

Product Availability: Still widely available, though restricted or prohibited by many codes due to their high energy use.

Comments and Caveats: Multizone systems often have damper, linkage, damper motor, or sensor problems, leading to even higher energy use and poor temperature control. Both of these systems offer retrofit opportunities, including worst-zone reset of hot deck and cold deck (central hot and cold air) temperatures, outside-air economizers, and conversion to VAV (easier and more common with dual-duct systems).

Technology Data Sheet:

Outside-Air Economizer Cycle

General Description: When the outside air is cool enough, it can be brought into the space to help meet cooling loads instead of mechanically cooling interior air. Dry bulb economizers include outside and interior air temperature sensors, damper motors, motor controls, and dampers depending on installation. Economizer cycles are required on all new commercial buildings by ASHRAE 90 and Title 24 (in California) standards. Savings for enthalpy controls are not included in this study.

Physical Characteristics: For smaller systems (packaged units), economizers can be bought "off the shelf." For larger applications, the controls and dampers are custom designed. Generally, one economizer control system will be required for each separate air distribution system.

Applicability: Most applicable in cold or temperate climates. Savings are smaller in hot and humid areas. Also not applicable to spaces requiring 100% outside air for ventilation purposes (unless space is over-ventilated). Applicable to all building types, and to new buildings, retrofits, and renovations. There are some cases where economizers cannot be installed because there is not enough space to install an outside air damper or ducts large enough to bring in 100% outside air. It may not be possible to retrofit some packaged units with economizers.

Energy Performance: Cooling savings from 10 to 80% compared to systems with fixed minimum outside air. Range is mainly dependent on climate and system type. Significant increases in heating energy requirements (up to 100% or more) are possible depending on control strategy, especially in Multizone systems. These results are based on DOE-2 simulations for this project and for an earlier project (Usibelli 1985).

Costs: Cost per ton of peak cooling capacity or square foot of building space decreases quickly with cooling system size and building size. Costs are highly variable in larger buildings due to variations in system configuration.

Reliability/Lifetime: Dampers, damper linkage, motors, and sensors can be damaged or broken. Unless the unit is inspected, there may be no evidence of economizer malfunction (except increase in energy bill). Requires frequent checks for proper operation. Early-vintage (through approximately mid-1980s) enthalpy controls have a history of premature failure.

Utility System Impacts: Energy consumption savings only, unless utility is winter-peaking. Otherwise, reductions in building peak during cooler months will not coincide with utility system or building annual peak.

User Impacts: Energy savings. May increase maintenance requirements (as noted above).

Product Availability: Widely available. Many installations have been performed nationwide.

Comment and Caveats: Not suitable for areas where precise humidity control is required. Savings will vary according to building hours, external and internal loads, and supply air temperatures. Economizers may not be suited for retrofits of packaged units, since their compressors may burn out unless some type of protection is provided (low lock-out temperature or modulation based on supply air temperature).

Technology Data Sheet:

Variable-Air-Volume System

General Description: Variable-air-volume (VAV) systems are air transport systems that respond to changes in heating and cooling load by reducing the amount of conditioned air flowing to the space; constant-volume air systems commonly respond to variations in load by varying the temperature of the supply air or reheating the supply air. VAV systems use significantly less air transport energy than constant-volume systems.

Physical Characteristics: VAV systems require the use of VAV terminal boxes at each zone supplied, as well as hardware to control the main HVAC fan. The exterior physical characteristics of VAV terminal differ little from other terminals. Main fan control is done by variable-speed motor drives, variable-pitch fans, fan inlet vanes, or fan discharge dampers. Duct and fan housing configurations sometimes make the retrofit of inlet vanes and discharge dampers difficult.

Applicability: Applicable to most new construction situations, except building requiring high ventilation rates such as hospitals. Applicable as a retrofit to HVAC systems with medium to high velocity ductwork, most typically dual-duct systems. Low velocity ductwork will often leak and bellow when operated at the higher static pressures present in a VAV system. As well as having ductwork that can withstand the higher static pressures of a VAV system, dual-duct terminals are easily converted to VAV terminals. A modified version of VAV can be used with low-velocity HVAC systems. For this type of system, VAV terminals are not installed, but the main fan flow rate is controlled by the warmest zone in the building. Reheat will be required in zones other than the warmest, but significant fan energy savings will be realized.

Energy Performance: The use of VAV systems has impacts on air-transport, cooling and heating energy use. Air-transport energy savings depend on the cooling load profile and the type of main fan control used in the VAV system. Buildings that operate at part-load conditions for significant periods of time will save more fan energy through VAV use. Different methods used to reduce the flow of the main fan also result in different energy savings.

