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Technology Data Characterizing Space Conditioning in Office Buildings: Application to End-Use Forecasting With Commend 4.0

Authors
Sezgen, A.O.
Franconi, E.M.
Greenberg, S.E.
et al.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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A.O. Sezgen, E.M. Franconi, S.E. Greenberg,
J.G. Koomey, and H. Akbari

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TECHNOLOGY DATA CHARACTERIZING SPACE CONDITIONING IN OFFICE BUILDINGS: APPLICATION TO END-USE FORECASTING WITH COMMEND 4.0

A. Osman Sezgen, Ellen M. Franconi, Steve E. Greenberg, Jonathan G. Koomey, and Hashem Akbari

Energy Analysis Program
Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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Abstract

This report characterizes the present commercial floorstock for offices in terms of space-conditioning technologies and develops cost-efficiency data for these technologies. The report also characterizes the annual and peak space-conditioning requirements for the building stock. The representation of space conditioning end uses is complicated by several factors. First, the number of configurations of HVAC systems and heating and cooling plants is very large. Second, the properties of the building envelope are an integral part of the energy consumption characteristics of the building. 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 tackle the above complications and create a consistent forecasting framework.

Data in this report come from various sources including the U.S. Department of Energy (DOE), EPRI, and LBL publications. Other sources include cost-estimation publications used in industry. Prototype simulations using the DOE-2 building energy analysis program were used for the generation of data related to the efficiencies of shell measures, HVAC systems and utilization systems (controls and economizers).

Acknowledgments

This report on office space conditioning is the second in a series summarizing technology data for various commercial end-uses in the United States. A companion report describes technology data for the lighting end-use in commercial buildings. Reports due later in 1994 will characterize HVAC, water heating, office equipment, and refrigeration in all building types.

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INTRODUCTION

Office buildings account for 19% of the commercial-sector floorspace in the U.S. Site energy consumption is 21% of the energy consumed by the commercial sector. Other building types ordered by the size of their energy consumption are: mercantile and service (18%), education (12%) and warehouse (9%). The four building types mentioned above account for 60% of the site energy consumed by the commercial sector [1].

Office buildings consume 781 trillion Btu of site electricity (28% of commercial-sector electricity), 238 trillion Btu of natural gas (11% of commercial-sector natural gas), 43 trillion Btu oil (12% of commercial-sector oil), and 167 trillion Btu of district heating (29% of commercial-sector district heating)[1]. District heat is mostly generated using natural gas. It is obvious that electric consumption is considerably higher than the sum of the consumption of other fuel types. This makes the source energy consumption of office buildings even higher compared to the other building types. Office buildings consume 25% of primary energy used by the commercial sector.

Forecasting energy consumed by the commercial sector is an important issue for the utilities in their capacity planning since this sector is the fastest growing consumer of energy. Previously, utilities forecasted electricity and gas consumption based on time series analysis. More recently, with the growth of Demand Side Management (DSM) programs, there is a need to forecast by building type and end use. Such models where end-uses are accessible for implementing end-use specific policies are also very important for state and federal policy makers--both for standards and R&D related policies. The Electric Power Research Institute (EPRI) develops and maintains the commercial sector end-use forecasting program COMMEND together with end-use programs for residential and industrial sectors.

COMMEND 3.2 represented end-use technologies using a single cost efficiency curve. These curves are built using market data but once they are built, the analyst loses the information on what a certain point on the curve actually represents in terms of technology options available in the market. As the forecast progresses, the saturation data output from COMMEND becomes meaningless in terms of correspondence to actual technologies. Although it is possible to analyze several policy options such as performance standards, it becomes very difficult, if not impossible, to analyze policy options addressing individual technology options. To address this and other analysis needs, the Electric Power Research Institute (EPRI) has enhanced its Commercial End-Use Planning System (COMMEND) to allow modeling of specific lighting and space conditioning (HVAC) technology options. The EPRI contractor for this effort, Regional Economic Research, Inc. (RER), worked with Lawrence Berkeley Laboratory (LBL) in the development and testing of the technology modules contained in COMMEND 4.0. LBL is also providing assistance in the development and refinement of technology data for the model.

This report is intended to put together space-conditioning-technology data for this new extended version of COMMEND. It should be noted that this report covers only office buildings and similar data development is in progress for the other building types.

COMMEND STRUCTURE AND DATA REQUIREMENTS

COMMEND is an end-use forecasting model for the commercial sector. This program forecasts future energy consumption by fuel, end-use and building type. It starts with a user-provided characterization of the present status of related parameters for the commercial sector. It forecasts future consumption levels by simulating user decisions on energy end-use technology options.

The commercial sector floor stock is segmented into building types and vintages. Energy use is segmented into different end-uses. The base year situation is characterized by the user by providing COMMEND with input on energy use intensities within this framework.

Over and above this base-year characterization, in order to generate future consumption patterns, COMMEND requires two major groups of data. The first is cost-efficiency data on end-use technology options, and the second is data on the decision behavior of the consumers. Technology options are represented by technology tradeoff curves which relate operating costs to equipment costs. This form can be viewed as a variation of cost-efficiency curve. For end-uses which may consume more than one fuel type, such curves are defined for each fuel type. Decision parameters are for discount rate preferences, consumers resistance to change, short term utilization elasticities, consumers price expectations based on past fuel prices, etc. The decision makers are segmented into levels of discount rate preferences.

Fuel prices and growth of commercial floor space is exogenous to the model. Based on these exogenous time series, for each forecast year, the program incorporates choices for new buildings and retrofit situations into the stock, building up the future forecast. Fuel switching and technology-efficiency level choices are based on Life Cycle Cost (LCC) minimization criteria. A more detailed discussion of the COMMEND framework is given in Appendix E.

In COMMEND 3.2 and earlier versions of the model, heating , space-conditioning end uses were each represented with a technology tradeoff curve, as mentioned above. In version 4.0, this end-use level of modeling remains available. However, a more detailed option is also available, and it allows modeling of specific HVAC distribution systems and a wide variety of heating and cooling technologies.

The main features of the detailed HVAC model are as follows[1] :

- In place of general end-use concepts, an expanded set of technology definitions is used in the model.

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

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

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

- The model deals directly with an enumerated list 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, system controls are covered by the model. This allows estimation of the impacts of simple controls, like setup/setback, as well as advanced controls, like energy management and control systems. On the cooling side, economizer cycles are included.

- A wide variety of plant options are covered, including conventional heating equipment, chillers, unitary equipment, packaged equipment, and heat pump alternatives. 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.

- 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 give system and plant shares in new buildings, (2) plant replacement models, which allow efficiency changes at the time of equipment decay and replacement, (3) system conversion models, which cover changes in distribution system and changes in heating and cooling plant.

End-use forecasting models expanded to address individual technology options will require characterization of the present floorstock in terms of annual and peak service requirements, energy technologies used, and cost-efficiency attributes of energy technologies available for the choosing of consumers for new buildings and retrofits. This report elaborates on how this information was gathered for COMMEND 4.0 and how it is mapped into COMMEND 4.0 input format. Another major area of data requirement is related to consumer choice modeling. This report does not consider how future choices of users may change or what the choice parameters of decision makers are. These data are most effectively developed regionally using utility DSM surveys.

Energy technologies related to heating, cooling, and ventilation may be classified into four groups: shell technologies, HVAC distribution systems, HVAC plant, and systems related to the utilization of energy services. Shell technologies include wall and roof insulation, window technologies, and weatherization. HVAC distribution systems are used to distribute heating, cooling and/or ventilation to the different parts of the building. HVAC plant are where heat and coolth are generated. Utilization technologies are related to changing the pattern of use maintaining the same level of service while conserving energy--with the exception of thermal energy storage systems which are mainly used to reduce peak demand rather than to conserve energy.

Although saturation/cost/efficiency data for many technologies are explicitly input to COMMEND, in some cases the input procedure is not that straightforward. For example, saturations of shell technologies can not be explicitly specified as COMMEND inputs. Instead, these values are imbedded in the stock and marginal averages for shell attributes. The following table summarizes the form of the data accepted by COMMEND as input. COMMEND building types are small office, large office, restaurant, retail, grocery, warehouse, school, college, health, lodging, and miscellaneous.

Table 1. Input Format of COMMEND for Saturation, Cost and Efficiency Data

Energy Technology	Saturation	Cost	Efficiency
Shell Measures (roof/wall insulation, window technologies etc..)	Imbedded in the stock and marginal averages for key parameters like wall R-value, window R-value and window shading coefficient (by building type)	For retrofit and new applications as a function of R-value and Shading Coefficient (by building type)	Heating and cooling slopes(1) (2) (by building type)
HVAC System	(By building type)	As a function of size (by building type)	System multipliers to modify load and system energy use(2) (by building type)
HVAC Plant	(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)	For retrofit and new applications (by building type)	Impacts of controls, economizers and thermal energy storage systems on energy use(2) (by building type)

(1) Heating and cooling slopes quantify the sensitivity of heating and cooling loads to changes in measure values.

(2) Output of prototype simulations.

As seen on Table 1, saturation data for shell measures are not explicitly specified in COMMEND--they are implicit in the stock and marginal averages for shell attributes. On the other hand, saturation data for equipment is input explicitly to COMMEND--these data are required by building type. Costs for shell measures are input as functional forms relating cost to key attributes of the measure like R-value and/or shading coefficient. Equipment cost are generally expressed as a function of capacity for different levels of efficiency (if applicable). Much of the efficiency data are developed using the simulation results. Efficiency data for HVAC plant are derived from manufacturer's catalogs.

There are a few more classes of data which are developed as COMMEND inputs:

(1) Average building heating and cooling loads by building type are developed using the prototype simulations. COMMEND utilizes these parameters at the core of the energy equations it uses to calculate energy consumption. These loads, which are developed for the base year, are modified for the forecast years using the slope parameters to calculate new building loads which reflect the introduction of conservation measures. The slope parameters are developed using simulation results.

(2) Sensitivity of the building heating and cooling loads to exogenous variables such as occupancy level and changes in weather are also developed using prototype simulations.

(3) There are conservation measures which are not technology options by themselves but are conversions from one option to the other. One example is a system conversion from a multizone system to a variable air volume (VAV) system. We developed cost figures for such conversions.

(4) Finally, there are conservation measures for other end uses like lighting and equipment which interact with HVAC service requirements. One good example is lighting/HVAC interactions: improved lighting efficiency can decrease cooling requirements and increase heating requirements. To be able to deal with such interactions, coincidence factors are defined in COMMEND. We developed coincidence factors for lighting and equipment interactions by building type using prototype simulations.

In the following sections, the data sources used in this study are introduced and discussed, and data required for COMMEND are developed. The Technology Options and Saturation Section describes the technology options covered in this report and characterizes the saturation of these options in the present building stock. The Cost and Efficiency Section covers the cost/efficiency characteristics of the technology options. Since the saturations related to the shell are not explicitly defined and these are imbedded in the representative prototypes, issues regarding selection of prototype parameters are discussed in the Office Prototypes Section. The efficiency data related to technology options, with the exception of plant efficiencies, are developed using simulation results which are discussed in the DOE-2 Simulations Section. Finally, the last section discusses how the regional data related to the prototypes and their simulation results are compiled and can be averaged to obtain U.S. averages for these parameters.

INPUT DATA SOURCES

Saturation Data

The main source of shell-related saturation data is the Commercial Building Energy Consumption Survey (CBECS)[1].

There are two general types of saturation data related to HVAC required by COMMEND 4.0. The first is the characterization of the buildings in terms of basic equipment like heating and cooling plant and distribution system. The second is the saturation of conservation measures which are added on the HVAC equipment like economizers and control equipment.

Saturation data for basic HVAC equipment mostly comes from CBECS data [1]. One problem is that the format and nature of the questions asked in the CBECS survey do not match the requirements of the task here. Nevertheless, CBECS is the best source for this purpose. Some saturations for the conservation measures can also be developed using CBECS.

Saturation data for conservation measures can be obtained more accurately from utility surveys related to their Demand Side Management (DSM) activities. A major source of data is a XENERGY report prepared for DOE [2]. XENERGY data draws upon several utility studies to provide estimates of conservation potential by U.S. census region, and in aggregate to provide a picture of resources available through DSM nationwide. Data on conservation measures were obtained for the census regions of West, Midwest and Northeast. The XENERGY report, as published, has very little on the saturations of basic HVAC equipment.

Cost Data

Cost data were obtained from several sources. The values from these different sources were compared before input values for COMMEND were determined. This section gives a brief description of the sources and the nature of the data in each source. Table 2 summarizes the availability of cost data for technologies examined in the various data sources.

MEANS [3,4]

Means construction cost catalogues are intended to be used for cost estimation for new construction. Energy conservation measures are not the main emphasis of the publications. This is an important source of cost data for HVAC equipment and a useful source to determine baseline shell costs.

HVAC cost data are given both for components and for typical systems as a whole. This means that cost data for plant equipment like chillers, boilers, etc. are readily available as a function of capacity. Distribution system costs as used in COMMEND can also be obtained by subtracting the plant cost from the given total system costs. Except for data for electric resistance heaters, all the HVAC equipment cost data can be obtained from Means Mechanical Cost Data [3]. Means [3] also gives total HVAC system costs by capacity and building type which can be used to determine distribution system costs for office buildings.

Shell-related cost data can be obtained from Means Square Foot Costs [4]. Means [4] presents typical shell costs for office building of three different sizes. The different office buildings are 2-4 story, 5-10 story and 11-20 story. Although the shell-cost data given in Means [4] is helpful, they are not exactly what are needed for COMMEND. For example, it is hard to make the link between the incremental improvement (like change in R-value due to insulation) and the incremental cost for that improvement.

WAPA - DSM Pocket Guidebook [5]

This series of guidebooks is intended as a tool for utility personnel involved in Demand Side Management (DSM) programs and services. The main emphasis of the publication is Energy Conservation Measures (ECMs). It is an attempt to characterize the costs, benefits, and applicability of selected ECMs.

It is possible to obtain cost data for ECMs like economizers, energy management systems, and thermal energy storage systems from this source. There are also some data on window costs--but not much cost information on other shell measures. There is limited cost information on HVAC distribution system cost and hardly any data on plant costs.

EPRI - Technical Assessment Guide [6]

This document is intended to provide a consistent database 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 hardly any shell-related cost data.

LBL - Commercial Sector Conservation Technologies Report [7]

This report describes and documents selected commercial-sector energy conservation technologies with special emphasis on their application in the Pacific Gas and Electric and the Southern California Edison service territories. The report presents cost, energy and power savings, and lifetime. The report is intended for DSM professionals.

For HVAC, the document contains data on ECMs like economizers, cool storage, conversion to Variable Air Volume (VAV), etc. There are no baseline plant and distribution system cost data.

The document contains data on roof and wall insulation costs, but is weak on windows-related measures.

Wisconsin Center for Demand-Side Research(WCDSR) - Commercial Sector Technology Data Base [8]

This document is intended for DSM professionals and contains cost data mainly on ECMs. 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 like roof insulation, wall insulation and measures related to windows.

LBL-Demand-Side Efficiency Technology Summaries [9]

This document was prepared for technology characterization database of the intergovernmental panel on climate change. The report contains extensive information on window technology efficiencies and costs.

Efficiency Data

Except for plant efficiency data, prototype simulations are used to develop efficiency data. The prototypes are based on CBECS [1] data. Plant efficiency data are developed mainly from a review of manufacturer's catalogues at Lawrence Berkeley Laboratory.

Table 2. Availability of Cost Data

		WAPA[5]	EPRI[6]	LBL[7]	WCDSR[8]	MEANS[3,4]	LBL[9]
SHELL							
	ROOF			X		X	
	WALL			X			
	WINDOWS	X					X
SYSTEM							
	Multizone					X	
	Duct CV					X	
	Duct VAV	X	X				
	Fan Coil	X	X			X	
	Hydronic					X	
	Water HP	X	X				
	Unitary		X				
SYSTEM CONVERSION							
	Multizone to VAV			X	X		
UTILIZATION							
	Controls	X	X		X		
	Economizer	X	X	X			
	Cool Storage	X		X			
PLANT							
	Electric Resistance		X				
	Electric Furnace					X	
	Electric Boiler		X			X	
	Gas Furnace		X			X	
	Gas Boiler		X			X	
	Oil Furnace					X	
	Oil Boiler		X			X	
	Electric Package Unit					X	
	Air-Source Heat Pump		X		X	X	
	Duel-Fuel Heat Pump						
	Water-Loop Heat Pump		X			X	
	Gas Package Unit		X			X	
	Electric Chiller		X	X		X	
	Gas Chiller		X				
	Window/Wall Unit					X	

TECHNOLOGY OPTIONS AND SATURATION

Saturation indicates how much of the floorspace is already equipped with the type of equipment or measure. This section enumerates the technology options covered and tries to determine present saturation levels for these options.

Shell Options

Technology options related to shell are: variations in roof, wall, and window R values; variations in window Shading Coefficients (SC); variations in window-to-wall ratios; and variations in air change rates for the building. Saturation of certain levels of these attributes for the stock and new buildings are not characterized explicitly. The saturations for the shell measures are imbedded in the stock and marginal averages for these parameters.

The values for these parameters and the prototypes are selected to meaningfully represent the floorstock based on CBECS 1989 data. The methodology is covered in detail in the prototype definition section.

HVAC Options

An HVAC option, generally, is a combination of an HVAC system that distributes the heat and/or the coolth in the building, a heating plant and a cooling plant. Although, more than one of these three components may happen to be within a single piece of equipment. For example, heat pumps and package units function as both heating and cooling plant. Also, sometimes unitary systems do not utilize an external distribution system--in one sense, the system and the plant are the same thing.

The HVAC technology options are summarized in Table 3. This table is a general overview of compatibility of classes of HVAC system and plant options. Each plant class may be divided into subclasses which we refer to as design options. Electric chillers, for example, may be divided into centrifugal, reciprocating, and screw types. In our database, design options are defined for gas furnaces, gas boilers, heat pumps, and electric chillers.

Many of the HVAC system options are summarized in 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. A list of the covered technologies appears at the beginning of Appendix D.

Table 3. Applicability of HVAC Technologies

System Plant	Multi Zone & Dual Duct	Ducted Constant Volume	Ducted Variable Volume	Fan Coil	Hydronic	Water -Loop HP	Unitary
Resistance Heater							*
Electric Furnace							*
Electric Boiler	*	*	*	*	*		
Gas Furnace	*	*	*				*
Gas Boiler	*	*	*	*	*		
Oil Furnace							*
Oil Boiler	*	*	*	*	*		
Package Unit (Electric)		*	*				*
Air-Source Heat Pump			*				*
Duel-Fuel Heat Pump			*				*
Water-Loop Heat Pump						*	
Package Unit(Gas)		*	*				*
Electric Chiller	*	*	*	*			
Gas Chiller	*	*	*	*			
Window/Wall Unit					*		*
CONTROLS	*	*	*	*	*	*	*
ECONOMIZER	*	*	*				

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

Saturations related to the above HVAC technology options are developed mostly using CBECS 1989 [1]data. Data related to economizers and controls come from XENERGY [2].

Table 4 summarizes the HVAC equipment saturation levels as obtained from CBECS 1989 [1]. 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 which clearly do not belong with a certain fuel type are discarded, for example, there would not commonly (in the stock) be 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 add 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. Table 4 also presents data on the saturations of utilization systems like time clocks and economizers as a percentage of the total commercial floor area.

The data presented in the XENERGY report [2] is very different in nature than the data presented in CBECS. We obtained data on applicability, feasibility and the saturation level of measures related to HVAC equipment form the XENERGY report. The data do not characterize the equipment but rather the saturation of conservation measures added on to the equipment (with the exception of high-efficiency equipment which is a design option). Table 5 presents the data obtained from the XENERGY report. The saturation of a measure is typically the product of the applicability, feasibility, and the saturation level of that measure. Figures are not available for all regions of the U.S. Data for the West is limited to the Pacific region and absent for the South.

An important class of conservation measures is conversion. Although such measures can not be classified under a technology option class, such activities are related to replacement of a certain existing option with another option. Examples of such activities are the conversion of a multizone to a VAV system or the replacement of an electric with a gas boiler. It is not meaningful to define saturations for such activity since this data is already covered by the saturations of the involved technology options. System and plant conversions are allowed in COMMEND.

Lighting and Miscellaneous Equipment

Conservation measures related to lighting have very important impacts on HVAC energy consumption. Although the primary effects of conservation measures related to efficient lighting and equipment are covered in reports devoted to these end-uses, secondary effects because of interactions have to be covered in this report. Characterization of lighting and office equipment energy use levels are imbedded in the prototypes based on CBECS 1989 data.

Table 4a.
Plant , System, and Measure Saturations for Small-Office Buildings (1)

Source: CBECS 1989 [1].

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	10%		9%	
Electric Furnace	7%		5%	
Electric Boiler	2%		2%	
Gas Furnace	14%		23%	
Gas Boiler	5%		10%	
Oil Furnace	1%		1%	
Oil Boiler	2%		5%	
Package Unit(Electric)	19%	50%	11%	47%
Package Unit(Gas)	10%		13%	
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

Multizone	36%	44%	41%	47%
Ducted VV				
Ducted CV	6%		7%	
Fan Coil	2%	3%	2%	2%
Hydronic	3%		8%	
Unitary	46%	40%	31%	34%

SUM (Conditioned Area)	92%	88%	91%	83%

UTILIZATION SYSTEM

Load Management	1%	1%
Time Clock	2%	3%
Economizer	4%	1%

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

Table 4b.
Plant , System, and Measure Saturations for Large-Office Buildings (1)

Source: CBECS 1989 [1].