Costs: Medium to high, depending on configuration. Lower with only perimeter reheat and with electric reheat and with inlet vanes or discharge dampers on the fans. Higher with all-zone reheat, fan-powered boxes, hot water reheat, and variable-frequency drives on the fans.

Reliability/Lifetime: Reliability of VAV systems is generally worse than constant-volume systems because of more complex hardware, but the decrease in reliability is not a major concern. The additional complexities are controllable dampers in the VAV terminals, and equipment to vary the main fan air flow.

Utility System Impacts: Lower energy use and peak power than constant-volume reheat, multizone, or dual-duct systems. Higher than hydronic or fan-coil systems.

User Impacts: VAV systems produce less air movement in building spaces than constant-volume systems. This can lead to comfort complaints, but air temperature seems to be the more critical comfort parameter. VAV systems tend to maintain lower space humidity than constant-volume variable-temperature systems, because supply air temperatures are lower with VAV systems. Also noise can sometimes be a problem with poorly isolated vane-axial, variable-pitch fans.

Product Availability: Widely available. VAV systems are now the standard in new medium to large office buildings.

Comment and Caveats: Reliability may be a concern, especially in systems with many fan-powered boxes. Sophisticated reset strategies are possible, especially with direct digital control (DDC) systems that can reset supply air temperature and fan speed based on worst-zone conditions. In zones with no reheat, care must be taken to avoid starving the zone for ventilation air or overcooling the zone.

Technology Data Sheet:

Water-Loop Heat Pump System

General Description: Water-source heat pumps located in each comfort zone are used to extract heat from or reject heat to a circulating water loop. The temperature of the water in the loop is maintained between established limits, typically 50 to 90°F, by the use of boilers and cooling towers.

Physical Characteristics: Each zone is served by a separate heat pump, controlled by a heating/cooling thermostat in that zone. Often, the units are located along outside walls for access to outside air. There may or may not be any ducting from the unit to the zone.

Applicability: Any building with multiple zones and access to outside air for each occupied zone. The economies of scale for the central boiler, tower, and pumping plant make medium to large buildings more likely to be good candidates than small buildings.

Energy Performance: Relatively low. No simultaneous heating and cooling in any one zone. Since the heat pumps operate at low lift between the cold and warm temperatures, they operate at high efficiencies. Especially good where there are some zones heating and some zones cooling at the same time (the boiler and tower may be inactive). Fan energy consumption is low, especially in the typical application with a minimum of ducting.

Costs: High. However, the plant costs are minimal, and there may be significant savings in the ducts and the space they would otherwise occupy.

Reliability/Lifetime: Medium. The many compressors and fans in this system are a drawback, but using water-to-air equipment is a plus. Water treatment, especially in the cooling tower, is essential to a reasonably long life.

Utility System Impacts: Can be low energy and relatively low peak usage. If all zones are cooling, peak will be higher than a central water-cooled system.

User Impacts: Energy savings. Supply air temperatures are typically lower than other systems while heating, which may result in discomfort.

Product Availability: Widely available, though less common than air-based systems.

Comments and Caveats: Automatic outside-air economizers are generally not available.

Appendix E - COMMEND End-Use Planning System[1]

[1] This appendix is adapted from "COMMEND End-Use Planning System, " by J. Stuart McMenamin, Regional Economic Research, Inc., San Diego, CA, 1992.

The COMMEND end-use planning system provides a framework for organizing and analyzing commercial-sector market data. COMMEND has been developed by the Electric Power Research Institute (EPRI) for use by its member utilities. The main analysis uses are load forecasting for power system planning, demand-side management planning, and market planning.

The purpose of this section is to provide an overview of the following:

• Commercial sector market data and model definitions,
• COMMEND model structure, and
• Market data and forecast results.

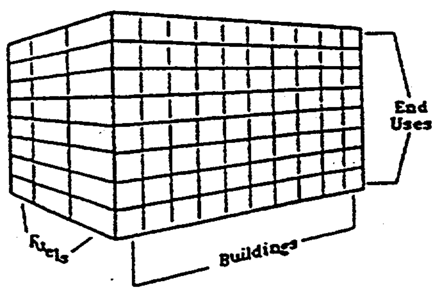
BACKGROUND

EPRI initiated a research project (RP1216) in 1981 to develop and transfer end-use analysis tools, market information, and data gathering strategies to the industry. At the core of this effort is the COMMEND framework, the COMMEND programs, and their supporting data bases.

The COMMEND Framework

The COMMEND framework segments the commercial market by building type, end use and fuels. The framework is illustrated in Figure E.1.

Figure E.1. COMMEND Framework



Uses for Market Data

- Forecasting
- Demand-Side Planning
- Integrated Planning
- Marketing

BUILDINGS	END USES	FUELS
Small Office	Space Heat	Electricity
Large Office	Cooling	Natural Gas
Restaurant	Ventilation	Fuel Oil
Retail	Water Heat	
Grocery	Cooking	
Warehouse	Refrigeration	
Schools	Lighting	
Colleges	Miscellaneous	
Health		
Lodging		
Miscellaneous		

This detailed focus is driven naturally by emerging market issues and analysis needs. For example:

- Changes in energy growth trends in the 1970s reflected changes in end-use technologies as well as behavioral changes.

- The impact of building performance standards on energy-use patterns must be evaluated by building type at the end-use level.

- Understanding the potential impact of demand-side management programs requires information on energy-use patterns for specific end uses.

- Appropriate strategies for both energy conservation and energy marketing are developed at the end-use or technology level.

The primary use of the COMMEND framework is long-term forecasting. However, the market data bases that result from model implementation are vital inputs to a wide variety of planning and analysis activities.

The COMMEND Models

The COMMEND 2.0 model was a mainframe model, which has been distributed to over 80 utilities in the U.S. and abroad. COMMEND-pc 3.0 became available in 1988, and has been distributed to over 100 utilities in the U.S. and abroad. It differs from the previous version in two significant ways:

- First, the economic logic of the model was restructured to use the probabilistic choice approach to modeling efficiency and fuel decisions. This logic replaced the micro simulation and fixed elasticity framework used in previous versions.

- Second, this version has been developed for the PC to take advantage of the interactive features of this environment. These features are used to provide data development abilities and diagnostic review procedures into the program.

In 1990, version 3.1 became available. It contained minor changes to version 3.0. Version 3.2 was released in April 1992.

COMMEND Data Bases

COMMEND-pc is distributed with a national data base, which is refined and updated as new information becomes available.

DISCUSSION OF THE COMMEND MARKET FRAMEWORK

The COMMEND model provides a conceptual framework for organizing market information. The purpose of the following discussion is to describe this framework, and to introduce the main analysis concepts. The focus is on the description of current energy-use patterns. This discussion has four main parts:

- The first part of this section discusses the types of market segments used in COMMEND. The dimensions discussed are building types, building vintages, and end uses.

- The second part of the section focuses on the central energy equation. This equation provides a definition of current energy use for each building type and end use.

- The third part discusses the logical progression from annual energy use to peak-day energy use and to peak-day load profiles.

- The last part presents some results from a market data development effort. The results presented are based on the COMMEND National Data Base.

Market Segments

The purpose of segmenting a market is to group customers into segments with common properties. Across groups, the customers should have different product requirements or different market attitudes and preferences. Within groups, these requirements and attitudes should be more homogeneous.

The COMMEND framework uses a two-way primary segmentation scheme. The dimensions are building type and end use.

Building-Type Segments

Building types define the primary market segments. This approach is useful because energy-use patterns differ strongly across building types. These differences reflect:

- Different operating hours
- Different types of energy-using activities
- Different types of energy-using equipment
- Different energy-using technologies.

The building-type concept has great intuitive appeal. For example, we all know what a high-rise office building looks like, and we are unlikely to confuse it with a fast-food restaurant. Further, the linkage with energy-use patterns is clear. Offices have different operating hours and house a different mixture of energy-using equipment than do restaurants, hospitals, or warehouses.

However, there are ambiguities that arise in applying the building-type concept. For example, the term "building type" refers to the use of the internal space as well as the characteristics of the structure itself. Further, the use may change over time or a single structure may have mixed uses at a point in time. Because of this, many analysts refer to the segments as building/activity types.

End-Use Segments

An energy end use is the ultimate service delivered by energy-using equipment. In COMMEND 3.2 the end-use categories are:

- Space heat
- Cooling
- Ventilation
- Water heating
- Cooking
- Refrigeration
- Exterior lighting
- Interior lighting
- Office equipment
- Miscellaneous.

These segments are defined in terms of the final service being provided by energy inputs. Within each end-use segment, three classes of decisions will impact the type of fuel and the level of energy use:

• Fuel choice refers to decisions among alternative equipment that provide the same service but use different types of fuel. The main competitive uses are heating and cooling, and the main fuels are electricity, natural gas, and fuel oil.

• Efficiency decisions refer to decisions about equipment features and structure features that determine how much energy is required to deliver a given level of end-use service.

• Utilization refers to the frequency and duration of equipment usage. This is affected by customer behavior and equipment operating controls.