	NEW		STOCK	
PLANT	Heating	Cooling	Heating	Cooling
Electric Resistance	18%		13%	
Electric Furnace	3%		2%	
Electric Boiler	6%		4%	
Gas Furnace	4%		6%	
Gas Boiler	20%		30%	
Oil Furnace	0%		1%	
Oil Boiler	2%		7%	
Package Unit(Electric)	17%	40%	10%	33%
Package Unit(Gas)	8%		11%	
Air-Source Heat Pump	12%	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

Multizone	12%	45%	10%	39%
Ducted VV				
Ducted CV	22%		25%	
Fan Coil	9%	25%	13%	22%
Hydronic	8%		16%	
Unitary	36%	19%	27%	23%

SUM (Conditioned Area)	88%	89%	92%	84%

UTILIZATION SYSTEM

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

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

Table 5. Plant and Measure Saturation Data

Source: XENERGY 1992 [2]

	WEST	MIDWEST		NORTHEAST	
	Pacific	W.N.Central	E.N.Central	N. England	Mid Atlantic
Economizer					
Applicability	81%	70%	52%	68%	48%
Feasibility	75%	90%	90%	90%	90%
Percent Applied	20%	50%	50%	50%	50%
Saturation(1)	12%	31%	23%	31%	22%
EMS for Cooling					
Applicability	81%	57%	23%	67%	10%
Feasibility	95%	100%	100%	100%	100%
Percent Applied	15%	10%	10%	10%	10%
Saturation(1)	11%	6%	2%	7%	1%
EMS for Heating					
Applicability	N/A	72%	4%	71%	0%
Feasibility	N/A	100%	100%	100%	100%
Percent Applied	N/A	10%	10%	10%	10%
Saturation(1)	N/A	7%	0%	7%	0%
EMS for Ventilation					
Applicability	79%	71%	30%	68%	18%
Feasibility	34%	95%	95%	95%	95%
Percent Applied	40%	7%	7%	7%	7%
Saturation(1)	11%	5%	2%	5%	1%

(1) Saturation = Applicability X Feasibility X Percent Applied

N/A: Not Available

COST AND EFFICIENCY DATA FOR THE TECHNOLOGY OPTIONS

In general, cost is a function of efficiency and capacity/size. The costs for the shell measures are generally given as a cost per applied area, and assumed constant regardless of size. For HVAC systems, cost given as a function of size. For much of the plant equipment, cost is given as function of capacity alone since design options are not defined for that equipment class (resistance heaters for example). For some plant equipment (gas furnace and electric chiller) cost is considered to be a function of both size and design option (efficiency). For economizers, cost is a function of size. For controls, it is more a function of capabilities.

Efficiencies of shell, HVAC systems, and utilization systems are dependent on region and climate. Therefore, such efficiencies are developed based on building simulations. HVAC plant efficiencies are estimated based on manufacturer's data.

Shell Technologies

Roof and Wall Insulation

Means [4] puts perlite/urethane composite roof insulation cost to $1.33-$1.38 /ft2 for new construction. According to LBL [7], for retrofit insulation jobs, blown-in insulation or insulating with rolled batts cost about $0.02-$0.04/R-value-ft2. Blown-in insulation for walls costs significantly more because of costs to drill and then refinish walls. Retrofitting batts into walls is not practical except during extensive remodeling. Spray-on fiberglass costs about $0.05/R-value-ft2, and rigid foam board costs $0.06 - $ 0.09/R-value-ft2 if applied at the time of reroofing 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 come up with overall impacts of insulation in the U.S. These values are input to COMMEND in the form of heating and cooling slopes which are indications of the changes in the heating and cooling requirements for the building type for changes in the roof and wall insulation levels.

Window Technologies

COMMEND can accept window costs as a function of R-value of the window and shading coefficient. According to WAPA 1991 [5] incremental costs of window technologies are as shown on Table 6. Similar figures with more detail related to the window frame were obtained from LBL [9] as shown in Table 7.

Table 6. Incremental Costs over Clear Insulating Glass for Glass Features (Source WAPA [5])

Feature	Cost/ft2 of window area (1991 dollars)
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

Table 7. Window Measure Costs in 1991 Dollars (Source Koomey et al. [9]) (1)

Feature	Cost/ft2 of window area	U-value	Shading Coefficient
Single glaze, aluminum frame	6.43	1.26	0.90
Single glaze, aluminum frame, gray tint	7.72	1.25	0.71
Single glaze, aluminum frame, reflective coating	9.00	1.03	0.33
Double glaze, aluminum frame	9.62	0.80	0.79
Double glaze, wood frame	16.85	0.48	0.66
Double glaze, aluminum frame, low-e	11.64	0.64	0.71
Double glaze, aluminum frame, spectrally selective	18.00	0.30	0.52
Double glaze, aluminum frame, selective tint, selective coating	20.00	0.29	0.38
Double glaze, wood frame, low-e	18.87	0.36	0.59
Heat mirror, wood frame	22.37	0.29	0.39
Double glaze, wood frame, argon fill	17.48	0.46	0.66
Double glaze, wood frame, argon fill, low-e	19.50	0.30	0.59
Super window(2 low-e coatings on 2 suspended plastic films)	32.39	0.20	0.51
Retrofit film on single pane	1.70	0.69	0.43

(1) Assumes 3ft X 4ft window

As a function of ΔR-value and ΔSC over a single glaze, aluminum frame window, the cost of window per square foot of glazing area can be represented by the following linear relation based on a linear regression of the data in Table 7 with an R^2 of 0.94:

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

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 which are indications of the changes in the heating and cooling requirements for the building type for changes in the window R-values and shading coefficients.

HVAC Technologies

An HVAC system is defined to be the system which is utilized to distribute the heat or coolth generated by HVAC plant and excludes the plant. HVAC plant is where the heat and coolth are actually generated like chillers and boilers. There is also the issue of plant auxiliaries which stand for equipment like cooling towers. In our compilation of data, we consider auxiliaries as part of the plant and factor them in both cost and efficiency values for the plant.

HVAC Systems

Means [3], WAPA [5] and EPRI [6] provide HVAC costs for the totality of system and plant. Plant costs are also available from the same sources with the exception of WAPA [5]. COMMEND 4.0 requires system and plant costs separately. Therefore, in this section we try to deduce plant costs from the total HVAC costs to estimate the system costs. To do this, the components of the overall system and the components related to the plant are determined for each capacity level. The cost of plant is then subtracted from the cost of the overall system. Table 8 summarizes the total HVAC costs from the above sources. Table 9 shows costs after the plant and auxiliary equipment costs are deducted from the total.

We recommend inputting Means data in a piece-wise-linear functional form to COMMEND. Where Means data are not available, other sources can be used--in the case above, Means data do not include cost data on ducted VAV and the EPRI estimates can be used.

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 are developed in this report based on prototype simulations. The following chapters elaborate on the development of such values.

Table 8. HVAC Costs in Nominal Dollars / Ton Including System and Plant

SYSTEM	MEANS 1992 [3,4] for several capacity levels (1992 dollars)	EPRI TAG 1988 [6] for 400 ton cooling capacity (1986 dollars)	WAPA 1991 [5] for 100 ton cooling capacity (1991 dollars)
Multizone(1)	5021(9.5 ton) 3705(32 ton) 2870(79 ton)		
Ducted CV(1)	3047(1.58 ton) 2078(3 ton) 1986(9.5 ton) 1996(32 ton)		
Ducted VAV		1720 (4)(7) 1245 (5)	1830 (4)(6)
Fan Coil	2890(12.66 ton) 2542(19 ton) (2)(6) 1914(32 ton) (2)(6) 1774(127 ton) (2)(6) 2891(13 ton) (2)(7) 2030(32 ton) (2)(7) 2400(190 ton) (2)(7)	1600 (2) 1950 (3)	2130 (3)(6)
Hydronic(8)	205/MBH (61 - 410 MBH) 69/MBH (510 - 12000 MBH)		
Water Loop HP		1400	1500
Unitary		1390	

(1) Rooftop Unit

(2) Central 2-pipe Fan Coil

(3) Central 4-pipe Fan Coil

(4) Central 2-pipe VAV

(5) Multiple Unitary VAV

(6) Reciprocating Air-cooled Chiller

(7) Reciprocating Water-cooled Chiller

(8) Electric Boiler

(9) MBH = Thousand Btus / Hour

Table 9. HVAC System Costs in Nominal Dollars / Ton

SYSTEM	MEANS 1992 [3,4] for several capacity levels (1992 dollars)	EPRI TAG 1988 [6] for 400 ton cooling capacity (1986 dollars)	WAPA 1991 [5] for 100 ton cooling capacity (1991 dollars)
Multizone(1)	2268(9.5 ton) 1630(32 ton) 1732(79 ton)		
Ducted CV(1)	669(3 ton) 1040(9.5 ton) 942(32 ton)		
Ducted VAV		1444(4) 656(5)	1180 (4)
Fan Coil	1573(19 ton) (2) 1132(32 ton) (2) 1150(127 ton) (2)	1325(2) 1557(3)	1480(3)
Hydronic	190/MBH (410 MBH) 61/MBH (6148 MBH)		
Water Loop HP		0(7)	0(7)
Unitary		1390	

(1) Rooftop Unit

(2) Central 2-pipe Fan Coil

(3) Central 4-pipe Fan Coil

(4) Central 2-pipe VAV

(5) Multiple Unitary VAV

(6) MBH = Thousand Btus / Hour

(7) The costs for the water loop are included in the plant costs.

System Conversion

System conversion is also a retrofit option. One of the major system conversion options is from Multizone to Variable Air Volume (VAV).

For retrofit situations, the cost of 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 10 summarizes cost information. The costs are expressed in $/cfm of air flow. Typical flow-to-area ratios are 0.7-2.0 cfm/ft2 for office buildings.

Table 10. Variable Air Volume Costs in 1985 Nominal Dollars / CFM(1) in a Retrofit Situation. Source: LBL [7]

VAV Fan Control	Converted from Dual Duct	Converted from Other
Discharge Dampers	0.2 - 0.5	0.6 -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

(1) Cubic Feet per Minute

HVAC Plant

Plant cost data are presented in Tables 11,12, and 13. Table 11 is for heating plant options, Table 12 is for combined plant options and Table 13 is for cooling plant options. Cost is a function of size and 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, two design options are presented as standard and efficient. The tables indicate the differences in the physical characteristics between the design options corresponding to different efficiency levels.

We recommend inputting Means data in a piece-wise-linear functional form to COMMEND. EPRI data are also good sources where Means data are not available for certain plant types.

Seasonal plant heating and cooling efficiencies are presented in Table 14. Efficiencies are developed both for stock and new equipment. For combined plants, secondary heating efficiencies are also developed.

Table 11. Heating Plant Costs in Nominal Dollars / MBH (5)

Plant Type	Means 1992 [3,4] (1992 dollars)	EPRI TAG 1988 [6] (1986 dollars)
Electric Resistance		18.50(14 MBH) 13.00(15-170 MBH)
Electric Furnace	17.00(30 MBH) 11.50(91 MBH) 8.50(141 MBH)	
Electric Boiler	88.00(41 MBH) 38.00(103 MBH) 15.00(410 MBH) 7.50(6143 MBH) 5.75(12300 MBH)	10.00(1000 MBH) 6.00(6000 MBH)
Gas Furnace Standard	14.50(42 MBH)(1)(3) 7.50(105 MBH)(1)(3) 7.50(400 MBH)(1)(3)	7.50 (100-350 MBH) 7.50(350 MBH) 6.00(900 MBH)
Gas Furnace Efficient	22.00(55 MBH)(1)(4) 17.00(72 MBH)(1)(4)	
Gas Boiler	21.50(100 MBH) 13.00(400 MBH) 9.50(6100 MBH) 3.77(18000 MBH)	10.00(1000 MBH) 7.00(4000 MBH) 8.50(6000 MBH)
Oil Furnace	18.00(55 MBH)(2) 9.80(125 MBH)(2) 7.00(400 MBH)(2)	
Oil Boiler	23.80(109 MBH) 13.75(480 MBH) 7.00(3820 MBH) 9.30(6100 MBH) 9.76(7000MBH)	10.00(1000 MBH) 7.00(4000 MBH) 8.50(6000 MBH)

(1) Not including gas/oil and flue piping.

(2) Atomizing gun type burner.

(3) Direct drive.

(4) Pulse combustion.

(5) MBH = Thousand Btus / Hour

Table 12. Combined Plant Costs in Nominal Dollars / Ton

Plant Type	Means 1992 [3,4] (1992 dollars)	EPRI TAG 1988 [6] (1986 dollars)	WCDSR 1990 [8] (1990 dollars)
Electric Packaged	805(1 ton, 14 MBH) 742(3 ton, 35 MBH) 750(4 ton, 54 MBH)		
Air-source HP (1)	1616(1.5 ton, 5 MBH) 960(5 ton, 27 MBH) 1170(10 ton, 45 MBH) 1173(30 ton, 163 MBH)	1000(1.5 ton) 800(5 ton) 750(10 ton) 770(20 ton) 900(30 ton)	930(2 ton) 790(40 ton)
Water-loop HP (without the water loop)(1)	1250(1 ton, 13 MBH) 555(5 ton, 29 MBH) 872(10 ton, 50 MBH) 585(20 ton, 100 MBH)	1000(1 ton) 880(5 ton) 840(10 ton) 890(20 ton)	
Gas Package	1045(5 ton, 112 MBH) 1040(10 ton, 200 MBH) 1040(25 ton, 450 MBH) 1160(100 ton, 1350 MBH)	550(<5 ton) 700(10 ton) 870(30 ton) 780(60 ton)	

(1) Heating capacity quoted is for the auxiliary resistance heating only.

(2) MBH = Thousand Btus / Hour

Table 13. Cooling Plant Costs in Nominal Dollars / Ton

Plant Type	Means 1992 [3,4] (1992 dollars)	EPRI TAG 1988 [6] (1986 dollars)	LBL 1985 [7] (1985 dollars)
Chiller-Centrifugal	540(200 ton) 375(400 ton) 257(1000 ton)	460(200 ton) 450(400 ton) 400(1000 ton)	350 - 600 + 10% for installation
Chiller-Reciprocating	870(20 ton) 650(100 ton) 480(160 ton)	500(20 ton) 500(200 ton)	200 - 500 + 10 % for installation
Chiller-Screw		500(180 ton) 420(400 ton) 450(700 ton)	
Gas Chiller		8.00 - 11.00/ft2(15 - 500 tons)(1)	
Window/Wall Unit	450(1/2 ton) 625(1 ton)		

(1) Source EPRI TAG 1992 [10] (1992 dollars).

Table 14. 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 Standard	0.63	0.76	4
Gas Furnace Efficient	0.85	0.89	5
Gas Boiler Standard	0.6	0.65	6
Gas Boiler Efficient	0.85	0.9	7
Oil Furnace	0.68	0.76	8
Oil Boiler	0.6	0.65	9

	Seasonal Plant Efficiency or COP (BTU out/BTU in)						
	Primary Heating		Secondary Heating		Cooling		
Plant Type	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	2.9	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

Footnotes to Table 14

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 same as marginal gas (both have power burner or induced draft).
9. Average and marginal assumed same as 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 EPRI 1989 and 1992 and LBL 1985; marginal assumed 0.5 COP point (absolute) higher
11. Primary heating from EPRI '89 and '92; secondary same as electric furnace. Cooling same as electric packaged.
12. Primary heating from EPRI '89 and '92; secondary same as electric furnace. Cooling from EPRI '89.
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 EPRI '89 and '92; averaged assumed to be at lower end of range of most-common COPs; marginal at upper end.
15. From EPRI '89: cooling same as electric packaged; heating at lower end of range of conventional and effic. units to account for seasonal effects.
16. From EPRI and E-Source. 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 E-Source.
18. From EPRI '89 and '92. 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 LBL. Assumed 0.1 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 EPRI '89, 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 the window/wall units are smaller, they borrow from the more-efficient residential technology.

Sources:

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

Utilization Systems

Costs for multi-function controls and economizers are presented in Table 15. Efficiency characteristics of these utilization system options are building specific and are developed in this report based on prototype simulations. The following chapters elaborate on the development of such values.

Table 15. Utilization System Costs in Nominal Dollars

System	EPRI TAG 1988 [6] (1986 dollars)	WAPA 1991 [5] (1991 dollars)	LBL 1985 [7] (1985 dollars)
Multi-Function Controls		0.27/ft2 (30,000 ft2)	
Economizers	140/ton(10 ton) 48/ton(75 ton) 48/ton(100 ton)	125/ton(5-10 ton) 62.50/ton(15-20 ton) 35/ton(<100 ton)	75-175/ton(5-10 ton) 50-75/ton(15-20 ton) 25-50/ton(25-100 ton)

Due to the complex nature of Energy Management and Control Systems (EMCSs) and custom design features for each installation, it is hard to obtain average costs for them. We assume, based on our experience, that energy savings of 10% can be achieved at a cost of $0.20/ft2.

OFFICE BUILDING PROTOTYPES

Building stock, building loads, and HVAC energy use are input data for the COMMEND HVAC forecasting model. The stock and load data are categorized by building type and vintage. COMMEND specifies large and small offices as different building types. The model calculates energy use in existing and new buildings using values for average building load and load multipliers. Specifically, COMMEND uses building load factors, system factors, and plant efficiencies to describe building energy use. To generate these COMMEND input data, we developed office building prototypes and simulated their energy use with the DOE-2 computer program.

In COMMEND, the building load factor or load elasticity is the ratio of the change in building load to the change in building characteristic. These ratios can also be thought of as a technology efficiency. Elasticities for about ten different building characteristics are analyzed in this study. We developed building load factors for window R-value, window shading coefficient, wall R-value, roof R-value, air leakage rate, window area to wall area ratio, internal gains, lighting power density, and number of occupants. The efficiencies are based on the heating and cooling loads that must be satisfied by the HVAC system. Office prototypes are used to determine building loads for the basecase and retrofit conditions.

The system factor is a multiplier used with the basecase office load to translate the building load to the system load. The system load is the amount of heating and cooling the plant has to provide to the HVAC distribution system in order for the building temperature set points to be met. The system factor varies depending on the type of distribution system and its control strategy. In addition to the system heating and cooling load, energy is used by the HVAC system to drive fans and pumps. COMMEND accounts for this energy consumption with the system electric energy-use factor. We simulated the HVAC systems analyzed in COMMEND with the office prototypes to develop the system and HVAC auxiliary energy-use factors. The distribution systems analyzed include hydronic, multi-zone, constant volume reheat, variable air volume, and fan coils.

The total heating and cooling energy required by the building is determined in COMMEND from the system load and plant efficiencies. The performance of the plants are based on fixed average operating efficiencies and in general they did not require simulation analysis. However, we did model the water loop heat pump with the prototypes to characterize its performance. The heat pump loop plant efficiency is still based on an average operating efficiency. The simulation was performed to determine the additional heating and cooling energy that needed to be supplied to the loop in order for the working fluid to be within the operating temperature range. This energy is accounted for in the system factors for the heat pump loop and is not part of the plant efficiency. The heat pump loop is discussed in more detail in the section describing the DOE-2 simulations.

Office Building Data

Office stock data were used to characterize the office building prototypes used in the DOE-2 modeling. The characteristics of the prototypes are mostly based on the 1989 CBECS data [1]. We accessed CBECS data using Statistical Analysis Software (SAS) to characterize the office stock in the country. The 1989 survey contains data for over 1,100 office buildings. Each surveyed building is assigned a weighting factor. The statistic has been developed by EIA based on regional building size and floor area data. It represents the number of similar buildings in the country similar to the surveyed building. The weighting factor and the building's floor area are used to extrapolate total office floor area. We also used the statistic to determine floor-area weighted office characteristics. Tables 1a through

1e in Appendix B present the data determined directly from the 1989 CBECS (a few items as noted in the tables were taken from the 1986 survey). The data are presented for two office size categories, two vintages, and four U.S. regions. The regional categorization coincides with the four U.S. census regions, the Northeast, the Midwest, the South, and the West.

We categorized and modeled the office prototypes to satisfy the input requirements of COMMEND. We categorized offices as small and large, older and newer. The small offices represent buildings less than 25000 square feet in floor area, the large offices are 25000 square feet or greater. The older building characteristics are based on survey data for offices built before 1980, the newer building characteristics are based on offices built between 1980 and 1989. The split at 1980 was made because past studies have revealed that commercial buildings have become more efficient during this period due to building standards and high fuel costs. We assumed the characteristics of offices built between 1980 and 1989 represent the characteristics of new offices being built today. Also, newer CBECS data are not yet available. Since building characteristics and their energy use are climate dependent, we developed office prototypes for two U.S. regions, the North and the South. In the next sections, we discuss in more detail the development of office building categorization and characteristics.

In the analysis, the biggest limitation for developing building characteristics and prototypes is the lack of data characterizing the national building stock and end-use energy consumption. Yet it is because of this lack of data that we are developing data for the COMMEND forecasting program. Thus while there are limitations to characterizing the national building stock, we are using the available data, making engineering judgments, and analyzing technologies and their efficiencies to form a more detailed and technologically oriented description of national building energy consumption. Because of the limited available data, some of our estimates of building characteristics are rough as discussed below. But we hope to encourage the development of better data sources in the future by recognizing the limitations of existing sources.

The CBECS survey is one of the most exhaustive sources of U.S. building characteristics. But the questions asked in the survey are not all of the questions 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 not the amount. Individual heating and cooling equipment are specified but not the fraction of floor area that they condition. Heating and cooling equipment are reported separately so one can not directly determine the combinations of equipment found together. It is also difficult to distinguish between primary and secondary equipment or distribution systems. For most HVAC related questions, more than one answer can be selected. In these cases we totaled the weighted floor area of each piece of equipment reported (each answer to the question is credited with the floor area of the building times its weight factor). Because some buildings had more than one piece of equipment, the sum of the floor area weighted answers for the equipment questions was greater than the total floor area . To correct for this over counting, we normalized the sum of question responses to the total floor area.