From the perspective of the equipment producers and distributors, the end-use segments are separate markets. For example, heating, ventilation, and air conditioning (HVAC) equipment manufacturers do not view lighting appliance manufacturers as competitors. This perspective could also be adopted here, in which case we would refer to the heating market rather than the heating segment of the commercial energy market.

Other Segments

The COMMEND framework also tracks buildings according to the year of construction, referred to as the building vintage. This allows fuel and efficiency decisions to be analyzed separately for new construction versus retrofits and replacements.

In many applications, building types are further split on the basis of size. The most common example of this is the separate treatment of large versus small office buildings. This separate treatment is prompted by the fact that large buildings have different thermal properties and tend to utilize different types of HVAC technologies than do smaller buildings.

Central Energy Equation

The COMMEND framework provides an analysis structure for describing energy-use patterns. The primitive concepts in the framework are as follows:

• Floor stock (square feet of building space)
• Energy intensity (energy per square foot)
• Fuel share (percent of area served by an end use and fuel type)
• Energy-use index (energy per square foot for an end use)
• Peak-day fractions (share of annual energy)
• End-use load profiles.

These are the key concepts used in commercial sector energy analysis. By developing data for these concepts, a complete profile of the commercial sector can be produced.

For each market segment, the central energy equation in COMMEND defines current energy use as the produce of three factors. These are floor stock, fuel share, and energy use index (EUI). For a single building/end-use segment, the central equation is:

Annual Energy Use = EUI * S * F

where F is square footage of floor stock, S is average share of space served by the end use and fuel, and EUI is average energy use for served space.

In this definition, the floor stock is the total amount across all building vintages, and the share and EUI values are averages across buildings of all vintages. As an average, the EUI value embodies both average equipment efficiencies and average usage levels across the customer base in the segment.

As an example of this equation:

- Fifty million square feet of office space
- With 25% electric space heated, and
- An electric heating EUI value of 10 kWh/foot/year, gives
- Annual energy use of 125 gWh (50 million feet * 0.25 * 10 kWh/foot).

The central energy equation is a definition of energy use. Other definitions are possible and are sometimes used. For example, one alternative is to use employment times energy use per employee. Another is to use a measure of output times energy use per unit of output. These alternative definitions are valid, but for the commercial sector have not proven as useful as the floor stock approach.

Floor Stock

Floor Stock provides the basis for energy-using equipment and activities in the commercial sector. In new construction, energy-using technologies are an integral part of building design. In fast-growth areas with high construction levels, many energy equipment decisions are being made and new technologies can penetrate the market rapidly. In slow-growing areas, there are relatively few equipment decisions made, and they are restricted to replacement and retrofit in the existing stock.

Energy Intensity

The term energy intensity applies to total energy use per square foot for all end uses. For example:

- A typical office building intensity is 18 kWh/foot for electricity and 45 kBtu/foot for natural gas.
- A typical restaurant intensity is 36 kWh/foot for electricity and 140 kBtu/foot for gas.

The numerator in these intensity ratios is annual energy use. The denominator is total square footage.

Trends in energy intensities reflect changes in fuel shares, changes in equipment efficiencies, and changes in usage levels. At a point in time, the efficiency and usage factors are captured by the average EUI value.

Fuel Shares

Fuel shares indicate the share of building space that is served by a particular end use and fuel type. The term is used to indicate both stock and flow concepts.

- The stock concept refers to the share of all buildings existing at a point in time. This is sometimes referred to as a penetration or a market saturation. We call this the average share.

- The flow concept refers to the share of current decisions in new construction and replacements. This corresponds more closely to an equipment supplier's concept of the share of current shipments. We call this the marginal share.

The share concept used in COMMEND is applied to total floor stock, rather than the penetrated portion of the stock. For example, if 90% of floor space is in buildings with heating, the fuel shares will add up to 90% across fuels.

Two types of share definitions are commonly used. The first is the "whole-building" approach. This approach measures shares of space in buildings with an end use regardless of the portion of each building that is served or conditioned by the end use. The second is the "conditioned-space" approach, which accounts for the fraction of each building that is conditioned by the end use.

Energy Use Index (EUI)

The term energy use index (EUI) refers to a measure of average annual energy use per square foot of floor space in buildings that are served by an end use.

In the residential sector, a similar concept is used, called unit energy consumption, or UEC. This measures annual energy use by an average household appliance unit. This approach is not suitable for the commercial sector due to the wide range of building sizes and equipment types that are used in these buildings. By focusing on a typical square foot, the EUI is a standardized concept.

EUI values embody an average level of service and average equipment efficiency. There are several options for units of measurement. The standard approach is to develop electric values in kWh/foot and fossil fuel values in kBtu/foot.

For each end use, EUI values will differ across building types and across fuels. For example, for space heating in offices, suppose that:

- The electric EUI is 20 kBtu/foot (about 6 kWh/foot) and
- The gas EUI is 50 kBtu/foot.

This difference in EUI values across fuels reflects differences in equipment efficiencies, differences in the thermal features of buildings using gas and electricity, and differences in usage levels. Differences in usage levels may reflect fuel price differences as well as technology-related factors.

Usage Levels

Usage level is the most difficult of the COMMEND concepts to quantify. Ideally, it would be measured in terms of energy services delivered. Examples are:

- Delivered heat in Btu for space heating
- Heat removed in tons for air conditioning
- Lighting delivered in lumen hours.

Given these measures, usage is determined by occupant behavior, equipment controls, and other factors. Usage levels would change, for example, if thermostat settings are changed, comfort levels are altered, lighting fixtures are changed, or operating hours are altered.

Load Shapes

The discussion thus far has focused on annual energy use. The COMMEND framework also deals with daily energy use and with peak-day load shapes. The approach used relies on fixed fractions.

The first set of fractions indicates the share of annual energy use that occurs on the winter and summer peak days. These are referred to as peak-day fractions. The second set of fractions contains load profiles for each electric end use. These fractions are used to spread annual energy use from the daily total to hours of the day. Combined, these values allow the translation of annual energy usage levels to peak-day loads.

COMMEND FORECASTING FRAMEWORK

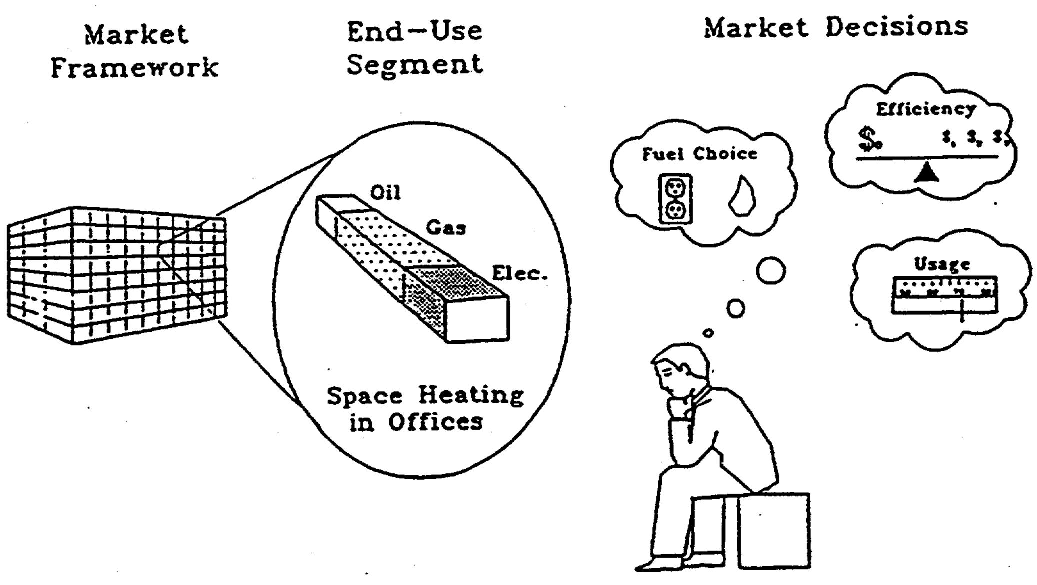
For the base year, the market profiles discussed above provide a detailed depiction of energy-use patterns at the end-use level. The purpose of the COMMEND forecasting framework is to project these detailed profiles into the future.

By forecasting at the end-use level, it is possible to isolate the influences of economic growth, changes in fuel shares, changes in efficiencies, and changes in usage levels on energy sales. This approach allows consideration of key issues in future markets, such as fuel competition, technology competition, building standards, and customer behavior.

Central Energy Equation

As discussed above, end uses within building types are referred to as market segments. The COMMEND forecast framework applies separately to each segment. As a result, it is appropriate to think of COMMEND as a matrix of models, as depicted in Figure E.2.