We used the CBECS weight factor assigned to the surveyed building and its floor area to weight building characteristics. Since the weight factor represents the number of buildings in the country in the same region with the same floor area, this assumes that the buildings of the same size have the same construction, equipment, and operating characteristics. Although this is not necessarily true, using the weight factor for scaling is a plausible method for characterizing many buildings based on a sample of buildings.

Additionally, some of the CBECS data describing HVAC distribution systems and controls (determined from the 1986 survey) were very different from values published in other sources. In general examining the raw data without discretion can lead one to draw conclusions about differences between size and vintage categories that may not exist. With these caveats in mind, we prepared **Table 16** which presents U.S. office building characteristics based on the CBECS data. We have averaged some values from the raw data to eliminate categorical differences that we believe to be insignificant or unreliable.

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 before it becomes useful in describing prototype buildings. The process we followed to develop the prototype data is described below.

Climate and Size Categorization

Although dividing the CBECS data into many regions allows us to examine regional differences, it also reduces the sample size that the office characteristics are based on. We examined the office data for each of the four regions and found that many shell and equipment characteristics are similar for offices in the Northeast and Midwest and in the South and West. Therefore, we combined the survey data for the Northeast and the Midwest to determine North office characteristics and the data for the South and the West to determine South office characteristics. The CBECS office data aggregated into the two regional categories of North and South are presented in Appendix B, Table 2. The characteristics are based on the following number of offices surveyed in CBECS; in the North - 159 small, old; 41 small, new; 206 large, old; 75 large, new; in the South - 238 small, old; 96 small, new; 183 large, old; 130 large, new.

The degree day data reported by CBECS is also very similar for the North/Midwest and South/West groups (Appendix B, Table 1, percent floor area by climate). The office floor area in the Northeast and the Midwest are located in climates with heating degree days ranging from 4,000 to over 7,000, with the majority in the 5,500-7,000 range. For the West and South, the predominant climates have less than 4,000 heating degree days, with the majority also having less than 2,000 cooling degree days. About 20% of the offices in the West, totaling approximately 5% of the total U.S. office area, are located in areas with more than 4,000 heating degree days. We assumed these buildings in the West in the colder climate category have characteristics more similar to buildings in the North/Midwest than in the South/West. Therefore we added their floor area to the floor area of the buildings in the cold climate category in the North/Midwest.

To be consistent with COMMEND, we divided the offices into two size categories; small and large. We split up the offices by floor area where we believe differences in building construction, operation, and equipment occur . We also wanted to be have the size categories correspond to categories used in the published CBECS data tables. Therefore, we selected the cut off between small and large offices at 25,000 ft^2.

Prototype Characteristics

The shell and operating characteristics of the office prototypes developed in this study are presented in **Table 17**. The values are based on the CBECS data except those for lighting and office equipment energy use. The data describe the prototypes in their basecase condition. Eight office prototypes have been developed; two sizes, two vintages in two regions. To establish the building floor area for each prototype, we examined both mean and median office floor areas based on the 1989 CBECS data. We found the median values to be much lower than the mean. The median for the large office is about 50,000 square feet while the mean is about 105,000 square feet. For small offices the median is about 3,500 square feet while the mean is about 6,000 square feet. The median value is low because there are many more smaller buildings than large ones. But large buildings comprise the majority of the office floor area and a high percentage of the total office energy-use. According to the CBECS 1989 survey, about 3% of the number of buildings are larger than 100,000 square feet. Yet this 3% of the building population comprise 45% of the total office floor area. Conversely, about 70% of office buildings are less than 10,000 square feet and comprise about 15% of the total floor area. Our goal in developing input data for COMMEND is to represent energy use in the total office sector and not to match energy use for individual buildings. Thus we are using mean building floor area values for specifying prototype floor areas.

Shell Characteristics

To specify shell characteristics, we used floor area weighted averages determined from CBECS "present" or "not present" percentages and nominal R-values which we specified. The nominal value we used for wall insulation is R-7. Since 35% of older, large offices in the North have wall insulation, we determined the weighted average value of wall insulation to be R-2.5 for the prototype. The nominal value we used for roof insulation is R-14. For windows, the nominal value for single glazing is R-1.1, for double glazing (storm windows present) the value is 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 forty percent of the windows were reported tinted, that forty percent of the double-paned windows were tinted and forty percent of the single-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.

Operating Characteristics

CBECS gives limited information on energy end-uses. For lighting it specifies the percentage of floor area lit by different categories of lighting equipment. But the extent that the systems overlap and the amount of energy they use is not known. Also, details on office equipment are not requested by the survey. For making these specifications for the prototypes we used other sources. The equipment energy use specified in the prototypes is based on values established in a previous LBL study [11]. The office equipment power density for the large office prototypes is 0.75 W/ft^2, for small offices it is 0.50 W/ft^2. For lighting, we based the lighting power densities on the performance of different lamp/ballast/fixture systems under actual operating conditions [12]. The lighting power density of the older offices is based on a standard lamp/standard ballast fluorescent system in a four lamp recessed troffer with incandescent task lighting. The power requirement of the fluorescent system alone is about 1.6W/ft^2 (based on approximately 1 fixture per 100 ft^2, the same lighting power density would apply if you had a more efficient fluorescent system with fixtures spaced closer together). The newer offices have energy efficient lamps/electronic ballasts using about 1.1 W/ft2 (with the same fixture and spacing). They also have incandescent task lighting. Based on the CBECS data, small offices have more incandescents than the large offices. Thus the incandescent portion of lighting is larger in the small office prototypes than in the large office prototypes and, therefore, their lighting power densities are higher.

Since we are developing yearly load estimates and not evaluating peak demand, total energy use is of primary importance. The yearly energy use in offices from lights and equipment is dependent on the number of hours of operation and the fraction of their capacity that is used. We have established weekday and weekend operating schedules for the prototypes. For lighting, the scheduled operating time for the year is equivalent to 4190 full load hours in the large office and 3340 full load hours in the small office. Similarly, the full load equipment hours are 3580 for the large office and 3360 for the small office. In establishing the lighting and equipment power densities and operating schedules, we verified that the yearly consumption was consistent with measured office loads. The comparison was made with values published in "Integrated Estimation of Commercial Sector End-Use Load Shapes and Energy Use Intensities" [13].

Table 18 presents operating schedules for lighting, equipment, and occupancy. The fractions listed in the table are the fraction of their peak power requirement that is used during the specified hour. The table also lists the office heating and cooling temperature set points. Uniform zone temperatures during operating hours and heating setback and cooling setup during off hours characterize the basecase office condition.

HVAC Characteristics

To develop data for COMMEND, we did not have to identify the predominant heating, cooling, and distribution systems for the prototypes. For COMMEND, we developed system factors by simulating the prototypes with the HVAC systems analyzed in the forecasting model. But to complete the characterization of the prototypes and make them useful in other applications, we did investigate office HVAC characteristics. We examined the CBECS data for heating/cooling fuel type, heating and cooling equipment, and distribution systems. The CBECS survey asks for heating and cooling data independently and it is not always clear what systems appear together (except for heat pumps). Also, as mentioned previously, the survey does not differentiate between primary or secondary systems or how much floor area one system conditions. The predominance of one type of equipment over another and its effect on our averaging is uncertain. Nevertheless we worked between all the fuel/equipment/distribution system data and tried to maintain consistency between the combinations we established and the individually reported values.

We used engineering judgment along with the data to specify real and sensible HVAC systems. From this process, we have established twelve predominant HVAC systems for offices. Each of the eight office categories (2 regions * 2 sizes * 2 vintages) has between three to five HVAC systems associated with it. Within an office category, the building shell, internal gains, and operation are the same (see Table 17), only the HVAC systems are different. Table 3 and Table 4 in Appendix B presents the HVAC systems we found predominant for the large and small offices based on the CBECS data An estimate of the floor area weighted saturation of each system is also provided in the tables.

Table 16
Stock, Climate, Shell, Operation, and Lighting Characteristics for Offices

	Large Offices (>= 25,000 ft2)				Small Offices (< 25,000 ft2)			
	Pre 1980		1980-1989		Pre 1980		1980-1989	
	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)	2706	1593	1117	2805	1747	1593	234	711
Percent of total U.S. office area	23	13	9	24	15	13	2	6
CLIMATE WEIGHT FACTORS								
HDD >7000; CDD <2000	10	1	6	2	18	3	4	4
HDD 5500-7000; CDD <2000	49	5	44	9	51	5	79	5
HDD 4000-4999; CDD <2000	41	21	50	13	31	12	17	14
HDD <4000; CDD <2000	0	54	0	55	0	43	0	51
HDD <4000; CDD >2000	0	19	0	20	0	37	0	26
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft2)	103000	96000	137000	90000	5500	5800	6400	6600
Floors	7	6	7	6	2	2	2	1
SHELL								
Percent glass	40	40	50	50	20	20	15	15
Percent storms	35	30	65	60	70	25	95	50
Percent tinted	40	65	95	80	15	35	55	65
Percent shaded	65	65	80	80	35	45	75	45
% with wall insul.	35	35	65	85	70	55	90	80
% with roof insul	65	80	65	90	85	75	95	90
Wall material	masnry	masnry	masnry	masnry	masnry	masnry	masnry	masnry
Roof material	built-up	built-up	built-up	built-up	built-up	built-up	built-up	built-up
OCCUPANCY								
Occupcy (ft2/pers)	460	460	390	390	420	420	470	470
Weekday hours	12	12	11	12.5	11	11	9.5	10
Saturday hours	6	6	7	7	6	6	4	4
Sunday hours	5	4	5	4	5	5	3	3
LIGHTING								
% incand. lit area	36	36	9	9	12	12	9	9
% fluor. lit area	90	90	90	90	90	90	90	90
% HID lit area	10	10	17	17	1	1	2	1

Table 17
Stock, Climate, Shell, Operation, and Lighting Characteristics for Office Prototypes

	Large Offices (>= 25,000 ft2)				Small Offices (< 25,000 ft2)			
	Pre 1980		1980-1989		Pre 1980		1980-1989	
	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)	2706	1593	1117	2805	1747	1593	234	711
Percent of total U.S office area	23	13	9	24	15	13	2	6
LOCATION WEIGHT FACTORS								
Minneapolis	11	0	8	0	21	0	8	0
Chicago	54	0	53	0	56	0	84	0
Washington DC	41	21	50	13	31	12	17	14
Charleston	0	54	0	55	0	43	0	51
Pasadena	0	19	0	20	0	37	0	26
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft2)	103000	96000	137000	90000	5500	5800	6400	6600
Floors	7	6	7	6	2	2	2	1
SHELL								
Percent glass	40		50		20		15	
Window R-value	1.44	1.39	1.71	1.67	1.76	1.34	1.99	1.58
Window shading coefficient	0.8	0.77	0.69	0.71	0.79	0.82	0.71	0.75
Wall R-value	2.5	2.5	4.6	6	4.9	3.9	6.3	5.6
Roof R-value	9.1	11.2	9.1	12.6	11.9	10.5	13.3	12.6
Wall material	mansonry				masonry			
Roof material	built-up				built-up			
OCCUPANCY								
Occupcy (ft2/pers)	460		390		420		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)	3580				3360			
LIGHTING								
Power density (W/ft2)	1.8		1.3		2.2		1.7	
Full lighting hours (hrs/year)	4190				3340			

Table 18
Operating Schedules for Office Prototypes

Large Office

Schedule	Day Type*	Hour of Day																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		Fraction of Maximum																							
Occupancy	WD	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
	WEH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.13	0.20	0.20	0.20	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lighting	WD	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	WEH	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.40	0.40	0.40	0.40	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Equipment	WD	0.17	0.17	0.17	0.17	0.17	0.17	0.17	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	WEH	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
		Set Point Temperature																							
Cooling	WD	90	90	90	90	90	90	75	75	75	75	75	75	75	75	75	75	75	75	90	90	90	90	90	90
	WEH	90	90	90	90	90	90	75	75	75	75	75	75	75	90	90	90	90	90	90	90	90	90	90	90
Heating	WD	55	55	55	55	55	55	70	70	70	70	70	70	70	70	70	70	70	70	55	55	55	55	55	55
	WEH	55	55	55	55	55	55	70	70	70	70	70	70	70	55	55	55	55	55	55	55	55	55	55	55

Small Office

Schedule	Day Type*	Hour of Day																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
		Fraction of Maximum																							
Occupancy	WD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
	WEH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.13	0.20	0.20	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lighting	WD	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.20	0.20	0.20	0.20	0.20	0.20	0.20
	WEH	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Equipment	WD	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.17	0.17	0.17	0.17	0.17	0.17	0.17
	WEH	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
		Set Point Temperature																							
Cooling	WD	90	90	90	90	90	90	90	75	75	75	75	75	75	75	75	75	75	75	90	90	90	90	90	90
	WEH	90	90	90	90	90	90	90	75	75	75	75	75	75	90	90	90	90	90	90	90	90	90	90	90
Heating	WD	55	55	55	55	55	55	55	70	70	70	70	70	70	70	70	70	70	70	55	55	55	55	55	55
	WEH	55	55	55	55	55	55	55	70	70	70	70	70	70	55	55	55	55	55	55	55	55	55	55	55

*WD - Week day, WEH - Weekends and Holidays

DOE-2 SIMULATIONS

We modeled the prototypes in the DOE-2 computer simulation program to determine the building loads, system loads, and auxiliary energy use. The data will be used to generate the load elasticities, system load factors, and system electric energy-use factors required by COMMEND.

DOE-2 calculates hourly energy use for a year for a building in a specific location. The location's weather file contains average ambient temperature, dew point, wind speed, and solar data for each hour throughout a year. Although we developed the prototypes for two regions, North and South, we used several locations to describe the energy use of the buildings in each region. We specified five locations that correspond to the five climate zone categories used in CBECS. As mentioned previously, offices in the North have climates in the three colder degree day classifications while in the South, they are primarily in the three warmer classifications. The North and the South each share a common classification. The locations we selected to represent the five climate zone categories are listed in the table below. We chose these locations because they are heavily populated areas or have a climate similar to other well populated areas.

Climate Classification	Location	HDD	CDD
CDD<2000; HDD>7000	Minneapolis	8158	585
CDD<2000; 5500<HDD<7000	Chicago	6125	923
CDD<2000; 4000<HDD<5500	Washington DC	5008	940
CDD<2000; HDD<4000	Pasadena	1670	1053
CDD>2000; HDD<4000	Charleston	2148	2077

DOE-2 simulations were completed for the north prototypes using Minneapolis, Chicago, and Washington DC weather data. Simulations were completed for the south prototypes using Charleston, Pasadena, and Washington DC weather data. 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 U.S. and southern U.S. Washington DC was selected because it is the population-weighted national average climate. This selection of climates will enable us to investigate the effect of climate averaging in determining sector energy use. To develop the COMMEND data describing the entire U.S., we weighted the results of the simulations according to the fractional floor area in each climate category. The methods used to average the DOE-2 results are described in detail in the section on data analysis and formatting.

Building Loads

We modeled each of the four north office prototypes and the four south office prototypes in three locations and determined the building cooling and heating loads. The building load is the amount of heating and cooling that must be provided to the building in order for the set point temperatures to be maintained. For the runs, the prototypes are in the basecase conditions described in Table 17. A sample of the DOE-2 simulation input for the older, large office and small office, both in the North, is listed in Appendix C.

The building loads were determined in DOE-2 by specifying the system type as SUM[2] in the system command section of the input file. System SUM does not model any heating or cooling system or plant. It determines the amount of energy required to maintain the set points specified for the space. Since no HVAC system is modeled, the effect fresh ventilation air has on the load is not considered. In accounting for building and system loads, we wanted to include the load from ventilation air with the building shell load and not with the system load. Therefore, we included the outdoor air requirements for the building during occupied hours as an infiltration rate. This strategy allows us to use the system sum command and still have the fresh-air ventilation load included in the building load calculation. The ventilation requirement specified is fifteen cubic feet per minute per person of fresh air. The total flow rate is determined for each prototype from its occupant density, floor area, and ventilation requirement.

To develop load elasticities for COMMEND, we also simulated prototype energy use and determined building loads for conditions differing from the basecase. We developed elasticities based on the change in load affected by changes in window R-value, window shading coefficient, wall R-value, roof R-value, infiltration rate, window/wall ratio, internal gains, and lighting power density. For most of the run parameters, we modeled a low and high value case. The value for the basecase condition falls between the low and high value. **Table 19** presents a set of load values for one building. The loads given are for the older, large office in Washington DC for the basecase and the deviant conditions. Appendix D contains the complete set of twenty-four tables for all the offices analyzed.

HVAC Distribution System Loads and Electrical Energy Use

COMMEND uses system factors to calculate system loads from basecase building loads. The system factor is the ratio of system load to building load. The system load is the load that must be supplied by the heating and cooling plant to the HVAC distribution system. The efficiency of the distribution system is dependent on the system type and its control strategy. Some HVAC equipment are integrated systems and plants. In COMMEND, the energy use of these systems is accounted for as part of the plant efficiency. The systems we analyzed in DOE-2 to develop system load factors for COMMEND are hydronic baseboards, constant volume reheat, multizone, variable air volume with reheat, and fan coils. COMMEND also considers unitary HVAC equipment and heat pump loops. The energy use of unitary systems is determined by the plant efficacy. Heat pump loops are also considered to be a plant. We did simulate the energy requirements of the heat pump loop in DOE-2 but the interpretation of the loads is different than the other systems modeled. **Table 20** presents the system loads - that is the loads supplied by the plant to the system, as reported in DOE-2 for the systems modeled. The data is for the older, large office in Washington DC. The complete set of tables listing system loads are included in Appendix C. In the tables, the heat load is the amount of heat supplied to the system, the cooling load is the amount of cooling supplied to the system. The system electricity use is energy used by ventilation/supply fans and distribution pumps. For the heat pump loop, the loads are the amount of energy that must be supplied to the loop to keep in within its specified operating temperature range. The values are not related to compressor energy consumption, which is accounted for in the plant efficiency. A general description of the

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[2] SUM is a DOE-2 system type. When specificed, the building load is calculated and no HVAC system or plant is simulated. SUM is equivalent to having a heating/cooling distribution system and plant with an efficiency of 100%.

different system types are given in Appendix D and the DOE-2 modeling of each system is discussed in more detail below.

Hydronic System

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 although we were not specifically interested in the cooling load. The hydronic system and the AC units to not include mechanical ventilation although operable windows were modeled. One system factor for heating, equaling the system heat load divided by the basecase building heat load, is defined for the hydronic system. The system heat load determined by DOE-2 and listed in Table 20 is not much greater than the building load since heat is only delivered when needed and the distribution loses are small. Also, part of the energy used by the circulation pump is absorbed by the hot water and contributes towards meeting the load. The auxiliary energy use listed in the table for the hydronic system is the energy used by the circulation pump.

Constant Volume Reheat System

The constant volume reheat system supplies a constant volume of cooled air to the zone terminals. We modeled this system slightly differently for the small and large office. The large office is modeled in DOE-2 with a constant volume reheat system (CVRH). It 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 office system is modeled as a single zone reheat system (SZRH). It conditions the air to meet the requirements of a control zone (usually specified as the zone that needs the most cooling). 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 heat load is low compared to the basecase building load because part of the fan energy, accounted for in the system electrical energy-use column, contributes to the heat load. We simulated both types of reheat systems with and without an economizer. An economizer enables the system to use 100% outdoor air to help reduce the cooling load. The 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. A detailed description of economizers is presented in the economizer technology sheet. For the CVRH system, cooling always occurs so the economizer is always working. As seen in the table, 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. The electrical energy use reported in Table 20 is the energy used by the system supply and exhaust fans.

Multizone System

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 the 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. The system electrical energy use is the energy required by supply and exhaust fans.

Variable Air Volume System with Reheat

Variable air volume systems are some of 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 less reheating, less air flow, and less fan energy use. We modeled this system with and without an economizer. Since less reheating is done with 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. The electrical energy use by the system is the energy required by the supply and exhaust fans.

Fan Coils

We used a four pipe fan coil system (FPFC) 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 systems using air distribution systems. Thus the fan energy consumption for this system is much lower than the consumption for the air distribution systems. Since the piping losses are low, the FPFC system loads are not much higher than the basecase office loads. We determined two system factors for fan coils, one for heating and one for cooling. The electrical energy use by the system is the energy needed to pump the hot and cold water and the energy used by the zone fans.

Heat Pump Loop

The heat pump loop circulates working fluid to heat pump units located in individually controlled zones. The heat pumps provide a fixed quantity of outside air to the zones for ventilation. Each heat pump 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 between a specified temperature range. When the range is exceeded, the excess heat is ejected When the temperature falls below the range, heat is added. We modeled a cooling tower and a gas boiler in DOE-2 to reject and add heat for this system. The heat pump loop system/plant is different from the previous systems described and does not fit the COMMEND input data format as well as the others. Therefore, to account for the energy used by the heat pump loop we defined the COMMEND factors as follows. We considered the heat pump loop to be a plant. The energy used by the compressors, zone fans, cooling tower fans, and distribution pumps are included in the value established for plant efficiency. The system load is defined for heating, as is the system factor. The heating system load is the energy that must be supplied by the boiler to the working fluid. This is the value presented in the system load tables. The system electrical energy use listed in the tables is the energy used by zone fans. The value is not used as input to COMMEND since fan energy use is accounted for in the plant efficiency.