Figure E.2. COMMEND Framework for Long-Term Forecasting



Within each market segment or model cell, COMMEND computes energy sales using the central energy equation. This equation sums across all building vintages as follows:

$$Salesf = \sum Ufv * Efv * Sfv * Fv$$

This equation defines annual energy sales for each fuel (f) as the sum across vintages (v) of the product of four factors. Starting from the right-hand end, these factors are:

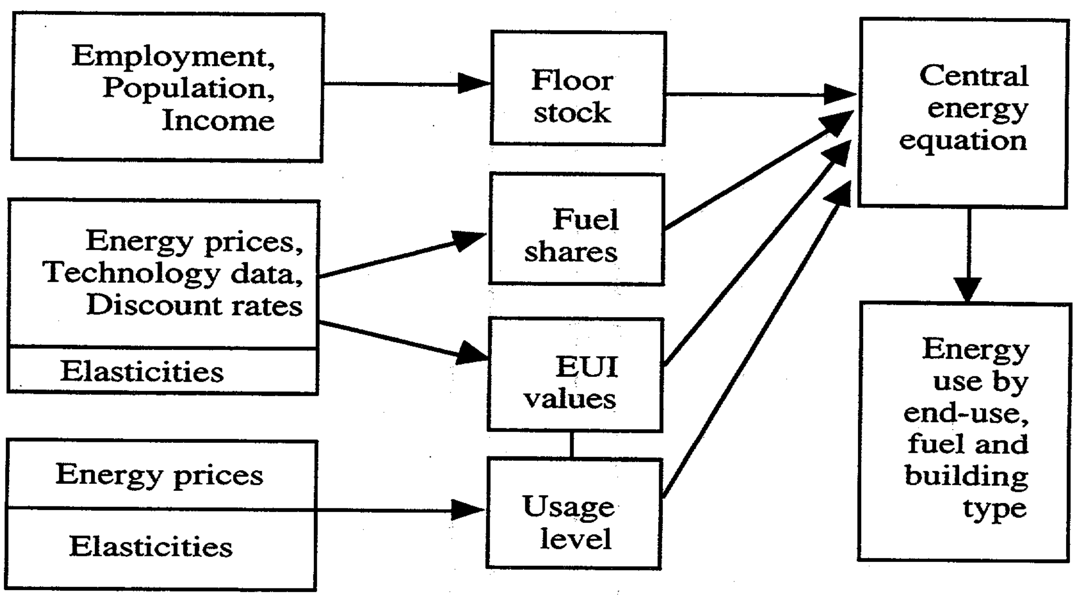
- Floor stock of vintage v (Fv)
- The share of vintage v space using fuel f equipment (Sfv)
- EUI for fuel f equipment in vintage v space (Efv)
- Utilization rate for fuel f equipment in vintage v space (Ufv).

This definition holds in each forecast year for each fuel.

All end-use models use this type of definition as a starting point. The definition is not a static one, since each of the model components will change over time. These changes reflect economic decisions in the commercial market, such as the decision to build, the choice of construction materials, the type of energy-using equipment to install, and the eventual usage pattern of this equipment. The challenge in end-use modeling is to provide an abstract model that captures the main influences on these decisions, and that projects over time the basic trends in each component.

COMMEND's general framework is presented in Figure E.3. The remainder of this discussion focuses on Version 3.2 and briefly describes each model component, forecast logic, and forecast results.

Figure E.3: COMMEND Forecast Framework



Floor Stock

The floor stock component of COMMEND is used to organize information about the existing floor stock and to forecast future stock levels. The floor stock outlook embodies the utility planning assumptions about growth in economic activity for the commercial sector. This outlook will be tightly linked to population growth, employment growth, and regional income.

Data about historical stock is input to the model. The key input values are:

- Base year floor stock (e.g., 1987)

- A historical floor stock series from a distant year to the base year (e.g., from 1941 to 1987). This series can be developed in the model using historical additions, scale variables (such as employment or population), or a combination of both.

- Survival functions describing building survival and decay over time.

A flexible forecasting framework is provided. Two general approaches can be used:

- In the flow approach, annual building construction is projected directly. The stock is inferred as the old stock, survived for one more year, plus the new additions.

- In the stock approach, the final stock is projected directly. Additions are inferred as the amount of construction required to produce the projected stock value.

With either approach, the user provided forecasting equations, including estimated coefficients and exogenous variable forecasts. Typically, the exogenous variables come directly from a service territory economic model. Variables that are used are: (a) employment in the commercial SIC codes, (b) population by age group, (c) regional income, and (d) construction industry conditions, such as interest rates. Within this general framework, simple and complex forecast approaches can be implemented.

Modeling Share, EUI, and Usage Decisions

The remaining three items in the central energy equation are fuel share, EUI values, and usage levels. Fuel shares and EUI values both reflect the outcome of choices among energy technologies. These choices are investment decisions made by building owners, designers, and contractors at the time of construction or equipment replacement. Decisions involved include:

- The decision to include the end use (for example, to have air conditioning or water heating present). This decision impacts the end-use penetration across all fuels.