Plant Energy Use

All of the systems described above except for the heat pump loop were modeled with the same plant configuration in DOE-2; namely, a gas boiler, centrifugal chiller, and cooling tower. System factors defined for COMMEND are independent of the type of plant used to generate the energy. COMMEND calculates plant energy use by multiplying the load the plant sees with the integrated part load efficiency for the plant.

Table 19. Office Building Loads (1)

Northern Large Office in Washington DC							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-2	7.41	7.55	-1.76	6.14	5.45
high window R	2.80	-1.04	7.88	7.55	-1.02	6.48	5.45
low window R	1.10	-2.58	7.23	7.55	-2.78	5.86	5.45
high shading coef.	0.90	-1.9	7.7	7.55	-1.55	6.8	5.45
low shading coef.	0.60	-2.2	6.87	7.55	-1.86	5.87	5.45
high wall R	11.00	-1.3	7.63	7.55	-1.49	6.21	5.45
low wall R	0.01	-3.19	7.2	7.55	-2.9	5.95	5.45
high roof R	19.00	-1.94	7.48	7.55	-1.69	6.19	5.45
low roof R	7.00	-2.03	7.39	7.55	-1.8	6.13	5.45
high air changes	0.50	-2.23	6.89	7.55	-2.01	5.62	5.45
low air changes	0.10	-1.8	8.03	7.55	-1.56	6.75	5.45
high window/wall ratio	0.75	-2.69	8.76	7.55	-2.21	6.85	5.45
low window/wall ratio	0.25	-1.7	6.83	7.55	-1.32	5.43	5.45
high internal gains (W/ft2)	1.20	-1.75	8.6	7.55	-1.52	7.33	5.45
low internal gains (W/ft2)	0.50	-2.14	6.77	7.55	-1.91	5.5	5.45
high occupancy (ft2/person)	200.00	-2.21	7.5	7.55	-1.95	6.19	5.45
low lighting power density (W/ft2)	0.70	-2.87	4.43	2.94	-2.21	4.46	2.94

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Table 20. Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

	Northern Large Office in Washington DC					
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)
Hydronic	2.4	0	0.18	2.13	0	0.15
CV Reheat	6.62	16.86	3.58	5.76	14.39	3.08
CV Reheat with economizer	7.94	11.09	3.64	6.88	9.65	3.12
Multizone	4.53	14.29	3.17	4.01	12.19	2.73
Multizone with economizer	7.57	9.81	3.24	6.56	8.51	2.77
VAV with reheat	3.95	12.72	2.33	3.38	10.74	1.99
VAV with reheat and economizer	4.33	8.43	2.22	3.73	7.37	1.9
Fan Coil	2.17	8.31	0.46	1.94	6.97	0.4
Heat Pump Loop	0.41	0	0.2	0.49	0	0.17

(1) HVAC loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

COMPILATION OF PROTOTYPE DATA AND SIMULATION RESULTS IN COMMEND FORMAT

Several prototypes were developed and their energy response was 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 the findings of this report may also be used for regional simulations and/or analysis. This characterization data and simulation results are organized in three dimensional matrices, one for each attribute. The three dimensions are: (1) building type (small and large offices), (2) vintage (buildings built before 1980 are classified as old and buildings built in 1980 or later are classified as new), and (3) climate zone (the five U.S. climate zones used in CBECS are mapped into 6 climate zones where the NBECS Climate Zone 3 is superficially divided between south and north). The reason for dividing the Climate Zone 3 is that in this climate zone it is possible to have buildings with the characteristics of both the south and the north type prototypes. Figure 1 shows this classification. Figure 2 shows the NBECS climate zones referred to in this study.

COMMEND data requirements for shell characterization and efficiency parameters which are based on simulation results can be developed using the data in these three dimensional matrices by averaging them using weights based on the distribution of floor area. The total floor area is also distributed to the three dimensional matrix defined above using CBECS data. For each cell in this matrix, the percentage of area heated and cooled are also determined. These data are presented in Table A.1. Averages for the characterization data and the efficiency data can be developed using these three sets of area-related matrices (total area, percent cooled, percent heated). Some results are averaged using just the distribution of total area as weights, some others are averaged using the distribution of conditioned area as weights. Stock average values required by COMMEND are developed averaging over vintages (old and new) and climate zones. Marginal average values are obtained averaging the values for only the new buildings over the climate zones--this assumes that the characteristics of the buildings to be built will be similar to the buildings built after 1980. For a regional project, regional weights can be developed using the conditional probability approach from the same matrices.

Shell-related saturation data is implicitly considered in the prototype parameters developed using CBECS. Values for roof R-value, wall R-value, window R-value, window shading coefficient, window/wall ratio, air change and occupancy used in the regional prototypes can be averaged using the weights based on the distribution of floor area. The matrices for these characterization data are presented in Table A.2. Basecase heating and cooling loads, and heating and cooling degree days for the weather data used for these simulations are also presented in Table A.2.

Figure 1: Building prototypes and associated weather

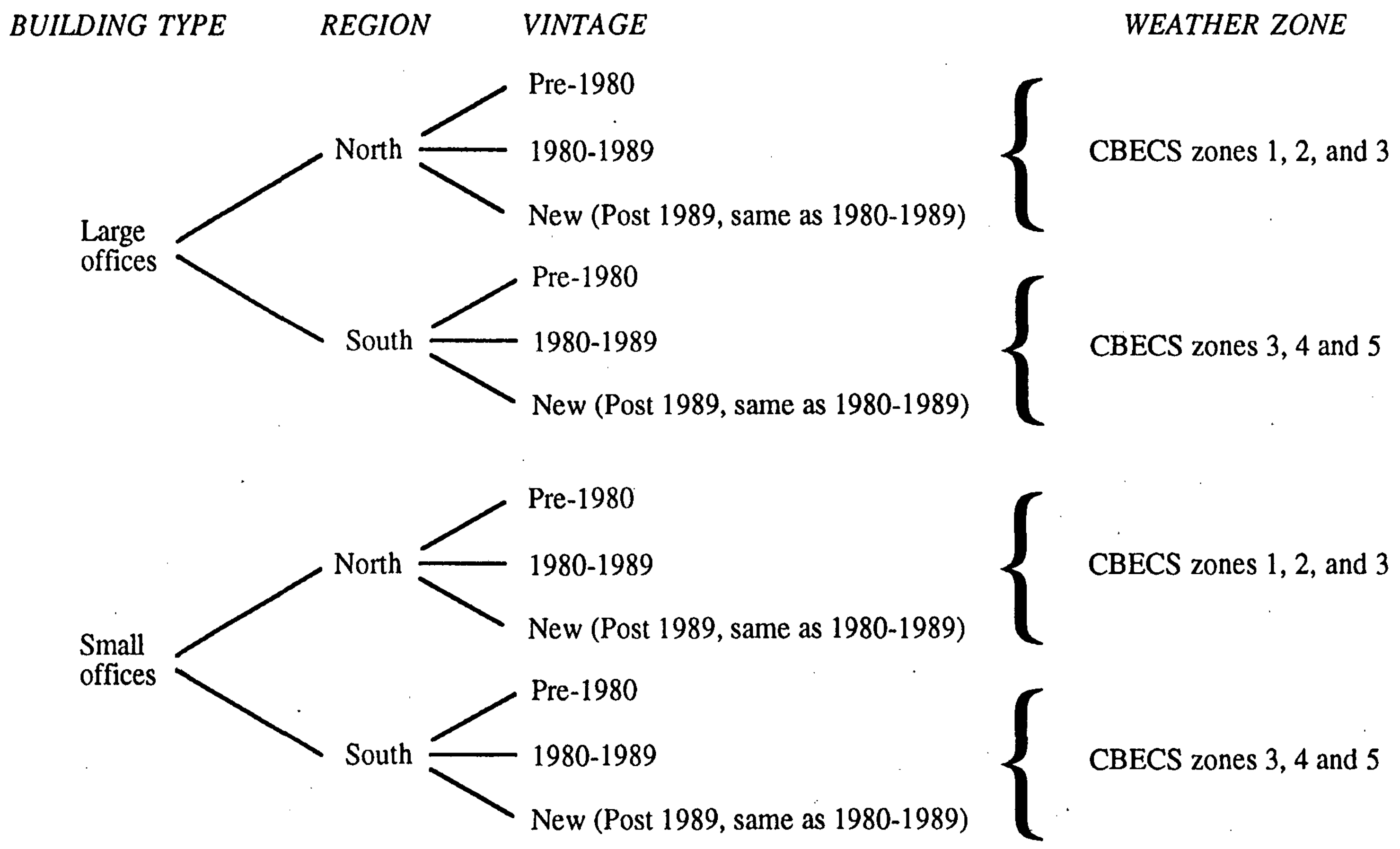
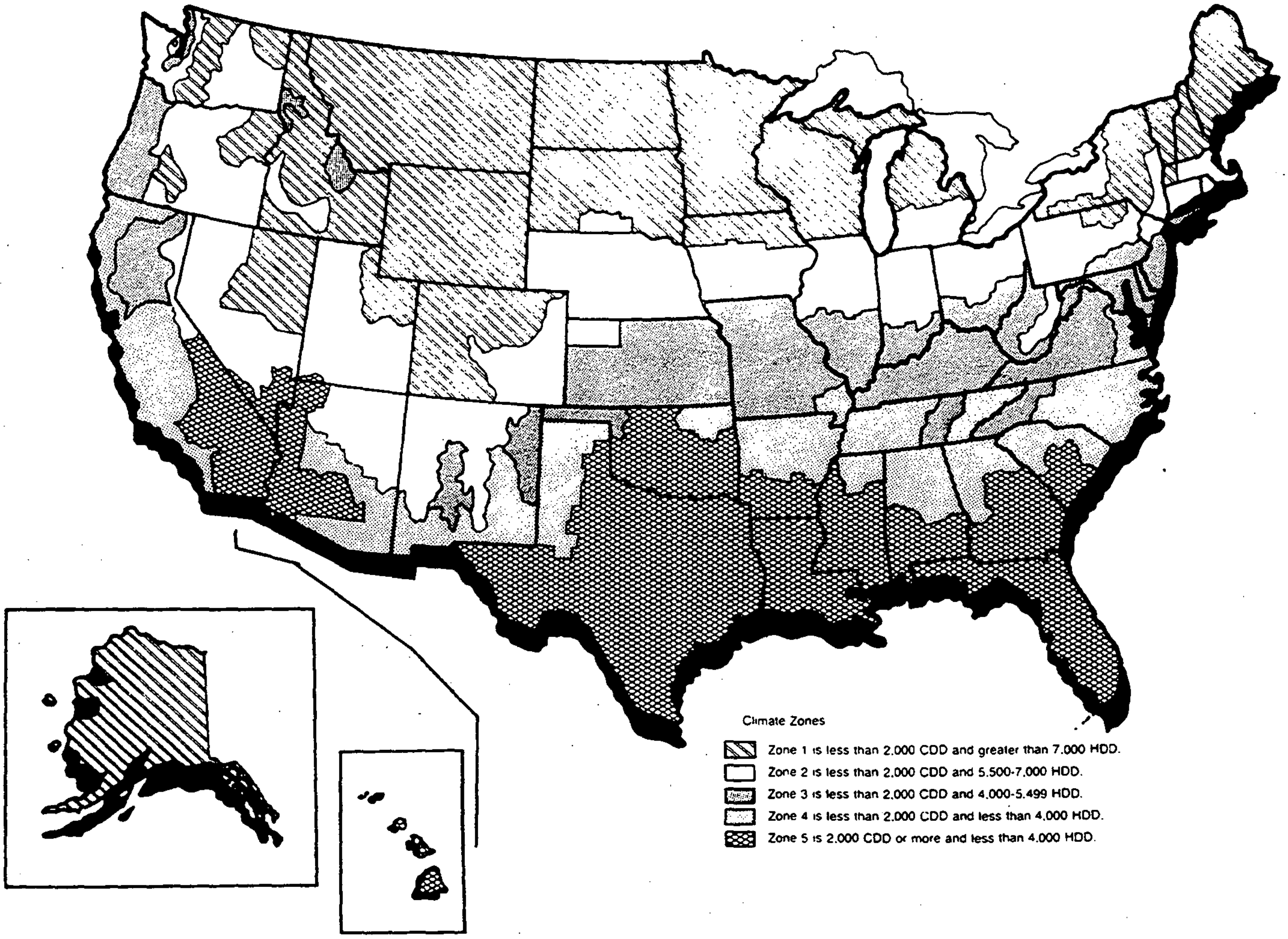


Figure 2. U.S. Climate Zone Map



COMMEND requires inputs on response of building stock to changes in exogenous variables like heating degree days, cooling degree days and occupancy levels in the buildings. Simulations for varying occupancy levels are performed and sensitivity of building loads (heating and cooling) to a variation in occupancy level is shown in Table A.3. The sensitivity of the building loads to a change in weather conditions is developed using the basecase simulations for a fixed building type and vintage, by comparing simulation results for different weather data for the similar prototype class (north or south). In other words, for new small offices, the sensitivity of building loads to weather in the north (Zone 1, Zone 2, and Zone 3-N) is determined using the basecase simulations for new-small office in Zone 1 and Zone 3-N and the associated variation in heating and cooling degree days between Zone 1 and Zone 3-N (or simply Zone 3).

Secondary effects of lighting and equipment energy reduction on building energy use are mainly due to lighting/HVAC interactions. A reduction in lighting level may introduce the need for more heating and/or less cooling. The level of this interaction is very dependent on the climate and the schedules of the building. The level of this interaction is characterized by heating and cooling coincidence factors. The heating coincidence factor for lighting, for example, quantifies the amount of extra heating required annually as a percentage of the annual reduction in energy use due to a reduction in lighting level. The sum of the heating and cooling coincidence factors is less than 100 because generally there are times when buildings are lit and the HVAC equipment is not on. Coincidence factors for building type, vintage and climate zone are developed using the results of parametric runs and are presented in Table A.4. For lighting coincidence factors, it was assumed that all the energy generated by the lighting equipment ends up in the space. The reason the lighting/HVAC interactions are different from the equipment/HVAC interactions is that the schedules for each are different.

Efficiency data for shell improvements are input to COMMEND as heating and cooling slopes. These values correspond to changes in heating and cooling loads to unit changes in the measure value. For example, heating slope for wall R-value is the change in heating load in kWh/ft2 for a change in wall R-value of 1. Such slopes are developed from the parametric simulations performed and the results are presented in Table A.5. There is a heating and a cooling slope associated with each of the shell attributes mentioned in the previous paragraphs.

Efficiency data for HVAC distribution system technology options are developed by simulating the prototypes with the different system options. Table A.6 presents the heating and cooling loads as seen by the plant for different technology options. The ratio between the load seen by the plant and the actual building load gives the system multipliers required by COMMEND. These multipliers together with the annual energy consumption by the system (mainly distribution pumps, fans and associated controls) describe the efficiency of a particular distribution system. Table A.7 presents the energy used by the different distribution systems. Table A.8 gives the sizing requirements for the prototypes used in this study and these numbers correspond to the peak loads for the prototypes when simulated with the appropriate weather data.

HVAC system and HVAC plant are generally separated. HVAC system covers all the distribution pumps which carry cooled water to the building or the coils, all the fans which distribute air, and also fans for ventilation. HVAC plant covers the equipment generating heat or coolth together with all the auxiliaries like cooling towers and the pumps associated with cooling towers. There is a special section in the COMMEND input where the auxiliary electricity use can be defined. We decided not to use this option and embed the auxiliaries into plant efficiencies since we are already dealing with seasonal efficiencies.

There are two types of systems which require special attention: hydronic systems and water loop heat pump systems. Simulations for the hydronic system were done with complementing room AC units. Therefore, in the simulation results in Tables C.13-21 the system energy use includes the fan energy for these AC units. In our analysis in this section we dropped the fan consumption from the system energy use and used only the pump energy. Water loop heat pumps unfortunately do not fit into the data structure defined in COMMEND. If this type of system is treated similarly to the other types, the hydronic system behind the heat pumps should be treated as plant auxiliary. But it is only possible to input electricity consumption for plant auxiliary and in this case we have the boiler which may or may not be using electricity. Simulation results in Tables C.13-21 give the load seen by the boiler, the pump electricity use and the fan electricity use. In our analysis we placed pump electricity to the plant auxiliaries which is not used for any of the other systems. We did not use the fan energy since this function is already built in the heat pump efficiency. The boiler consumption may either be converted to an electricity consumption and placed under plant auxiliary electricity use or the code has to be changed to accommodate gas and oil auxiliaries.

Utilization systems include controls, economizers, and thermal energy storage systems.

Controls cover a wide range of technologies and quite hard to characterize. However, certain types of controls are very commonly used. We have assumed that the majority of the buildings have setup/setback control and all the basecase load simulations are done with prototypes with such controls. The buildings which are not equipped with setup/setback control would typically turn the HVAC equipment off during unoccupied hours. Table A.9 presents simulation results for the cases where no setup/setback control is assumed. As can be seen from these results, the loads are strikingly similar to the basecase where there is setup/setback control. It should be noted, however, that many buildings do not switch equipment off during unoccupied hours, but the level of which they leave equipment on is hard to characterize. It is obvious that the level of savings achieved using setup/setback can also be achieved without them with proper building operation. For our purposes, we are assuming that all buildings are equipped with setup/setback and/or are being operated rationally. Energy Management and Control Systems vary a lot in terms of sophistication, cost and impact. No simulations are done to characterize the savings for EMCS and cost and savings are assumed based on expert judgment.

Simulations are done for all the prototypes with economizers where feasible. The comparison of plant loads with and without economizers give the impact required by COMMEND. The loads seen by plant (by system type) with economizer are presented in Table A.10. COMMEND input data structure defines only the cooling impacts which are generally positive and avoids heating impacts which are generally undesirable.

COMMEND data structure 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.

CONCLUSIONS

This study developed technology-characterization data for space conditioning for small and large office buildings. An ongoing project at LBL is extending this work to cover the other commercial building types. Parallel to the work on HVAC characterization, lighting technologies were also characterized and findings were published [14]. The data from these three projects will make the use of COMMEND 4.0 possible for national level policy analysis and will provide help to utilities involved in DSM-related regional forecasting and analysis.

Detailed technology representation is currently available only for space-conditioning and lighting end uses in COMMEND 4.0. Extension of such representation to other end uses such as office equipment and refrigeration is also in progress.

This project, together with the ongoing project for building types other than offices, is facilitating the creation of a large set of prototypes capable of representing the commercial building stock in the U.S. and answering a wide range of policy questions. This set of commercial sector prototypes can be utilized to generate data that may be required for future versions of COMMEND and/or used for policy analysis independent of COMMEND.

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APPENDICES

Appendix A - COMMEND Data Related to Prototypes and Simulation Results

(See pages 41-45 for details related to Tables A.1 - A.10)

Table A.1. Weights for averaging regional data

Floor Area (million ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5	All Zones
SMALL	Pre - 1980	226.0	575.3	302.4	192.7	680.6	590.7	2567.9
	1980-1989	40.7	218.4	39.6	102.4	362.1	182.5	945.7
	Total	266.7	793.7	342.0	295.2	1042.8	773.2	3513.6
LARGE	Pre - 1980	297.6	1476.8	1112.1	575.0	1515.4	529.0	5506.0
	1980-1989	103.1	641.5	563.0	234.1	965.1	358.0	2864.8
	Total	400.7	2118.4	1675.1	809.1	2480.5	887.0	8370.7

Conditioned Area-Cooling (%)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	80.6	80.6	80.6	85.1	85.1	85.1
	1980-1989	89.4	89.4	89.4	87	87	87
LARGE	Pre - 1980	75	75	75	85.9	85.9	85.9
	1980-1989	93.3	93.3	93.3	87.8	87.8	87.8

Conditioned Area-Heating (%)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	94.6	94.6	94.6	89	89	89
	1980-1989	97.5	97.5	97.5	86.9	86.9	86.9
LARGE	Pre - 1980	96.5	96.5	96.5	92.1	92.1	92.1
	1980-1989	97	97	97	87.9	87.9	87.9

Table A.2. Characterization of buildings and their environment

Roof R-Value

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	11.9	11.9	11.9	10.5	10.5	10.5
	1980-1989	13.3	13.3	13.3	12.6	12.6	12.6
LARGE	Pre - 1980	9.1	9.1	9.1	11.2	11.2	11.2
	1980-1989	9.1	9.1	9.1	12.6	12.6	12.6

Wall R-Value

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	4.9	4.9	4.9	3.9	3.9	3.9
	1980-1989	6.3	6.3	6.3	5.6	5.6	5.6
LARGE	Pre - 1980	2.5	2.5	2.5	2.5	2.5	2.5
	1980-1989	4.6	4.6	4.6	6	6	6

Window R-Value

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	1.76	1.76	1.76	1.34	1.34	1.34
	1980-1989	1.99	1.99	1.99	1.58	1.58	1.58
LARGE	Pre - 1980	1.44	1.44	1.44	1.39	1.39	1.39
	1980-1989	1.71	1.71	1.71	1.67	1.67	1.67

Window Shading Coefficient

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.79	0.79	0.79	0.82	0.82	0.82
	1980-1989	0.71	0.71	0.71	0.75	0.75	0.75
LARGE	Pre - 1980	0.8	0.8	0.8	0.77	0.77	0.77
	1980-1989	0.69	0.69	0.69	0.71	0.71	0.71

Table A.2 continued
Window/Wall Ratio

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.2	0.2	0.2	0.2	0.2	0.2
	1980-1989	0.15	0.15	0.15	0.15	0.15	0.15
LARGE	Pre - 1980	0.4	0.4	0.4	0.4	0.4	0.4
	1980-1989	0.5	0.5	0.5	0.5	0.5	0.5

Air Change

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.4	0.4	0.4	0.4	0.4	0.4
	1980-1989	0.4	0.4	0.4	0.4	0.4	0.4
LARGE	Pre - 1980	0.3	0.3	0.3	0.3	0.3	0.3
	1980-1989	0.3	0.3	0.3	0.3	0.3	0.3

Occupancy (ft2/person)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	420	420	420	420	420	420
	1980-1989	470	470	470	470	470	470
LARGE	Pre - 1980	460	460	460	460	460	460
	1980-1989	390	390	390	390	390	390

Heating Degree Day (65 °F)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	8070	6194	4236	4236	1670	2193
	1980-1989	8070	6194	4236	4236	1670	2193
LARGE	Pre - 1980	8070	6194	4236	4236	1670	2193
	1980-1989	8070	6194	4236	4236	1670	2193

Table A.2 continued
Cooling Degree Day (65 °F)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	750	998	1425	1425	1053	2047
	1980-1989	750	998	1425	1425	1053	2047
LARGE	Pre - 1980	750	998	1425	1425	1053	2047
	1980-1989	750	998	1425	1425	1053	2047

Cooling Load (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	15.81	18.64	22.50	21.30	26.83	28.61
	1980-1989	10.79	13.01	16.11	12.56	13.38	17.34
LARGE	Pre - 1980	19.43	21.85	25.30	24.51	27.31	30.01
	1980-1989	15.60	17.82	20.96	21.27	24.00	26.70

Heating Load (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	29.16	19.43	10.82	13.72	1.16	4.40
	1980-1989	26.39	17.96	10.28	15.64	1.84	5.53
LARGE	Pre - 1980	17.45	11.95	6.83	7.00	0.99	2.46
	1980-1989	15.26	10.45	6.01	6.69	0.89	2.29

Table A.3. Building response to exogenous variables

Cooling Slope for HDD (kBtu/ft2 degree days)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-0.002	-0.002	-0.002	-0.004	-0.004	-0.004
	1980-1989	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002
LARGE	Pre - 1980	-0.002	-0.002	-0.002	-0.003	-0.003	-0.003
	1980-1989	-0.001	-0.001	-0.001	-0.003	-0.003	-0.003

Heating Slope for HDD(kBtu/ft2 degree days)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.005	0.005	0.005	0.005	0.005	0.005
	1980-1989	0.004	0.004	0.004	0.005	0.005	0.005
LARGE	Pre - 1980	0.003	0.003	0.003	0.002	0.002	0.002
	1980-1989	0.002	0.002	0.002	0.002	0.002	0.002

Cooling Slope for CDD (kBtu/ft2 degree days)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.010	0.010	0.010	0.012	0.012	0.012
	1980-1989	0.008	0.008	0.008	0.008	0.008	0.008
LARGE	Pre - 1980	0.009	0.009	0.009	0.009	0.009	0.009
	1980-1989	0.008	0.008	0.008	0.009	0.009	0.009

Heating Slope for CDD (kBtu/ft2 degree days)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-0.027	-0.027	-0.027	-0.015	-0.015	-0.015
	1980-1989	-0.024	-0.024	-0.024	-0.016	-0.016	-0.016
LARGE	Pre - 1980	-0.016	-0.016	-0.016	-0.007	-0.007	-0.007
	1980-1989	-0.014	-0.014	-0.014	-0.007	-0.007	-0.007

Table A.4. Coincidence factors (1)

Cooling Coincidence Factor for Lighting

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.35	0.40	0.45	0.42	0.64	0.58
	1980-1989	0.33	0.38	0.43	0.37	0.53	0.49
LARGE	Pre - 1980	0.57	0.61	0.65	0.64	0.77	0.73
	1980-1989	0.58	0.63	0.67	0.64	0.79	0.74

Heating Coincidence Factor for Lighting

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-0.47	-0.40	-0.33	-0.35	-0.11	-0.18
	1980-1989	-0.48	-0.41	-0.34	-0.37	-0.18	-0.24
LARGE	Pre - 1980	-0.29	-0.24	-0.19	-0.19	-0.08	-0.10
	1980-1989	-0.29	-0.23	-0.18	-0.20	-0.06	-0.10

Cooling Coincidence Factor for Equipment

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.40	0.46	0.51	0.48	0.74	0.66
	1980-1989	0.38	0.43	0.48	0.41	0.63	0.56
LARGE	Pre - 1980	0.64	0.69	0.73	0.73	0.85	0.83
	1980-1989	0.64	0.69	0.73	0.71	0.85	0.82

Heating Coincidence Factor for Equipment

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-0.44	-0.36	-0.28	-0.32	-0.06	-0.13
	1980-1989	-0.46	-0.38	-0.31	-0.36	-0.12	-0.20
LARGE	Pre - 1980	-0.25	-0.20	-0.16	-0.16	-0.05	-0.07
	1980-1989	-0.25	-0.20	-0.16	-0.17	-0.04	-0.07

(1) The difference between the lighting and equipment coincidence factors is mainly due to the difference in schedules.

Table A.5. Shell Efficiency Data

Cooling Slope for Roof R-Value (kBtu/ft2 R)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.03	0.03	0.02	0.01	0.06	0.02
	1980-1989	0.02	0.02	0.01	-0.03	0.04	-0.03
LARGE	Pre - 1980	0.03	0.03	0.03	0.03	0.03	0.02
	1980-1989	0.02	0.02	0.02	0.02	0.03	0.02

Heating Slope for Roof R-Value (kBtu/ft2 R)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-0.26	-0.19	-0.13	-0.13	-0.03	-0.06
	1980-1989	-0.28	-0.20	-0.14	-0.30	-0.08	-0.14
LARGE	Pre - 1980	-0.07	-0.04	-0.03	-0.03	0.00	-0.01
	1980-1989	-0.07	-0.05	-0.03	-0.04	0.00	-0.01

Cooling Slope for Wall R-Value (kBtu/ft2 R)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.32	0.30	0.23	0.18	0.62	0.25
	1980-1989	0.20	0.17	0.11	0.00	0.21	0.01
LARGE	Pre - 1980	0.15	0.16	0.13	0.12	0.30	0.15
	1980-1989	0.10	0.10	0.08	0.09	0.24	0.11

Heating Slope for Wall R-Value (kBtu/ft2 R)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-3.35	-2.47	-1.66	-1.64	-0.39	-0.72
	1980-1989	-3.41	-2.55	-1.74	-1.26	-0.39	-0.60
LARGE	Pre - 1980	-1.15	-0.86	-0.59	-0.57	-0.18	-0.27
	1980-1989	-0.84	-0.64	-0.44	-0.50	-0.17	-0.24

Table A.5 continued

Cooling Slope for Window R-Value (kBtu/ft2 R)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	1.45	1.55	1.45	1.33	3.05	1.69
	1980-1989	0.80	0.86	0.80	0.34	0.98	0.42
LARGE	Pre - 1980	1.33	1.43	1.31	1.23	2.51	1.49
	1980-1989	1.29	1.35	1.25	1.51	3.11	1.85

Heating Slope for Window R-Value (kBtu/ft2 R)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-6.81	-5.10	-3.37	-3.35	-0.58	-1.37
	1980-1989	-4.94	-3.76	-2.55	-1.93	-0.54	-0.88
LARGE	Pre - 1980	-6.06	-4.60	-3.09	-3.01	-0.74	-1.31
	1980-1989	-6.71	-5.16	-3.53	-4.00	-1.08	-1.81

Cooling Slope for Window Shading Coefficient (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	15.02	16.39	17.41	15.82	28.45	20.48
	1980-1989	10.13	11.04	11.72	6.83	12.18	8.88
LARGE	Pre - 1980	7.85	8.42	9.45	9.22	13.43	11.84
	1980-1989	8.88	9.67	10.58	12.40	18.21	15.82

Heating Slope for Window Shading Coefficient (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-10.70	-8.88	-6.37	-7.06	-2.39	-3.76
	1980-1989	-7.97	-6.60	-4.89	-4.21	-2.28	-2.73
LARGE	Pre - 1980	-5.12	-4.10	-3.41	-3.30	-1.48	-1.82
	1980-1989	-5.23	-4.21	-3.53	-3.98	-1.59	-2.28

Table A.5 continued

Cooling Slope for Window/Wall Ratio (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	48.31	52.75	56.33	51.55	83.30	66.40
	1980-1989	39.47	43.02	46.02	29.22	48.21	38.51
LARGE	Pre - 1980	10.17	11.20	13.18	12.02	14.27	15.70
	1980-1989	7.44	8.19	9.70	11.54	13.18	15.09

Heating Slope for Window/Wall Ratio (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	12.97	6.49	2.90	7.85	-0.17	1.37
	1980-1989	10.79	5.05	2.05	2.87	-1.91	-1.23
LARGE	Pre - 1980	15.50	11.20	6.76	7.17	1.57	2.73
	1980-1989	13.45	9.76	6.08	7.85	1.78	3.07

Cooling Slope for Air Change (Infiltration) (kBtu/ft2 Air Change per Hour)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	-3.28	-3.55	-3.55	-2.94	-6.83	-4.23
	1980-1989	-2.73	-3.00	-2.87	-1.78	-4.64	-2.59
LARGE	Pre - 1980	-11.95	-11.01	-9.73	-9.64	-9.82	-8.54
	1980-1989	-11.44	-10.92	-9.64	-8.88	-10.16	-8.02

Heating Slope for Air Change (Infiltration) (kBtu/ft2 Air Change per Hour)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	15.16	11.13	7.31	7.58	1.71	3.41
	1980-1989	16.32	12.15	8.26	9.49	2.73	4.57
LARGE	Pre - 1980	8.62	5.97	3.67	3.76	0.94	1.62
	1980-1989	9.30	6.23	3.84	4.27	0.94	1.79

Table A.5 continued
Cooling Slope for Occupancy (kBtu/ft2 person/1000 ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.14	0.20	0.26	0.27	0.27	0.42
	1980-1989	0.17	0.21	0.29	0.29	0.31	0.43
LARGE	Pre - 1980	-0.23	-0.08	0.11	0.11	0.24	0.45
	1980-1989	-0.20	-0.10	0.07	0.08	0.22	0.41

Heating Slope for Occupancy (kBtu/ft2 person/1000 ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.82	0.55	0.36	0.38	0.07	0.14
	1980-1989	0.82	0.53	0.36	0.32	0.08	0.12
LARGE	Pre - 1980	0.64	0.43	0.25	0.27	0.05	0.11
	1980-1989	0.70	0.46	0.27	0.29	0.06	0.11

Table A.6. System load multiplier data

The plant loads presented in this table are divided by the building loads given in TableA.2 to obtain the system multipliers. For the water-loop heat pumps, plant loads and building loads are assumed to be identical--therefore, the system multiplier for this system type is 1.

Plant Heating Load-with Hydronic System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	33.56	23.08	13.76	16.76	1.88	5.80
	1980-1989	31.34	22.05	13.52	19.84	2.94	7.34
LARGE	Pre - 1980	19.77	13.83	8.19	8.47	1.40	3.18
	1980-1989	17.45	12.22	7.27	8.16	1.26	2.97

Plant Heating Load-with Ducted-CV System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	25.67	16.87	9.15	11.85	0.92	3.48
	1980-1989	25.16	17.21	9.70	14.78	1.30	4.81
LARGE	Pre - 1980	36.05	30.79	22.60	22.63	12.73	14.20
	1980-1989	31.24	26.63	19.66	22.33	12.43	14.13

Plant Heating Load-with Multizone System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	41.17	33.35	24.21	27.76	14.75	16.35
	1980-1989	34.69	27.86	20.21	24.00	10.79	13.21
LARGE	Pre - 1980	25.50	21.34	15.47	15.53	7.68	9.53
	1980-1989	22.63	18.78	13.69	15.60	7.68	9.63

Plant Heating Load-with Ducted-VAV System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	47.80	33.35	19.97	25.02	3.35	10.00
	1980-1989	42.30	29.94	18.30	24.92	4.68	11.03
LARGE	Pre - 1980	30.79	22.05	13.49	13.66	2.73	5.84
	1980-1989	26.39	18.85	11.54	12.80	2.46	5.36

Table A.6 continued
Plant Heating Load-with Fan Coil System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	30.25	20.62	11.91	15.06	1.40	4.98
	1980-1989	28.03	19.53	11.68	17.51	2.18	6.28
LARGE	Pre - 1980	18.30	12.73	7.41	7.65	1.16	2.77
	1980-1989	16.39	11.37	6.62	7.48	1.06	2.59

Plant Cooling Load-with Ducted-CV System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	21.82	26.12	31.10	29.43	39.19	40.42
	1980-1989	14.78	18.09	22.23	17.62	20.38	24.61
LARGE	Pre - 1980	53.29	56.91	57.56	56.23	55.82	60.70
	1980-1989	44.55	47.90	49.13	52.37	51.93	57.25

Plant Cooling Load-with Multizone System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	45.82	50.70	53.57	53.77	63.16	62.72
	1980-1989	31.65	35.68	38.95	32.60	36.19	39.12
LARGE	Pre - 1980	41.17	45.65	48.79	47.56	47.80	54.04
	1980-1989	34.52	38.44	41.62	43.94	44.01	50.56

Plant Cooling Load-with Ducted-VAV System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	48.51	45.51	44.01	45.51	40.32	49.20
	1980-1989	37.72	34.75	33.63	31.00	24.65	33.70
LARGE	Pre - 1980	45.00	43.43	43.43	42.30	38.75	46.60
	1980-1989	37.01	36.02	36.67	37.96	34.89	42.78

Table A.6 continued
Plant Cooling Load-with Fan Coil System (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	16.97	20.11	24.51	23.22	28.40	31.65
	1980-1989	11.64	14.13	17.82	13.86	14.20	19.49
LARGE	Pre - 1980	21.24	24.07	28.37	27.45	29.02	34.14
	1980-1989	17.17	19.77	23.80	24.10	25.54	30.79

Table A.7. System energy use data

System Energy Use- Hydronic System (kWh/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.15	0.11	0.07	0.08	0.01	0.04
	1980-1989	0.14	0.11	0.07	0.08	0.01	0.04
LARGE	Pre - 1980	0.11	0.08	0.05	0.05	0.01	0.02
	1980-1989	0.11	0.07	0.04	0.05	0.01	0.02

System Energy Use- Ducted-CV System (kWh/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	3.62	3.58	3.37	3.49	3.73	3.54
	1980-1989	2.63	2.62	2.49	2.26	2.32	2.21
LARGE	Pre - 1980	3.82	3.84	3.58	3.51	3.42	3.50
	1980-1989	3.25	3.27	3.08	3.32	3.26	3.32

System Energy Use- Multizone System (kWh/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	4.24	4.16	3.84	4.00	4.14	3.98
	1980-1989	3.09	3.04	2.85	2.60	2.59	2.51
LARGE	Pre - 1980	3.33	3.35	3.17	3.12	3.01	3.10
	1980-1989	2.84	2.85	2.73	2.94	2.84	2.93

System Energy Use- Ducted-VAV System (kWh/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	3.28	2.88	2.61	2.72	2.50	2.67
	1980-1989	2.67	2.23	1.99	1.86	1.55	1.80
LARGE	Pre - 1980	2.91	2.54	2.33	2.28	2.07	2.28
	1980-1989	2.44	2.15	1.99	2.09	1.96	2.12

Table A.7 continued
System Energy Use- Fan Coil System (kWh/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.46	0.46	0.44	0.45	0.48	0.48
	1980-1989	0.34	0.34	0.33	0.28	0.28	0.28
LARGE	Pre - 1980	0.48	0.49	0.46	0.45	0.41	0.44
	1980-1989	0.41	0.42	0.40	0.43	0.40	0.43

System Auxiliary Energy Use- Water Loop HP System (kWh/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	0.04	0.03	0.02	0.03	0.00	0.01
	1980-1989	0.03	0.21	0.02	0.02	0.00	0.01
LARGE	Pre - 1980	0.02	0.01	0.01	0.01	0.00	0.00
	1980-1989	0.02	0.01	0.01	0.01	0.00	0.00

Table A.8. System sizing requirements

Heating Equipment Sizing Requirement (Btu/h ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	25.86	21.12	15.78	18.03	9.67	14.67
	1980-1989	21.42	17.36	12.99	13.55	7.69	11.11
LARGE	Pre - 1980	16.32	12.21	9.09	8.96	4.2	6.91
	1980-1989	14.21	10.92	7.63	8.41	4	6.6

Cooling Equipment Sizing Requirement (Btu/h ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	20.78	21.54	20.5	21.24	22.02	21.33
	1980-1989	15.31	15.93	15.24	14.01	14.37	13.48
LARGE	Pre - 1980	14.55	15.46	14.9	14.6	14.21	14.56
	1980-1989	12.62	13.4	12.93	13.8	13.43	13.74

Heating Equipment Sizing Requirements (ft2/kBtu/h) (1)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	38.67	47.35	63.37	55.46	103.41	68.17
	1980-1989	46.69	57.60	76.98	73.80	130.04	90.01
LARGE	Pre - 1980	61.27	81.90	110.01	111.61	238.10	144.72
	1980-1989	70.37	91.58	131.06	118.91	250.00	151.52

Cooling Equipment Sizing Requirements (ft2/ton) (1)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	577.48	557.10	585.37	564.97	544.96	562.59
	1980-1989	783.80	753.30	787.40	856.53	835.07	890.21
LARGE	Pre - 1980	824.74	776.20	805.37	821.92	844.48	824.18
	1980-1989	950.87	895.52	928.07	869.57	893.52	873.36

(1) In units commonly used by designers.

Table A.9. Effect of controls on loads

Cooling Load with no Setup/Setback Controls (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	15.81	18.64	22.50	21.30	26.83	28.61
	1980-1989	10.79	13.01	16.11	12.56	13.38	17.34
LARGE	Pre - 1980	19.43	21.82	25.26	24.48	27.28	29.97
	1980-1989	15.60	17.82	20.93	21.24	23.97	26.66

Heating Load with no Setup/Setback Controls (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	26.08	18.16	10.58	13.31	1.16	4.37
	1980-1989	23.69	16.73	10.07	14.92	1.84	5.50
LARGE	Pre - 1980	16.05	11.30	6.69	6.83	0.99	2.46
	1980-1989	14.07	9.90	5.91	6.55	0.89	2.29

Table A.10. Effect of economizers on loads

Plant Cooling Load-with Ducted-CV System and Economizer (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	15.74	19.19	26.05	24.82	24.44	35.40
	1980-1989	11.44	14.13	19.63	16.28	14.10	23.76
LARGE	Pre - 1980	25.40	29.39	37.86	36.94	39.33	54.79
	1980-1989	21.95	25.30	32.95	35.16	37.32	52.20

Plant Cooling Load-with Multizone System and Economizer (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	26.77	30.86	39.06	39.64	47.42	57.46
	1980-1989	19.73	22.81	29.43	26.15	27.76	36.97
LARGE	Pre - 1980	21.92	25.64	33.49	32.74	32.47	48.07
	1980-1989	18.88	22.12	29.05	30.90	30.45	45.44

Plant Cooling Load-with Ducted-VAV System and Economizer (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	23.18	25.78	31.55	31.78	34.24	43.80
	1980-1989	18.16	19.70	24.10	21.54	20.83	30.08
LARGE	Pre - 1980	19.05	22.53	28.78	27.96	30.69	40.46
	1980-1989	16.59	19.60	25.16	26.39	28.78	38.20

Table A.10 continued (1)

Plant Heating Load-with Ducted-CV System and Economizer (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	25.64	16.83	9.12	11.81	0.92	3.45
	1980-1989	25.09	17.14	9.63	14.71	1.30	4.78
LARGE	Pre - 1980	41.92	36.43	27.11	27.07	16.08	16.69
	1980-1989	36.12	31.31	23.49	26.63	15.77	16.63

Plant Heating Load-with Multizone System and Economizer (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	63.77	53.12	39.19	44.01	23.11	24.75
	1980-1989	51.38	42.74	31.68	36.15	17.07	19.22
LARGE	Pre - 1980	40.32	34.82	25.84	25.78	13.83	15.16
	1980-1989	34.72	29.91	22.40	25.37	13.52	15.02

Plant Heating Load-with Ducted-VAV System and Economizer (kBtu/ft2)

Bldg. Type	Vintage	Zone 1	Zone2	Zone3-N	Zone3-S	Zone 4	Zone5
SMALL	Pre - 1980	51.76	35.85	21.34	26.70	3.65	10.69
	1980-1989	45.78	32.06	19.43	26.15	5.02	11.57
LARGE	Pre - 1980	25.37	20.89	14.78	14.82	6.11	7.72
	1980-1989	21.78	17.86	12.73	14.44	5.84	7.51

(1) Plant heating loads are also affected by economizers, but this
effect of economizers can not be included in COMMEND 4.0 in its present form.