- The decision to use a generic technology (such as an electric heat pump or a gas furnace). This determines the fuel share for each fuel.

- The decision to select a specific technology (an equipment brand and model), along with structure characteristics and initial usage patterns. This determines the EUI for each fuel.

Once a building is constructed and equipment is in place, changes in usage levels reflect daily decisions about the frequency and intensity of equipment use. These decisions are determined by the behavior of building managers and occupants.

A variety of approaches has been used to model these decisions. The focus of these approaches is on the impact of fuel prices on market decisions. These impacts are:

- Fuel Choice. An increase in one fuel price may cause switching away from that fuel to other fuels. For example, an increase in electric prices will cause a switch to fossil fuels. An increase in gas prices will cause a switch to electric technologies.

• Technology Choice. An increase in a fuel price may cause switching to more efficient technologies. This can involve either more efficient equipment models or the addition of energy-conserving features.

• Usage Behavior. An increase in a fuel price may cause a reduction in the usage level through changes in the behavior of building occupants. Examples are reduced lighting levels and more conservative thermostat settings.

COMMEND 3.2 uses a probabilistic choice approach for fuel and efficiency choice. In this application, the model outcome is the probability that a specific system is installed in a particular building. The probability will depend on the following:

• The capital cost of all system options,
• The operating costs of all system options, and
• Characteristics of the building and other relevant factors.

The probabilistic approach is appealing because it is not possible to observe all the factors that affect equipment decisions. Therefore, it is not possible to predict these decisions perfectly. This philosophy contrasts with the life-cycle cost (LCC) minimization approach, which posits that each choice is known precisely, based on a complete set of cost information and pure economic optimization.

The probability approach does not have the knife's edge property associated with LCC minimization. For example, a change in fuel prices alters operating costs, which in turn reorients the probabilities. These shifts will be sudden and dramatic only if estimated parameters suggest a high sensitivity to operating costs.

Key inputs to the modeling process are grouped into technology data, economic data and standards and DSM data. These are described below.

Technology Data

Technology data center on equipment costs and efficiencies. The main technology inputs are:

• Heat Pump Data. Heat pump shares and relative efficiencies are needed to unbundle the overall electric heating EUI and share into resistance and heat pump components.

• Equipment Costs. Average installed system costs for all end uses by building type are entered in $/square foot.

• Efficiency Ranges. For each generic technology, the range of available sub options is described. The range for each system is described as a curve segment. Parameters of the segment are EUI range percentages, and a tradeoff elasticity between outlay and energy use. The implied cost range is computed internally. This is referred to as the generic technology curve approach. These data describe the opportunity for price-induced efficiency changes.

• Efficiency and Cost Trends. For each generic technology, trend values that alter equipment efficiencies and installed costs may be specified. These impacts can be used to evaluate the impacts of naturally-occurring technology improvements.

• Thermal Interactions. Thermal interaction elasticities are used to describe the impact of changes in lighting and miscellaneous loads on HVAC energy use. Separate parameters give the impact of changes in building thermal characteristics on HVAC energy use.

The equipment cost data determine the relationship between capital costs and operating costs, which is important in determining the importance of energy prices in equipment decisions.

Economic Data

The economic data describe decision makers and decision rules. These data are defined as follows:

- Decision Maker Data. Decision makers are described by a block distribution of discount rates. These distributions may differ across building types. The decision makers have price expectations which are based on a single distributed lag adjustment mechanism. This implies that price expectations are formed on the basis of past price events.

- Efficiency Option Elasticities. These parameters give the sensitivity of market shares to life-cycle cost, where life-cycle cost includes both initial equipment cost and the present value of operating costs. These sensitivities are used to model efficiency choice for all end uses.

- Share Option Elasticities. Like the efficiency option elasticities, these parameters give the sensitivity of market shares to life-cycle cost, where life-cycle cost includes both initial equipment cost and the present value of operating costs. These sensitivities are to model market shares of competing fuels and technologies.

- Automatic Calibration. The technology data and decision data are combined to compute implied efficiency elasticities and to calibrate fuel choice equations. These equations are calibrated to marginal shares in new construction.

- Utilization Elasticities. These parameters indicate the sensitivity of equipment usage to energy prices, as well as weather data, operating hours, vacancy rates and other factors. These parameters are used to simulate changes in usage levels over time.

- Replacement Factors. Fuel share inertial parameters apply to fuel choice decisions in appliance replacement. They reflect the presence of barriers to fuel conversion when equipment is replaced. EUI inertial factors apply to efficiency changes at the time of equipment replacement.

- Retrofit Penetration Changes. These parameters control changes in the penetration of end uses in existing structures.

- Office Equipment and Miscellaneous Equipment EUI Growth. These parameters allow office equipment and miscellaneous equipment EUIs to grow independently for each building type in the forecast period.

Standards and DSM Data

This section includes data related to equipment efficiency standards, thermal efficiency standards, and DSM program impacts.

- Efficiency Standards. This section contains data that identify the timing of efficiency standards and that describe the impact of these standards on (a) equipment efficiency ranges and (b) the level of thermal efficiency in new construction.

- Efficiency Incentives. This section allows introduction of incentive or rebate payments for equipment that meets specified efficiency requirements.

- Specific DSM Program Impacts. This section allows imposition of program impacts by building type, end use and fuel

- General DSM Program Impacts. This section allows imposition of impacts by building and fuel. Specific end uses are not identified.

Forecast Logic

Given the model parameters, the key steps in the forecast logic are summarized as follows:

- Compute price forecast
- Compute floor stock forecast
- Compute efficiency/cost changes
  - -Trends and standards move curves
  - -Simulated elasticities give changes along curves
- Compute share changes
- Compute replacement impacts
  - -Shares
  - -Average EUIs
- Compute utilization impacts
- Apply central energy equation.

Forecast Results

COMMEND 3.2 forecast results are:

- Price forecast
- Floor stock forecast
- Energy sales forecast
- Sales forecast by building type
- Sales forecast by end use
- Summer peak demand forecast
- Winter peak demand forecast.

Appendix F - Sources of Cost Data

MEANS [8, 9]
Means construction cost catalogues are intended to be used for cost estimation for new construction. Energy conservation measures are not the primary emphasis of the publication. This is an important source of cost data for HVAC equipment and is also useful for determining baseline shell costs.

HVAC cost data are given both for components and for typical systems as a whole. Consequently, cost data as a function of capacity are readily available for plant equipment such as chillers and boilers. The costs of distribution systems can also be obtained by subtracting the plant cost from the total system cost. Cost data for all the HVAC equipment, except for electric resistance heaters, can be obtained from Means Mechanical Cost Data [8]. Means [8] also provides total HVAC system costs by capacity and building type, which can be used to determine the costs of distribution systems in office buildings.

Shell-related cost data can be obtained from Means Square Foot Costs [9]. Means [9] presents typical shell costs for office buildings of three different sizes (two- to four-story, five- to ten-story, and 11- to 20-story). Although the shell cost data given in Means [9] are helpful, they are not exactly the type of data needed for COMMEND. For example, it is hard to make the link between the incremental improvement (such as the change in R-value as a result of insulation) and the incremental cost of that improvement.

WAPA - DSM Pocket Guidebook [10]
This series of guidebooks is intended as a tool for utility personnel involved in DSM programs and services. The main purpose of the publication is to characterize the costs, benefits, and applicability of selected energy conservation measures. It is possible to obtain cost data for energy conservation measures such as economizers, energy management systems, and thermal energy storage systems from this source. There is also some information on window costs, but there is little cost information for other shell measures. There is limited cost information for HVAC distribution systems and very little data for plant costs.

EPRI - Technical Assessment Guide [11]
This document is intended to provide a consistent data base of cost and performance estimates for electricity-driven and other end uses. For HVAC, this document covers plant costs and also conservation measures. It covers distribution systems in a limited fashion. There is very little shell-related cost data.

LBNL - Commercial Sector Conservation Technologies Report [12]
This report is intended for DSM professionals and describes and documents selected commercial-sector energy conservation technologies with special emphasis on their application in the service territories for Pacific Gas & Electric and Southern California Edison. The report presents cost, energy and power savings, and measure lifetimes. For HVAC, the document contains data on energy conservation measures such as economizers, cool storage, and conversion to VAV. There are no baseline cost data for plant and distribution systems. The report contains data on roof and wall insulation costs, but is weak on window-related measures.

Wisconsin Center for Demand-Side Research (WCDSR) - Commercial Sector Technology Data Base [13]
This document is intended for DSM professionals and primarily contains cost data on energy conservation measures. For HVAC, it contains cost data on economizers, cool-storage systems, and system conversion to VAV. There is some plant data derived from Means and no distribution system cost data. There is some evaluation of shell measures, but combinations of shell measures are considered as a package. Therefore, it is hard to derive costs for components such as roof insulation, wall insulation, and measures related to windows.

LBNL - Demand-Side Efficiency Technology Summaries [14]
This document was prepared for the technology characterization data base of the Intergovernmental Panel on Climate Change. The report contains extensive information on the costs and efficiencies of window-related measures.