Appendix B - Office Building Data

Tables B.1a-1e

CBECS Office Building Data for the Entire U.S., the North, the Mid-West , the South and the West

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Table 1a
OFFICE BUILDING CHARACTERISTICS FOR THE U.S.
SMALL <= 25,000 FT2; LARGE > 25,000 FT2

                               PRE 1980            1980 AND AFTER      ALL
                                  SMALL     LARGE     SMALL     LARGE     SMALL     LARGE
DESCRIPTION        UNITS

CBECS 89 OFFICE SURVEY DATA
NUMBER             SUM            397.0     389.0     137.0     205.0     534.0     594.0
CBECS 89 OFFICE FLOOR AREA DATA
FT2                SUM         2.5684E9  5.5106E9  9.4552E8  2.8639E9  3.5139E9  8.3745E9
%VACANT            MEAN             3.6       0.1       6.0       4.2       4.5       1.1
%HEATED            MEAN            91.2      94.2      89.6      90.5      90.8      93.0
%COOLED            MEAN            83.3      80.8      87.6      89.4      84.4      83.6
                   MEAN          5679.5   99536.5    6567.1  104241.6    5893.9  101097.0
FT2                MIN           1001.0   25001.0    1001.0   25001.0    1001.0   25001.0
                   MAX          25000.0   1500000   25000.0   1500000   25000.0   1500000
                   MEAN             1.7      48.9       1.4      37.4       1.7      45.1
#FLOORS            MIN              1.0       1.0       1.0       1.0       1.0       1.0
                   MAX              9.0     995.0       5.0     995.0       9.0     995.0
CBECS 89 OFFICE EUI DATA
FT2                SUM          2.568E9   5.511E9   9.455E8   2.864E9   3.514E9   8.375E9
ELECBTU            SUM          1.45E11   3.54E11   6.91E10   2.13E11   2.14E11   5.68E11
ELECFT2            PCTSUM         100.0      99.7     100.0     100.0     100.0      99.8
ELECEUI            MEAN            55.2      55.7      85.5      87.6      62.5      66.3
GASBTU             SUM          9.23E10   9.83E10   1.41E10   3.33E10   1.06E11   1.32E11
GASFT2             PCTSUM          59.3      62.7      34.4      68.8      52.6      64.8
GASEUI             MEAN            67.2      40.3      45.0      34.9      63.7      38.6
OILBTU             SUM          1.87E10   2.12E10    2.21E9   1.085E9   2.09E10   2.23E10
OILFT2             PCTSUM           7.2      24.0       6.1      21.0       6.9      22.9
OILEUI             MEAN            99.2      27.7      60.2       1.5      92.8      23.3
CBECS 89 FLOOR AREA WEIGHTED OFFICE HEATING FUELS
HEAT_TOTAL         PCTSUM           100       100       100       100       100       100
HEAT_NORMLZD       PCTSUM           100       100       100       100       100       100
NOHEAT             PCTSUM             1         1         1         1         1         1
ELHEAT             PCTSUM            33        18        65        53        42        30
NGHEAT             PCTSUM            52        44        30        28        46        38
OHEAT              PCTSUM             7         9         3         2         6         6
DSHEAT             PCTSUM             6        29         1        16         4        24
HWHEAT             PCTSUM             0         1         0         0         0         1
CBECS 89 FLOOR AREA WEIGHTED OFFICE COOLING FUELS
COOL_TOTAL         PCTSUM           100        92       100        99       100        94
COOL_NORMLZD       PCTSUM           100       100       100       100       100       100
NOCOOL             PCTSUM             5         1         0         0         4         0
ELCOOL             PCTSUM            91        91        97        98        93        94
NGCOOL             PCTSUM             4         2         3         1         4         2
OCOOL              PCTSUM             0         0         0         0         0         0
DSCOOL             PCTSUM             0         5         0         0         0         3
HWCOOL             PCTSUM             0         0         0         0         0         0
CBECS 1989 FLOOR AREA WEIGHTED OFFICE WATER HEATING FUELS
WATER_TOTAL        PCTSUM            99       103        99       101        99       102
WATER_NORMLZD      PCTSUM           100       100       100       100       100       100
NOWATR             PCTSUM            10         3         5         5         9         4
ELWATR             PCTSUM            46        40        73        51        53        43
NGWATR             PCTSUM            37        38        20        30        32        35
OWATR              PCTSUM             5         3         1         0         4         2
DSWATR             PCTSUM             2        15         0        15         1        15
HWWATR             PCTSUM             1         1         0         0         0         1
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEATING EQUIP
EQP_TOTAL          PCTSUM           129       125       141       110       132       120
EQP_NORMLZD        PCTSUM           100       100       100       100       100       100
BOILER             PCTSUM            17        37         8        24        15        33
FURN               PCTSUM            29         8        20         7        26         8
RESIST             PCTSUM            20        27        18        27        19        27
PKGHT              PCTSUM            22        16        29        22        24        18
HTPMPH             PCTSUM            11        12        25        21        15        14
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEAT DISTRIBUTION
EQP_TOTAL          PCTSUM            81       154        89       134        83       148
EQP_NORMLZD        PCTSUM           100       100       100       100       100       100
DUCTH              PCTSUM            66        13        78        23        69        16
REHEAT             PCTSUM            13        37        12        43        12        39
FCOILH             PCTSUM             4        21         5        18         4        20
BBDRAD             PCTSUM            17        29         6        16        14        25
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING EQUIPMENT
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EQP_TOTAL          PCTSUM           113       173       112       153       113       166
EQP_NORMLZD        PCTSUM           100       100       100       100       100       100
CHILLER            PCTSUM             8        37         7        37         8        37
ACWNWL             PCTSUM            21        19         3         5        16        15
PKGCL              PCTSUM            59        36        58        45        59        39
HTPMPC             PCTSUM            12         8        32        13        18        10
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING DISTRIBUTION SYSTEMS
EQP_TOTAL          PCTSUM            63       119        82       139        68       126
EQP_NORMLZD        PCTSUM           100       100       100       100       100       100
DUCTCL             PCTSUM            95        64        93        64        95        64
FCOILC             PCTSUM             5        36         7        36         5        36
CBECS 89 FLOOR AREA WEIGHTED OFFICE WINDOW CHARACTERISTICS
STORMS             PCTSUM          41.7      41.3      64.1      60.4      47.7      47.9
TINTREFL           PCTSUM          28.2      52.2      64.6      87.2      38.0      64.2
SHADINGS           PCTSUM          41.4      64.7      52.0      60.2      44.3      63.1
CBECS 89 FLOOR AREA WEIGHTED OFFICE INSULATION DATA
WALLINS            PCTSUM          60.6      34.3      81.1      76.8      66.1      48.8
ROOFINS            PCTSUM          79.8      74.0      91.8      80.7      83.0      76.3
CBECS 89 FLOOR AREA WEIGHTED OFFICE WALL CONSTRUCTION MATERIALS
WALLS_TOTAL        PCTSUM          98.3      85.9      92.6      96.3      96.8      89.5
WALLS_NORMLZD      PCTSUM         100.0     100.0     100.0     100.0     100.0     100.0
WINDOW_GLASS       PCTSUM           0.6      13.2       3.4      27.3       1.3      18.4
DECOR_GLASS        PCTSUM           0.3       0.5       1.6       2.0       0.6       1.0
CONCRETE_PANEL     PCTSUM           4.8      16.2       8.3      23.9       5.7      19.1
MASONRY            PCTSUM          74.7      64.4      61.8      41.0      71.4      55.8
SIDING/SHINGLE     PCTSUM          16.0       0.9      15.6       0.3      15.9       0.7
METAL_PANEL        PCTSUM           3.7       4.8       9.4       5.6       5.1       5.1
OTHER              PCTSUM           0.0       0.0       0.0       0.0       0.0       0.0
CBECS 89 FLOOR AREA WEIGHTED OFFICE ROOF CONSTRUCTION MATERIALS
ROOFS_TOTAL        PCTSUM          99.7      99.2     100.0      98.1      99.8      98.9
ROOFS_NORMLZD      PCTSUM         100.0     100.0     100.0     100.0     100.0     100.0
WOOD               PCTSUM           1.3       0.0       1.0       0.0       1.3       0.0
SLATE&TILE         PCTSUM           3.7       2.3       7.7       0.6       4.7       1.8
SHINGLE/SIDING     PCTSUM          29.4      13.7      28.7       0.0      29.2       9.6
BUILT_UP           PCTSUM          55.6      42.0      33.6      70.3      50.0      50.5
METAL_SURFCNG      PCTSUM           4.1       0.6      22.1       9.8       8.6       3.4
SYNTH_SHEETNG      PCTSUM           4.0      39.6       6.6       9.7       4.7      30.6
CONCRETE           PCTSUM           1.9       1.7       0.4       9.5       1.5       4.1
OTHER              PCTSUM           0.0       0.0       0.0       0.0       0.0       0.0
CBECS 89 FLOORSPACE LIT BY LIGHTING EQUIPMENT
INCAND             MEAN            11.8      36.4       9.4       8.7      11.2      26.9
FLUOR              MEAN            90.0      89.3      91.6      91.4      90.5      90.0
HID                MEAN             0.9      10.2       2.1      17.3       1.3      12.6
OTHER              MEAN             0.0       0.0       0.0       0.0       0.0       0.0
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS
VAV                PCTSUM          18.4      43.4      25.9      65.2      19.8      49.9
HTRCVRY            PCTSUM           2.3      23.6       7.9      22.4       3.4      23.2
TCLOCK             PCTSUM           3.2       4.3       2.4       4.5       3.0       4.4
ECNMZR             PCTSUM           0.3       8.1       4.3       6.1       1.0       7.5
LDMNGMT            PCTSUM           1.1       5.1       0.9       1.7       1.0       4.0
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS
%GLASS             MEAN            18.0      40.5      17.0      50.9      17.8      43.6
CBECS 89 OFFICE OCCUPANCY DATA
MFhrs              MEAN            10.8      11.9      10.0      12.1      10.6      12.0
SAThrs             MEAN             5.3       6.3       3.5       6.8       4.8       6.5
SUNhrs             MEAN             4.5       4.4       2.5       4.7       4.0       4.5
WEEKhrs            MEAN            63.1      69.9      56.3      71.8      61.2      70.6
CBECS 89 OFFICE OCCUPANCY DATA
#workers           SUM          6058870  12248123   1995853   7474933   8054723  19723056
#workers           MEAN            13.4     221.2      13.9     272.1      13.5     238.1
FT2/worker         MEAN           704.3    1169.5     646.0     664.3     690.2    1002.0
CBECS 89 OFFICE CLIMATE DATA
<2000/>7000        PCTSUM           8.8       5.4       4.3       3.6       7.5       4.8
<2000/55007000     PCTSUM          22.4      26.8      23.1      22.4      22.6      25.3
<2000/40005499     PCTSUM          19.3      30.6      15.0      27.9      18.1      29.7
<2000/<4000        PCTSUM          26.5      27.5      38.3      33.7      29.7      29.6
>2000/<4000        PCTSUM          23.0       9.6      19.3      12.5      22.0      10.6
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Table 1b
OFFICE BUILDING CHARACTERISTICS FOR THE NORTHEAST
SMALL <= 25,000 FT2; LARGE > 25,000 FT2

		PRE 1980		1980 AND AFTER	
DESCRIPTION	UNITS	SMALL	LARGE	SMALL	LARGE
CBECS 89 OFFICE SURVEY DATA					
NUMBER	SUM	61.0	116.0	24.0	41.0
CBECS 89 OFFICE FLOOR AREA DATA					
FT2	SUM	4.1968E8	1.4795E9	1.4394E8	6.7389E8
%VACANT	MEAN	1.7	0.1	0.0	0.0
%HEATED	MEAN	92.0	96.8	96.3	99.8
%COOLED	MEAN	75.0	78.2	88.5	96.3
	MEAN	6297.7	110918.7	5904.2	184753.0
FT2	MIN	1001.0	25001.0	1001.0	25001.0
	MAX	25000.0	1500000	25000.0	1500000
	MEAN	2.5	57.0	1.8	106.7
#FLOORS	MIN	1.0	1.0	1.0	1.0
	MAX	5.0	995.0	3.0	995.0
CBECS 89 OFFICE EUI DATA					
FT2	SUM	4.197E8	1.48E9	1.439E8	6.739E8
ELECBTU	SUM	1.69E10	8.41E10	8.7E9	4.05E10
ELECFT2	PCTSUM	100.0	99.1	100.0	100.0
ELECEUI	MEAN	45.0	37.6	176.7	112.3
GASBTU	SUM	1.36E10	1.66E10	1.969E9	3.494E9
GASFT2	PCTSUM	54.7	53.6	50.7	85.8
GASEUI	MEAN	74.9	25.0	35.9	29.3
OILBTU	SUM	9.925E9	1.56E10	1.835E9	7.217E8
OILFT2	PCTSUM	29.3	44.7	14.4	11.1
OILEUI	MEAN	97.8	34.1	81.7	8.7
CBECS 89 FLOOR AREA WEIGHTED OFFICE HEATING FUELS					
HEAT_TOTAL	PCTSUM	100	96	98	97
HEAT_NORMLZD	PCTSUM	100	100	100	100
NOHEAT	PCTSUM	0	0	0	0
ELHEAT	PCTSUM	10	10	30	17
NGHEAT	PCTSUM	49	24	48	19
OHEAT	PCTSUM	29	31	21	1
DSHEAT	PCTSUM	11	34	0	63
HWHEAT	PCTSUM	0	0	0	0
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEATING EQUIP					
EQP_TOTAL	PCTSUM	121	134	144	71
EQP_TOTAL	PCTSUM	100	100	100	100
BOILER	PCTSUM	38	37	14	37
FURN	PCTSUM	24	6	40	8
RESIST	PCTSUM	13	25	20	25
PKGHT	PCTSUM	12	11	6	8
HTPMPH	PCTSUM	13	20	19	22
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEAT DISTRIBUTION					
EQP_TOTAL	PCTSUM	70	180	86	189
EQP_NORMLZD	PCTSUM	100	100	100	100
DUCTH	PCTSUM	38	4	66	6
REHEAT	PCTSUM	6	33	7	43
FCOILH	PCTSUM	1	24	8	11
BBDRAD	PCTSUM	55	40	19	41
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING EQUIPMENT					
EQP_TOTAL	PCTSUM	112	211	110	186
EQP_NORMLZD	PCTSUM	100	100	100	100
CHILLER	PCTSUM	4	34	8	44
ACWNWL	PCTSUM	38	25	2	5
PKGCL	PCTSUM	48	30	64	44
HTPMPC	PCTSUM	10	12	27	8
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING DISTRIBUTION SYSTEMS					
EQP_TOTAL	PCTSUM	39	121	78	166
EQP_NORMLZD	PCTSUM	100	100	100	100
DUCTCL	PCTSUM	100	57	100	56
FCOILC	PCTSUM	0	43	0	44
CBECS 89 FLOOR AREA WEIGHTED OFFICE WINDOW CHARACTERISTICS					
STORMS	PCTSUM	68.3	52.5	98.3	43.1
TINTREFL	PCTSUM	4.7	47.8	43.4	93.6
SHADINGS	PCTSUM	38.9	66.2	79.3	87.4
CBECS 89 FLOOR AREA WEIGHTED OFFICE INSULATION DATA					
WALLINS	PCTSUM	66.0	42.9	89.8	45.9
ROOFINS	PCTSUM	82.3	63.1	93.9	44.8
CBECS 89 FLOOR AREA WEIGHTED OFFICE WALL CONSTRUCTION MATERIALS					
WALLS_TOTAL	PCTSUM	100.0	90.4	77.3	100.0
WALLS_NORMLZD	PCTSUM	100.0	100.0	100.0	100.0
WINDOW_GLASS	PCTSUM	0.0	5.7	0.0	64.0
DECOR_GLASS	PCTSUM	0.0	0.8	0.0	1.6
CONCRETE_PANEL	PCTSUM	2.0	3.2	0.0	1.1
MASONRY	PCTSUM	78.3	86.2	69.8	27.7
SIDING/SHINGLE	PCTSUM	17.6	1.9	30.2	0.0
METAL_PANEL	PCTSUM	2.1	2.0	0.0	5.5
OTHER	PCTSUM	0.0	0.0	0.0	0.0
CBECS 89 FLOOR AREA WEIGHTED OFFICE ROOF CONSTRUCTION MATERIALS					
ROOFS_TOTAL	PCTSUM	100.0	95.1	100.0	100.0
ROOFS_NORMLZD	PCTSUM	100.0	100.0	100.0	100.0
WOOD	PCTSUM	1.2	0.0	0.0	0.0
SLATE&TILE	PCTSUM	5.1	8.5	0.0	0.0
SHINGLE/SIDING	PCTSUM	41.4	47.6	49.0	0.0
BUILT_UP	PCTSUM	45.5	31.5	9.0	9.4
METAL_SURFCNG	PCTSUM	5.5	0.0	35.4	1.3
SYNTH_SHEETNG	PCTSUM	1.3	12.3	6.6	23.3
CONCRETE	PCTSUM	0.0	0.0	0.0	66.0
OTHER	PCTSUM	0.0	0.0	0.0	0.0
CBECS 89 FLOORSPACE LIT BY LIGHTING EQUIPMENT					
INCAND	MEAN	14.2	37.9	17.8	3.8
FLUOR	MEAN	85.9	88.4	82.1	95.1
HID	MEAN	0.8	11.0	0.0	18.3
OTHER	MEAN	0.0	0.2	0.0	0.0
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS					
VAV	PCTSUM	10.0	37.6	20.3	79.7
HTRCVRY	PCTSUM	4.1	30.6	16.2	33.0
TCLOCK	PCTSUM	2.7	2.0	0.0	14.8
ECNMZR	PCTSUM	0.0	4.8	4.1	6.9
LDMNGMT	PCTSUM	0.0	0.9	0.0	0.0
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS					
%GLASS	MEAN	18.2	32.9	13.5	50.3
CBECS 89 FLOOR AREA WEIGHTED OFFICE OCCUPANCY DATA					
MFhrs	MEAN	10.7	12.3	9.4	10.5
SAThrs	MEAN	5.0	7.8	1.7	8.2
SUNhrs	MEAN	3.3	5.6	0.2	6.9
WEEKhrs	MEAN	61.2	74.6	51.0	67.3
CBECS 89 OFFICE OCCUPANCY DATA					
#workers	SUM	1241667	3339897	322045.1	1747860
#workers	MEAN	18.6	250.4	13.2	479.2
FT2/worker	MEAN	675.2	1329.0	538.7	510.4
CBECS 89 OFFICE CLIMATE DATA					
<2000/>7000	PCTSUM	7.0	2.6	0.1	0.0
<2000/55007000	PCTSUM	50.5	36.2	74.9	28.4
<2000/40005499	PCTSUM	42.5	61.2	25.0	71.6
<2000/<4000	PCTSUM	0.0	0.0	0.0	0.0
>2000/<4000	PCTSUM	0.0	0.0	0.0	0.0

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Table 1d
OFFICE BUILDING CHARACTERISTICS FOR THE MIDWEST
SMALL <= 25,000 FT2; LARGE > 25,000 FT2

                              PRE 1980          1980 AND AFTER
                             SMALL     LARGE     SMALL     LARGE
DESCRIPTION        UNITS

CBECS 89 OFFICE SURVEY DATA
NUMBER             SUM            98.0       90.0       17.0       34.0
CBECS 89 OFFICE FLOOR AREA DATA
FT2                SUM        5.5591E8   1.2264E9   90188604   4.4312E8
%VACANT            MEAN            0.0        0.1        0.0        0.5
%HEATED            MEAN           96.1       96.2      100.0       94.7
%COOLED            MEAN           83.9       71.7       91.4       90.9
                   MEAN         5067.4    95482.8     7499.9    98847.1
FT2                MIN          1001.0    25001.0     1001.0    30000.0
                   MAX         25000.0    1500000    25000.0    1500000
                   MEAN            1.8       59.1        1.7       26.1
#FLOORS            MIN             1.0        1.0        1.0        1.0
                   MAX             5.0      995.0        5.0      995.0
CBECS 89 OFFICE EUI DATA
FT2                SUM         5.559E8    1.226E9    9.019E7    4.431E8
ELECBTU            SUM         3.32E10    6.04E10     1.1E10    2.51E10
ELECFT2            PCTSUM        100.0       99.6      100.0      100.0
ELECEUI            MEAN           55.0       53.2      109.5       59.9
GASBTU             SUM         4.08E10    4.63E10    4.832E9    1.35E10
GASFT2             PCTSUM         88.3       88.6       53.4       54.3
GASEUI             MEAN           94.5       66.0       84.6      131.5
OILBTU             SUM         7.216E9    2.866E9        0.0    7.191E7
OILFT2             PCTSUM          4.8       18.8          .       22.9
OILEUI             MEAN          174.7       28.7          .        0.8
CBECS 89 FLOOR AREA WEIGHTED OFFICE HEATING FUELS
HEAT_TOTAL         PCTSUM          105        101        100        101
HEAT_NORMLZD       PCTSUM          100        100        100        100
NOHEAT             PCTSUM            0          0          0          0
ELHEAT             PCTSUM           17          7         40         52
NGHEAT             PCTSUM           78         68         53         38
OHEAT              PCTSUM            5          0          0          7
DSHEAT             PCTSUM            1         25          7          3
HWHEAT             PCTSUM            0          0          0          0
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEATING EQUIP
EQP_TOTAL          PCTSUM          139        121        166        134
EQP_TOTAL          PCTSUM          100        100        100        100
BOILER             PCTSUM           19         56         39         30
FURN               PCTSUM           41          5         17         10
RESIST             PCTSUM           22         24          9         37
PKGHT              PCTSUM           15         12         18         18
HTPMPH             PCTSUM            2          4         17          5
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEAT DISTRIBUTION
EQP_TOTAL          PCTSUM           82        187        131        139
EQP_NORMLZD        PCTSUM          100        100        100        100
DUCTH              PCTSUM           67         12         23         33
REHEAT             PCTSUM           13         30         38         36
FCOILH             PCTSUM            3         16         18         20
BBDRAD             PCTSUM           17         42         21         12
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING EQUIPMENT
EQP_TOTAL          PCTSUM          118        192        166        132
EQP_NORMLZD        PCTSUM          100        100        100        100
CHILLER            PCTSUM            9         32         33         36
ACWNWL             PCTSUM           20         28          7          1
PKGCL              PCTSUM           66         37         40         57
HTPMPC             PCTSUM            4          4         20          6
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CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING DISTRIBUTION SYSTEMS
EQP_TOTAL          PCTSUM           73        102         93        135
EQP_NORMLZD        PCTSUM          100        100        100        100
DUCTCL             PCTSUM           96         80         88         71
FCOILC             PCTSUM            4         20         12         29
CBECS 89 FLOOR AREA WEIGHTED OFFICE WINDOW CHARACTERISTICS
STORMS             PCTSUM         72.6       57.8       91.2      100.0
TINTREFL           PCTSUM         18.6       30.2       78.9       99.8
SHADINGS           PCTSUM         28.9       61.8       70.7       63.4
CBECS 89 FLOOR AREA WEIGHTED OFFICE INSULATION DATA
WALLINS            PCTSUM         77.7       28.9       91.8       94.0
ROOFINS            PCTSUM         86.0       76.0       91.8      100.0
CBECS 89 FLOOR AREA WEIGHTED OFFICE WALL CONSTRUCTION MATERIALS
WALLS_TOTAL        PCTSUM         99.4       89.2       94.0       88.6
WALLS_NORMLZD      PCTSUM        100.0      100.0      100.0      100.0
WINDOW_GLASS       PCTSUM          0.1        6.4        0.3       16.6
DECOR_GLASS        PCTSUM          1.3        0.0        0.0        0.0
CONCRETE_PANEL     PCTSUM          2.7        6.8       29.6        8.9
MASONRY            PCTSUM         73.9       85.3       60.5       69.0
SIDING/SHINGLE     PCTSUM         13.8        1.0        6.3        0.0
METAL_PANEL        PCTSUM          8.3        0.6        3.4        5.5
OTHER              PCTSUM          0.0        0.0        0.0        0.0
CBECS 89 FLOOR AREA WEIGHTED OFFICE ROOF CONSTRUCTION MATERIALS
ROOFS_TOTAL        PCTSUM         99.2      100.0      100.0      100.0
ROOFS_NORMLZD      PCTSUM        100.0      100.0      100.0      100.0
WOOD               PCTSUM          0.0        0.0        0.0        0.0
SLATE&TILE         PCTSUM          1.6        0.9        0.0        0.0
SHINGLE/SIDING     PCTSUM         28.4        2.2       14.2        0.0
BUILT_UP           PCTSUM         51.1       56.3       26.0       42.4
METAL_SURFCNG      PCTSUM          3.4        0.6        1.0       35.8
SYNTH_SHEETNG      PCTSUM         10.2       35.7       58.8       21.3
CONCRETE           PCTSUM          5.3        4.3        0.0        0.4
OTHER              PCTSUM          0.0        0.0        0.0        0.0
CBECS 89 FLOORSPACE LIT BY LIGHTING EQUIPMENT
INCAND             MEAN            9.0       21.0        4.9       31.4
FLUOR              MEAN           90.4       89.8       89.3       87.8
HID                MEAN            1.6        8.5       10.1       31.4
OTHER              MEAN            0.0        0.0        0.0        0.0
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS
VAV                PCTSUM         20.0       52.5       17.2       88.7
HTRCVRY            PCTSUM          2.5       21.6       12.7       41.6
TCLOCK             PCTSUM          0.0        6.0        0.0        4.7
ECNMZR             PCTSUM          1.1        5.4        5.1        8.4
LDMNGMT            PCTSUM          0.0       15.9        3.3        2.3
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS
%GLASS             MEAN           18.2       46.5       19.9       48.5
CBECS 89 FLOOR AREA WEIGHTED OFFICE OCCUPANCY DATA
MFhrs              MEAN           11.0       11.1        9.5       12.1
SAThrs             MEAN            7.4        5.3        3.0        6.2
SUNhrs             MEAN            7.3        3.2        0.7        2.6
WEEKhrs            MEAN           69.5       63.8       51.3       70.1
CBECS 89 OFFICE OCCUPANCY DATA
#workers           SUM         1048069    2280684   184015.1   978392.4
#workers           MEAN            9.6      177.6       15.3      218.2
FT2/worker         MEAN          812.8     1714.2     1173.9      611.6
CBECS 89 OFFICE CLIMATE DATA
<2000/>7000        PCTSUM         26.1       18.1       10.3       13.8
<2000/55007000     PCTSUM         51.5       65.0       85.8       68.0
<2000/40005499     PCTSUM         22.4       16.9        3.9       18.2
<2000/<4000        PCTSUM          0.0        0.0        0.0        0.0
>2000/<4000        PCTSUM          0.0        0.0        0.0        0.0
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Table 1c
OFFICE BUILDING CHARACTERISTICS FOR THE SOUTH
SMALL <= 25,000 FT2; LARGE > 25,000 FT2

                             PRE 1980           1980 AND AFTER
                               SMALL    LARGE     SMALL    LARGE
DESCRIPTION        UNITS

CBECS 89 OFFICE SURVEY DATA
NUMBER             SUM          142.0      98.0      64.0      77.0
CBECS 89 OFFICE FLOOR AREA DATA
FT2                SUM       9.7062E8  1.5249E9   4.707E8  8.9549E8
%VACANT            MEAN           6.8       0.0       8.3       9.1
%HEATED            MEAN          89.2      92.1      85.6      89.9
%COOLED            MEAN          90.6      89.5      88.0      88.2
                   MEAN        5715.9  100048.4    5877.2   91988.1
FT2                MIN         1001.0   25001.0    1001.0   25001.0
                   MAX        25000.0   1300000   25000.0   1300000
                   MEAN           1.4      33.8       1.3      30.9
#FLOORS            MIN            1.0       1.0       1.0       1.0
                   MAX            9.0     995.0       3.0     995.0
CBECS 89 OFFICE EUI DATA
FT2                SUM        9.706E8   1.525E9   4.707E8   8.955E8
ELECBTU            SUM        5.97E10   1.08E11   2.64E10   7.82E10
ELECFT2            PCTSUM       100.0     100.0     100.0     100.0
ELECEUI            MEAN          64.0      61.5      55.4     110.6
GASBTU             SUM         1.8E10    1.3E10   4.036E9   5.504E9
GASFT2             PCTSUM        35.8      45.2      28.6      58.6
GASEUI             MEAN          46.3      18.6      33.8      16.3
OILBTU             SUM        1.519E9   9.041E8         .   1.107E8
OILFT2             PCTSUM         3.7      13.7         .      29.2
OILEUI             MEAN          70.2       7.4         .       1.2
CBECS 89 FLOOR AREA WEIGHTED OFFICE HEATING FUELS
HEAT_TOTAL         PCTSUM         100       101       100       100
HEAT_NORMLZD       PCTSUM         100       100       100       100
NOHEAT             PCTSUM           3         2         1         4
ELHEAT             PCTSUM          55        24        72        74
NGHEAT             PCTSUM          29        33        27        22
OHEAT              PCTSUM           3         1         0         0
DSHEAT             PCTSUM          10        38         0         0
HWHEAT             PCTSUM           0         1         0         0
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEATING EQUIP
EQP_TOTAL          PCTSUM         118        97       143       117
EQP_TOTAL          PCTSUM         100       100       100       100
BOILER             PCTSUM           9        28         3        12
FURN               PCTSUM          24        15        17         8
RESIST             PCTSUM          22        29        19        35
PKGHT              PCTSUM          28        19        34        16
HTPMPH             PCTSUM          17        10        26        29
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEAT DISTRIBUTION
EQP_TOTAL          PCTSUM          83       117        79       110
EQP_NORMLZD        PCTSUM         100       100       100       100
DUCTH              PCTSUM          69        22        92        32
REHEAT             PCTSUM          20        53         5        42
FCOILH             PCTSUM           7        17         3        25
BBDRAD             PCTSUM           5         8         0         2
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING EQUIPMENT
EQP_TOTAL          PCTSUM         114       141       104       148
EQP_NORMLZD        PCTSUM         100       100       100       100
CHILLER            PCTSUM          10        47         2        37
ACWNWL             PCTSUM          19        10         4         4
PKGCL              PCTSUM          55        35        57        35
HTPMPC             PCTSUM          16         8        37        23
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CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING DISTRIBUTION SYSTEMS
EQP_TOTAL          PCTSUM          71       121        83       118
EQP_NORMLZD        PCTSUM         100       100       100       100
DUCTCL             PCTSUM          92        68        96        70
FCOILC             PCTSUM           8        32         4        30
CBECS 89 FLOOR AREA WEIGHTED OFFICE WINDOW CHARACTERISTICS
STORMS             PCTSUM        23.6      31.3      51.9      74.6
TINTREFL           PCTSUM        37.1      57.8      66.8      76.8
SHADINGS           PCTSUM        46.0      76.5      47.3      52.1
CBECS 89 FLOOR AREA WEIGHTED OFFICE INSULATION DATA
WALLINS            PCTSUM        53.2      24.9      74.5      86.6
ROOFINS            PCTSUM        80.7      86.5      89.7      85.5
CBECS 89 FLOOR AREA WEIGHTED OFFICE WALL CONSTRUCTION MATERIALS
WALLS_TOTAL        PCTSUM        97.3      71.1      93.1      96.5
WALLS_NORMLZD      PCTSUM       100.0     100.0     100.0     100.0
WINDOW_GLASS       PCTSUM         1.6      15.4       2.1      14.1
DECOR_GLASS        PCTSUM         0.0       0.7       2.2       2.2
CONCRETE_PANEL     PCTSUM         6.1      20.4       7.5      32.0
MASONRY            PCTSUM        80.2      57.3      68.7      44.0
SIDING/SHINGLE     PCTSUM        10.3       0.0       3.9       0.0
METAL_PANEL        PCTSUM         1.8       6.2      15.5       7.8
OTHER              PCTSUM         0.0       0.0       0.0       0.0
CBECS 89 FLOOR AREA WEIGHTED OFFICE ROOF CONSTRUCTION MATERIALS
ROOFS_TOTAL        PCTSUM       100.0     100.0     100.0      93.2
ROOFS_NORMLZD      PCTSUM       100.0     100.0     100.0     100.0
WOOD               PCTSUM         1.5       0.0       1.8       0.0
SLATE&TILE         PCTSUM         1.6       0.0       8.1       0.0
SHINGLE/SIDING     PCTSUM        26.9       9.2      37.3       0.0
BUILT_UP           PCTSUM        63.2      25.3      32.8      63.9
METAL_SURFCNG      PCTSUM         3.6       0.9      17.9      22.3
SYNTH_SHEETNG      PCTSUM         1.5      63.7       2.0      13.7
CONCRETE           PCTSUM         1.8       1.0       0.0       0.1
OTHER              PCTSUM         0.0       0.0       0.0       0.0
CBECS 89 FLOORSPACE LIT BY LIGHTING EQUIPMENT
INCAND             MEAN          10.2      40.4       5.2       7.4
FLUOR              MEAN          93.7      87.2      93.5      87.5
HID                MEAN           0.2      11.6       2.2      21.6
OTHER              MEAN           0.0       0.0       0.0       0.0
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS
VAV                PCTSUM        22.1      39.7      36.9      67.9
HTRCVRY            PCTSUM         0.0      29.1       3.3      12.6
TCLOCK             PCTSUM         3.5       3.4       3.6       7.1
ECNMZR             PCTSUM         0.0       9.2       5.5       5.0
LDMNGMT            PCTSUM         2.9       0.0       0.0       0.8
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS
%GLASS             MEAN          16.0      40.8      16.7      51.0
CBECS 89 FLOOR AREA WEIGHTED OFFICE OCCUPANCY DATA
MFhrs              MEAN          11.2      12.1       9.7      12.1
SAThrs             MEAN           5.7       4.3       2.8       5.2
SUNhrs             MEAN           5.1       3.1       2.0       3.4
WEEKhrs            MEAN          65.2      67.4      53.6      68.6
CBECS 89 OFFICE OCCUPANCY DATA
#workers           SUM        2186156   3188563   1050955   2141073
#workers           MEAN          12.9     209.2      13.1     219.9
FT2/worker         MEAN         717.1     925.6     547.9     777.5
CBECS 89 OFFICE CLIMATE DATA
<2000/>7000        PCTSUM         0.0       0.0       0.0       0.0
<2000/55007000     PCTSUM         0.0       0.0       0.0       0.0
<2000/40005499     PCTSUM        14.7      23.6      15.3      23.3
<2000/<4000        PCTSUM        31.6      47.2      54.7      41.4
>2000/<4000        PCTSUM        53.8      29.2      30.1      35.3
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Table 1e
OFFICE BUILDING CHARACTERISTICS FOR THE WEST
SMALL <= 25,000 FT2; LARGE > 25,000 FT2

		PRE 1980		1980 AND AFTER	
DESCRIPTION	UNITS	SMALL	LARGE	SMALL	LARGE
CBECS 89 OFFICE SURVEY DATA					
NUMBER	SUM	96.0	85.0	32.0	53.0
CBECS 89 OFFICE FLOOR AREA DATA					
FT2	SUM	6.222E8	1.2799E9	2.407E8	8.5136E8
%VACANT	MEAN	4.9	0.0	0.0	0.0
%HEATED	MEAN	88.7	92.0	90.8	85.7
%COOLED	MEAN	76.2	82.1	84.1	87.3
	MEAN	5865.9	91820.3	8757.4	88608.9
FT2	MIN	1001.0	25001.0	1500.0	30000.0
	MAX	20000.0	1500000	22500.0	1300000
	MEAN	1.6	48.2	1.5	23.0
#FLOORS	MIN	1.0	1.0	1.0	1.0
	MAX	4.0	995.0	4.0	995.0
CBECS 89 OFFICE EUI DATA					
FT2	SUM	6.222E8	1.28E9	2.407E8	8.514E8
ELECBTU	SUM	3.5E10	1.01E11	2.3E10	6.96E10
ELECFT2	PCTSUM	100.0	100.0	100.0	100.0
ELECEUI	MEAN	48.0	68.6	81.6	67.7
GASBTU	SUM	1.99E10	2.25E10	3.221E9	1.08E10
GASFT2	PCTSUM	73.2	69.3	29.0	73.5
GASEUI	MEAN	51.4	40.7	49.8	14.5
OILBTU	SUM	0.0	1.84E9	3.745E8	1.811E8
OILFT2	PCTSUM	.	17.1	15.5	19.1
OILEUI	MEAN	.	23.3	11.1	0.9
CBECS 89 FLOOR AREA WEIGHTED OFFICE HEATING FUELS					
HEAT_TOTAL	PCTSUM	96	100	100	102
HEAT_NORMLZD	PCTSUM	100	100	100	100
NOHEAT	PCTSUM	1	1	1	0
ELHEAT	PCTSUM	27	28	82	58
NGHEAT	PCTSUM	68	54	17	38
OHEAT	PCTSUM	1	1	0	2
DSHEAT	PCTSUM	1	14	0	3
HWHEAT	PCTSUM	1	2	0	0
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEATING EQUIP					
EQP_TOTAL	PCTSUM	141	150	126	121
EQP_TOTAL	PCTSUM	100	100	100	100
BOILER	PCTSUM	14	30	0	28
FURN	PCTSUM	26	7	15	2
RESIST	PCTSUM	20	30	17	13
PKGHT	PCTSUM	28	22	39	36
HTPMPH	PCTSUM	11	10	29	21
CBECS 1989 FLOOR AREA WEIGHTED OFFICE HEAT DISTRIBUTION					
EQP_TOTAL	PCTSUM	86	138	93	114
EQP_NORMLZD	PCTSUM	100	100	100	100
DUCTH	PCTSUM	77	20	89	31
REHEAT	PCTSUM	5	38	11	49
FCOILH	PCTSUM	2	27	0	20
BBDRAD	PCTSUM	16	16	0	1
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING EQUIPMENT					
EQP_TOTAL	PCTSUM	107	151	107	143
EQP_NORMLZD	PCTSUM	100	100	100	100
CHILLER	PCTSUM	7	36	0	30
ACWNWL	PCTSUM	13	11	0	6
PKGCL	PCTSUM	65	45	68	52
HTPMPC	PCTSUM	15	8	32	11
CBECS 1989 FLOOR AREA WEIGHTED OFFICE COOLING DISTRIBUTION SYSTEMS					
EQP_TOTAL	PCTSUM	58	130	80	140
EQP_NORMLZD	PCTSUM	100	100	100	100
DUCTCL	PCTSUM	99	57	86	64
FCOILC	PCTSUM	1	43	14	36
CBECS 89 FLOOR AREA WEIGHTED OFFICE WINDOW CHARACTERISTICS					
STORMS	PCTSUM	24.4	24.7	57.1	38.7
TINTREFL	PCTSUM	38.6	71.8	67.7	86.5
SHADINGS	PCTSUM	47.1	51.6	38.0	45.6
CBECS 89 FLOOR AREA WEIGHTED OFFICE INSULATION DATA					
WALLINS	PCTSUM	53.0	40.9	84.9	81.9
ROOFINS	PCTSUM	71.1	69.7	94.6	93.8
CBECS 89 FLOOR AREA WEIGHTED OFFICE WALL CONSTRUCTION MATERIALS					
WALLS_TOTAL	PCTSUM	97.8	95.4	100.0	97.2
WALLS_NORMLZD	PCTSUM	100.0	100.0	100.0	100.0
WINDOW_GLASS	PCTSUM	0.0	25.7	8.2	16.3
DECOR_GLASS	PCTSUM	0.0	0.4	1.6	3.0
CONCRETE_PANEL	PCTSUM	6.5	35.3	6.1	41.1
MASONRY	PCTSUM	64.4	27.9	45.8	35.4
SIDING/SHINGLE	PCTSUM	25.7	0.4	33.4	0.9
METAL_PANEL	PCTSUM	3.3	10.2	4.9	3.4
OTHER	PCTSUM	0.0	0.0	0.0	0.0
CBECS 89 FLOOR AREA WEIGHTED OFFICE ROOF CONSTRUCTION MATERIALS					
ROOFS_TOTAL	PCTSUM	99.5	100.0	100.0	100.0
ROOFS_NORMLZD	PCTSUM	100.0	100.0	100.0	100.0
WOOD	PCTSUM	2.4	0.0	0.0	0.0
SLATE&TILE	PCTSUM	8.0	4.9	13.4	1.3
SHINGLE/SIDING	PCTSUM	26.4	10.1	3.4	0.0
BUILT_UP	PCTSUM	54.5	76.8	50.5	97.6
METAL_SURFCNG	PCTSUM	4.5	0.2	30.9	0.0
SYNTH_SHEETNG	PCTSUM	4.0	6.4	0.0	1.1
CONCRETE	PCTSUM	0.0	1.5	1.7	0.0
OTHER	PCTSUM	0.0	0.0	0.0	0.0
CBECS 89 FLOORSPACE LIT BY LIGHTING EQUIPMENT					
INCAND	MEAN	15.1	44.6	14.1	2.2
FLUOR	MEAN	86.8	92.5	94.5	94.3
HID	MEAN	1.7	9.1	0.2	4.8
OTHER	MEAN	0.0	0.0	0.0	0.1
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS					
VAV	PCTSUM	16.6	41.4	17.4	47.8
HTRCVRY	PCTSUM	4.5	11.8	4.2	17.4
TCLOCK	PCTSUM	6.3	5.6	5.1	0.3
ECNMZR	PCTSUM	0.0	14.7	0.0	5.6
LDMNGMT	PCTSUM	0.0	0.0	0.0	2.3
CBECS 86 FLOOR AREA WEIGHTED MISCELLANEOUS OFFICE CHARACTERISTICS					
%GLASS	MEAN	20.8	40.6	16.1	52.2
CBECS 89 FLOOR AREA WEIGHTED OFFICE OCCUPANCY DATA					
MFhrs	MEAN	10.2	12.0	10.9	13.3
SAThrs	MEAN	3.1	7.7	6.1	7.7
SUNhrs	MEAN	1.9	5.7	5.7	5.6
WEEKhrs	MEAN	55.3	73.4	66.5	79.7
CBECS 89 OFFICE OCCUPANCY DATA					
#workers	SUM	1582979	3438980	438838.0	2607608
#workers	MEAN	14.9	246.7	16.0	271.4
FT2/worker	MEAN	588.4	781.8	796.2	632.8
CBECS 89 OFFICE CLIMATE DATA					
<2000/>7000	PCTSUM	8.1	3.1	12.8	4.8
<2000/55007000	PCTSUM	12.5	11.1	13.9	17.6
<2000/40005499	PCTSUM	8.1	16.8	12.7	3.0
<2000/<4000	PCTSUM	60.3	62.3	43.7	69.9
>2000/<4000	PCTSUM	11.0	6.8	16.9	4.8

Table B.2

CBECS Office Building Data for Two Regions; the North and the South

Table B.2 1989 CBECS Data for Offices

tabb2.officedata

North/South, Old/New, Large/Small Office Data Aggregation

	Large Offices (>= 25,000 ft2)				Small Offices (< 25,000 ft2)			
	North U.S.		South U.S.		North U.S.		South U.S.	
	Pre 1980	1980-89	Pre 1980	1980-89	Pre 1980	1980-89	Pre 1980	1980-89
STOCK FLOOR AREA DATA								
Surveyed buildings	206	75	183	130	159	41	238	96
Total U.S. office buildings (1000s)	26.1	8.1	29.1	19.3	176.3	36.4	275.9	107.6
% of total U.S. office buildings	3.8	1.2	4.3	2.8	26.0	5.4	40.6	15.8
Total area (million of ft2)	2706	1117	2805	1747	976	234	1593	711
Percent of total U.S office area	23	9	24	15	8	2	13	6
%VACANT	0	1	0	5	1	0	6	7
%HEATED	97	97	92	88	95	98	89	87
%COOLED	75	93	86	88	81	89	85	87
Percent Floor Area by Climate								
CDD<2000;HDD>7000	10	6	1	2	17.9	4.1	3.2	4.3
CDD<2000;5500<HDD<7000	49	44	5	9	51.1	79.1	4.9	4.7
CDD<2000;4000<HDD<5500	41	50	21	13	31	16.9	12.1	14.4
CDD<2000;HDD<4000	0	0	54	55	0	0	42.8	51
CDD>2000;HDD<4000	0	0	19	20	0	0	37.1	25.6
FLOOR-AREA WEIGHTED AVERAGES								
Building area (ft2)	103347	137387	96118	90310	5532	6431	5774	6613
Floors	NA	NA	NA	NA	2.1	1.8	1.5	1.3
SHELL								
Percent glass	40	49	41	52	18	18	18	17
Percent storms	55	66	28	57	71	96	24	54
Percent tinted	40	96	64	82	13	57	38	67
Percent shaded	64	78	65	49	33	76	46	44
% with wall insul.	37	65	32	84	73	91	53	78
% with roof insul	69	67	79	90	84	93	77	91
Wall material	masnry	masnry	masnry	masnry	masnry	masnry	masnry	masnry
Roof material	built-up	built-up	built-up	built-up	built-up	built-up	built-up	built-up
OCCUPANCY								
Occupcy (ft2/pers)	481	410	423	368	426	463	421	479
Weekday hours	11.8	11.2	12	12.7	10.9	9.4	10.8	10.1
Saturday hours	6.7	7.4	5.9	6.4	6.4	2.2	4.7	3.9
Sunday hours	4.6	5.2	4.3	4.5	5.6	0.4	3.9	3.2
LIGHTING								
% incand. lit area	30	15	42	5	11	13	12	8
% fluor. lit area	89	92	90	91	89	85	91	94
% HID lit area	10	24	11	13	1	4	1	2
FLOOR-AREA WEIGHTED HVAC DATA								
PRIMARY HEATING FUEL (%)								
none	0	0	2	2	0	0	2	1
electricity	9	31	26	66	14	34	45	75
natural gas	44	27	43	30	66	50	44	24
oil	17	3	1	1	15	13	2	0
district steam	30	39	27	2	5	3	6	0
HEATING EQUIPMENT (%)								
total reported	128	96	122	119	131	153	127	137
total normalized	100	100	100	100	100	100	100	100
boiler	45	33	29	20	26	25	11	2
furnace	5	9	11	5	35	31	25	16
resistance	24	32	30	24	19	16	21	18
packaged heating	11	14	21	26	14	11	28	36
heat pump	13	12	10	25	7	18	14	27
HEATING DISTRIBUTION (%)								
total equipment reported	183	169	127	112	77	103	84	84
total normalized	100	100	100	100	100	100	100	100
ducts w/o reheat	7	15	21	31	56	45	72	91
ducts with reheat	32	40	45	45	10	22	14	7
fan coils	20	14	22	22	2	13	5	2
baseboards/radiators	41	31	12	1	32	20	9	0
COOLING FUELS (%)								
none	1	0	0	0	5	0	5	0
electricity	87	99	96	98	90	98	91	97
natural gas	2	1	3	2	5	2	3	3
oil	0	0	0	1	0	0	0	0
district cooling	10	0	0	0	0	0	0	0
COOLING EQUIPMENT (%)								
total equipment reported	202	165	145	145	115	132	111	105
total normalized	100	100	100	100	100	100	100	100
chiller	33	41	42	34	7	20	9	1
AC-window/wall	26	4	10	5	28	4	17	3
packaged cooling	33	48	40	43	59	52	59	61
heat pump	8	8	8	18	7	24	16	35
COOLING DISTRIBUTION (%)								
total equipment reported	112	154	125	129	59	84	66	82
total normalized	100	100	100	100	100	100	100	100
ducts	66	61	63	67	97	95	94	93
fan coils	34	39	37	33	3	5	6	7

Tables B.3 - B.4

Predominant Office HVAC Systems

Table B.3 System types and fuel types for large offices

	North		South	
	Pre-1980	1980-1989	Pre-1980	1980-1989
Number of large offices (thousands)	26.1	8.1	29.1	19.3
% of total comml buildings in 1989	1%	0%	1%	0%
% of total office buildings in 1989	4%	1%	4%	3%
% of total large office buildings in 1989	31%	10%	35%	23%
Total floor area of large offices (million ft2)	2705.9	1117	2804.8	1746.8
% of total comml floor area in 1989	4%	2%	4%	3%
% of total office floor area in 1989	23%	9%	24%	15%
% of total large office floor area in 1989	32%	13%	33%	21%
Mean floor area/building (ft2)	103347	137387	96118	90310

System type expressed as a percentage of floor area within a given vintage bin and region	North		South	
	Pre-1980	1980-1989	Pre-1980	1980-1989
System # and type				
1 Gas boiler w/baseboards - window/wall AC	0%	0%	0%	0%
2 Packaged, gas furnace - AC	0%	0%	0%	0%
3 Electric resistance heat - packaged AC	0%	0%	0%	0%
4 Electric heat - chiller	0%	0%	0%	0%
5 Heat pump	10%	10%	15%	25%
6 Fan coils, district heat - chiller	30%	30%	20%	30%
7 VAV with reheat, gas boiler - chiller	20%	0%	30%	0%
8 Multizone gas furnace - packaged AC	20%	0%	0%	0%
9 Gas boiler w/baseboard - packaged AC	20%	0%	0%	0%
10 VAV with fan powered boxes, gas boiler - c	0%	25%	0%	0%
11 VAV, electric reheat - packaged cool	0%	35%	35%	45%
12 Gas furnace - window/wall AC	0%	0%	0%	0%
Total	100%	100%	100%	100%

Table B.4 System types and fuel types for small offices

	North		South	
	Pre-1980	1980-1989	Pre-1980	1980-1989
Number of small offices (thousands)	176	36	276	108
% of total comml buildings in 1989	4%	1%	6%	2%
% of total office buildings in 1989	26%	5%	41%	16%
% of total small office buildings in 1989	30%	6%	46%	18%
Total floor area of small offices (million ft2)	976	234	1593	711
% of total comml floor area in 1989	2%	0%	3%	1%
% of total office floor area in 1989	8%	2%	13%	6%
% of total small office floor area in 1989	28%	7%	45%	20%
Mean floor area/building (ft2)	5500	6400	5800	6600

System type expressed as a percentage of floor area within a given vintage bin and region	North		South	
	Pre-1980	1980-1989	Pre-1980	1980-1989
System # and type				
1 Gas boiler w/baseboards - window/wall AC	30%	15%	0%	0%
2 Packaged, gas furnace - AC	50%	45%	20%	25%
3 Electric resistance heat - packaged AC	20%	0%	35%	43%
4 Electric heat - chiller	0%	20%	0%	0%
5 Heat pump	0%	20%	15%	32%
6 Fan coils, district heat - chiller	0%	0%	0%	0%
7 VAV with reheat, gas boiler - chiller	0%	0%	0%	0%
8 Multizone gas furnace - packaged AC	0%	0%	0%	0%
9 Gas boiler w/baseboard - packaged AC	0%	0%	0%	0%
10 VAV with fan powered boxes, gas boiler - chiller	0%	0%	0%	0%
11 VAV, electric reheat - packaged cool	0%	0%	0%	0%
12 Gas furnace - window/wall AC	0%	0%	30%	0%
Total	100%	100%	100%	100%

Appendix C - DOE-2 Modeling

DOE-2 Sample Input Files for the Small and Large, North, Pre-1980 Office Prototypes

```
$ File: LofNDCOH0R0.inp Created: Mon Apr 12 15:04:13 PDT 1993
$ DOE-2.1D BDL Input for Large_Office
$ COMMEND input data runs

##show
##set1 vintage   old
##set1 hvactype hvac0
##set1 condition basecase
##set1 location  washingtonwyec
##set1 region    North
##set1 comp      plant
##set1 report    none
##fileprefix     /icl/emfbca/D2/Commercial/LgOffInc/

POST-PROCESSOR  PARTIAL  ..
INPUT LOADS  ..



TITLE LINE-1 *COMMEND input data runs*
      LINE-2 *Large_Office in WashDCN basecase condition*
      LINE-3 *Pre_1980 construction characteristics*
      LINE-4 *No_HVAC*
      ..

RUN-PERIOD  JAN 1 1991 THRU DEC 31 1991  ..

$ File location.inc
$ (01/05/90)

               $ LOCATION SPECIFIC DATA $
               $    FOR ALL BUILDINGS   $


   BUILDING-LOCATION  LAT 38.1  LON 87.00  ALT   14  T-Z 5


$ defaults for all locations:
   AZIMUTH 0
   HOLIDAY YES
   DAYLIGHT-SAVINGS YES
   ..

ABORT ERRORS ..
LIST WARNINGS  ..
PARAMETER  CREDIT-DAYLTG NO  ..
$ File const.inc
$ (02/93)

                    $ CONSTRUCTION DATA FOR $
                    $     LARGE OFFICE     $

$ Region Non-specific Data $
##set1 aspect_ratio 0.67
##set1 wall_height 10.
##set1 perim_width 15.
$natural inf based on cfm = ACH*(Vol/AREA)*1hour/60min; no wind effect consider

##set1 ach .30
##set1 inf_cfm  #[ach[] * #[wall_height[] / 60] ]
$system outdoor air; 0 infil while fans are operating except with no system
##set1 oa_cfm/per 15.
##set1 system0_inf_ratio 0.
##set1 equip_load .75
```

```
$ DHW use (btu/hr/person)
##set1 hot_water 175.

$ Region and Vintage Specific Construction Data
$ File north_const.inc
$ (02/93)

                $ NORTHERN US DATA FOR $
                $    LARGE OFFICE      $
$ common values for both office vintages
##set1 floors 7.
##set1 slab_u 1.67
##set1 fuel_use 79
$ values for old offices
  ##set1 area 103000.
  ##set1 sqft_person 460.
  ##set1 glass_ratio 0.40
  ##set1 wall_r 2.5
  ##set1 window_r 1.44
  ##set1 window_sc .80
  ##set1 roof_r 9.1
  $ Intensities
  ##set1 light_load 1.8
  $ Schedules
  ##set1 wd_start 8
  ##set1 wd_stop  18
  ##set1 we_start 8
  ##set1 we_stop  13


$ System and Plant Assignment for HVAC systems

##set1 baseboards no

    ##set1 systemtype system0
$ Include Outdoor air Load in Building Load Calc through Infiltration Schedule
    ##set1 system0_inf #[oa_cfm/per[] / sqft_person[]]
    ##set1 system0_inf_ratio #[system0_inf[] / inf_cfm[]]
    ##set1 planttype  plant0


$ Run Parameter Evaluation
$   base condition evaluated

$ File loads.inc
$ (03/22/90)

                   $ LOADS DATA FOR $
                   $  LARGE OFFICE $

$ Load Schedules
$ File loads_sch.inc
$ (08/25/89)

                   $ LOADS SCHEDULE DATA FOR $
                   $      LARGE OFFICE      $
  $SCHEDULE MACROS

##def occ_sched [start, stop, low, high]
   $ Occupant schedules
   $ 2 hour ramp up, 1 hour ramp down

   (1,#[start - 1]) (low)
   (start) (#[low + #[#[high - low] / 3]])
```

```
   (#[start + 1]) (#[high - #[#[high - low] / 3]])
   (#[start + 2],#[stop - 1]) (high)
   (stop) (#[high - #[#[high - low] / 2]])
   (#[stop + 1],24) (low)

##enddef

##def lit_sched [start, stop, low, high]
   $ Lighting schedules
   $ no ramping

   (1,#[start - 1]) (low)
   (start,#[stop - 1]) (high)
   (stop,24) (low)

##enddef

##def eqp_sched [start, stop, low, high]
   $ Equipment schedules
   $ no ramping

   (1,#[start - 1]) (low)
   (start,#[stop - 1]) (high)
   (stop,24) (low)

##enddef

##def hvac_sched [start, stop, low, high]
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,#[start - 2]) (low)
   (#[start - 1],stop) (high)
   (#[stop + 1],24) (low)

##enddef


              $ STANDARD OPERATION $
$ OCC $
OCCDAY-1    DAY-SCHEDULE

   $ Occupant schedules
   $ 2 hour ramp up, 1 hour ramp down

   (1,7) (0.00)
   (8) ( 0.333333343)
   (9) ( 0.666666627)
   (10,17) (1.00)
   (18) ( 0.500000000)
   (19,24) (0.00)

        ..
OCCDAY-2    DAY-SCHEDULE

   $ Occupant schedules
   $ 2 hour ramp up, 1 hour ramp down

   (1,7) (0.00)
   (8) ( 0.066666670)
   (9) ( 0.133333325)
   (10,12) (0.20)
   (13) ( 0.100000001)
   (14,24) (0.00)
```

```
        ..
OCC-SCHED SCHEDULE THRU DEC 31
        (WD) OCCDAY-1 (WEH) OCCDAY-2
        ..

$ LIT $
LITDAY-1    DAY-SCHEDULE

   $ Lighting schedules
   $ no ramping

   (1,7) (0.30)
   (8,17) (0.90)
   (18,24) (0.30)

        ..
LITDAY-2    DAY-SCHEDULE

   $ Lighting schedules
   $ no ramping

   (1,7) (0.30)
   (8,12) (0.40)
   (13,24) (0.30)

        ..
LIT-SCHED SCHEDULE THRU DEC 31
        (WD) LITDAY-1 (WEH) LITDAY-2  ..

$ EQP $
EQPDAY-1    DAY-SCHEDULE

   $ Equipment schedules
   $ no ramping

   (1,7) (0.17)
   (8,17) (1.00)
   (18,24) (0.17)

        ..
EQPDAY-2    DAY-SCHEDULE

   $ Equipment schedules
   $ no ramping

   (1,7) (0.17)
   (8,12) (0.17)
   (13,24) (0.17)

        ..
EQP-SCHED SCHEDULE THRU DEC 31
        (WD) EQPDAY-1 (WEH) EQPDAY-2  ..

$ INFILTRATION $
INFIL-1    DAY-SCHEDULE

   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (1.)
   (7,18) (0.652173698)
   (19,24) (1.)
```

```
        ..
INFIL-2    DAY-SCHEDULE

   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (1.)
   (7,13) (0.652173698)
   (14,24) (1.)

        ..
INF-SCHED SCHEDULE THRU DEC 31
        (WD) INFIL-1 (WEH) INFIL-2  ..


$ BASEMENT SOURCE $
ALLWAYSON SCHEDULE THRU DEC 31 (ALL) (1,24) (1) ..

$ Exterior Surfaces
$ Wall - stone,insulation,air-space,gyp-board
IN-W MATERIAL  RES = 2.5 ..
WALLR LAYERS   MAT = (ST01,IN-W,AL21,GP02) ..
WALL-1 CONSTRUCTION LAYERS = WALLR ..

$ Roof - built-up roofing,4" conc.,insulation,air-space,accoustic tile
IN-R MATERIAL  RES = 9.1 ..
ROOFR LAYERS   MAT = (BR01,CC24,IN-R,AL33,AC02) ..
ROOF-1 CONSTRUCTION  LAYERS = ROOFR ..

$ Floor - 4" light-weight conc., pad, carpet
FLOORR LAYERS MAT = (CC24,CP01) ..
FLOOR-1 CONSTRUCTION LAYERS = FLOORR ..
$ Slab - 6" heavy-weight conc., 2' soil
SOIL MATERIAL  THICKNESS = 2.0  SPECIFIC-HEAT = 0.26
               CONDUCTIVITY = 1.0  DENSITY = 115  ..
SLABL LAYERS  MAT = (SOIL,CC15)  ..
SLAB-1 CONSTRUCTION LAYERS = SLABL  ..

$ Glass
COMPOSITE GLASS-TYPE PANES = 1
       SHADING-COEF = .80
       GLASS-CONDUCTANCE =  0.694444478
       ..


$ Zone Calculations
##set1 flr_area #[area[] / floors[]]
##set1 mult #[floors[] - 2]
##set1 long_len #[SQRT OF #[flr_area[] / aspect_ratio[]]]

$ Average perim area
##set1 perim1 #[long_len[] - perim_width[]]
##set1 perim2 #[#[long_len[] * aspect_ratio[]] - perim_width[]]
##set1 perim_area #[#[#[perim1[] + perim2[]] * perim_width[]] / 2]

$ Core area
##set1 core_area #[flr_area[] - #[perim_area[] * 4]]

$ Average perim length
##set1 perim_len #[#[long_len[] * #[aspect_ratio[] + 1]] / 2]


                       $ GENERAL SPACE CHARACTERISTICS $
```

```
SPACE-1   SPACE-CONDITIONS
          ZONE-TYPE          = CONDITIONED
          TEMPERATURE        = (73)
          PEOPLE-SCHEDULE    = OCC-SCHED   P-H-S = 255  P-H-L = 255
                                           $ ASHRAE Fund. 26.21
          LIGHTING-SCHEDULE = LIT-SCHED    L-W = 1.8
          LIGHT-TO-SPACE     = 1.00
          EQUIP-SCHEDULE     = EQP-SCHED   E-W = .75
          INF-SCHEDULE       = INF-SCHED
          INF-METHOD         = AIR-CHANGE
          INF-CFM/SQFT       = 0.050000004
          FLOOR-WEIGHT       = 70.
          ..

SPACE-2   SPACE-CONDITIONS  $ Basement
          ZONE-TYPE          = UNCONDITIONED
          INF-METHOD         = AIR-CHANGE
          AIR-CHANGES/HR     = 2           $ Combustion air
          SOURCE-TYPE        = PROCESS
          SOURCE-BTU/HR      =  46380.90625
                                                         $ 5% Jacket loss
          SOURCE-SCHEDULE    = ALLWAYSON
          FLOOR-WEIGHT       = 130
          ..

                         $ TOP FLOOR PERIMETER ZONE $

PER-1T    SPACE
         SPACE-CONDITIONS = SPACE-1
         AREA             = 1631.136352539
         VOLUME           =  16311.36230
         NUMBER-OF-PEOPLE =  3.545948267
         ..

EW1-P1T   EXTERIOR-WALL CONSTRUCTION = WALL-1
         HEIGHT       = 11
         WIDTH        = 123.742439270
         AZIMUTH      = 0
         ..

W1-P1T    WINDOW GLASS-TYPE = COMPOSITE
         HEIGHT =  4.400000095
         WIDTH  = 123.742439270
         ..

RF1-P1   ROOF  CONSTRUCTION = ROOF-1
         TILT             = 0.0
         GND-REFLECTANCE = 0.0
         HEIGHT           =  13.181705475
         WIDTH            = 123.742439270
         ..

PER-2T    SPACE LIKE PER-1T ..
EW1-P2T   EXTERIOR-WALL LIKE EW1-P1T AZ = 90 ..
         WINDOW LIKE W1-P1T ..
         ROOF LIKE RF1-P1 ..

PER-3T    SPACE LIKE PER-1T ..
EW1-P3T   EXTERIOR-WALL LIKE EW1-P1T AZ = 180 ..
         WINDOW LIKE W1-P1T ..
         ROOF LIKE RF1-P1 ..

PER-4T   SPACE LIKE PER-1T ..
EW1-P4T  EXTERIOR-WALL LIKE EW1-P1T AZ = 270 ..
```

```
         WINDOW LIKE W1-P1T ..
         ROOF LIKE RF1-P1 ..

                       $TOP FLOOR CORE ZONE $

COR-1T   SPACE
         SPACE-CONDITIONS = SPACE-1
         AREA             = 8189.741210938
         VOLUME           =  81897.41406
         NUMBER-OF-PEOPLE =  17.803785324
         ..

RF1-C    ROOF  CONSTRUCTION = ROOF-1
         TILT            = 0.0
         GND-REFLECTANCE = 0.0
         HEIGHT          =  90.497192383
         WIDTH           =  90.497192383
         ..

                      $ FIRST FLOOR $

PER-1F   SPACE LIKE PER-1T  ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..

F-P1     INTERIOR-WALL  $ Floor to Basement
         CONSTRUCTION     = FLOOR-1
         AREA             = 1631.136352539
         NEXT-TO BASE-1
         ..

PER-2F   SPACE LIKE PER-2T  ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..
         INTERIOR-WALL LIKE F-P1 ..

PER-3F   SPACE LIKE PER-3T  ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..
         INTERIOR-WALL LIKE F-P1 ..

PER-4F   SPACE LIKE PER-4T  ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..
         INTERIOR-WALL LIKE F-P1 ..

COR-1F   SPACE LIKE COR-1T  ..
         INTERIOR-WALL LIKE F-P1  AREA = 8189.741210938  ..

                      $ INTERIOR FLOORS $

PER-1I   SPACE LIKE PER-1T  FLOOR-MULTIPLIER = 5 ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..


PER-2I  SPACE LIKE PER-2T  FLOOR-MULTIPLIER = 5 ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..

PER-3I   SPACE LIKE PER-3T  FLOOR-MULTIPLIER = 5 ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..
```

```
PER-4I   SPACE LIKE PER-4T  FLOOR-MULTIPLIER = 5 ..
         EXTERIOR-WALL LIKE EW1-P1T ..
         WINDOW LIKE W1-P1T ..

COR-1I   SPACE LIKE COR-1T  FLOOR-MULTIPLIER = 5 ..

                  $ Basement

BASE-1   SPACE
         SPACE-CONDITIONS = SPACE-2
         AREA             = 14714.28613
         VOLUME           = 117714.28906
         ..

SLB-1    UNDERGROUND-FLOOR
         CONSTRUCTION     = SLAB-1
         AREA             = 14714.28613
         U-EFFECTIVE      =   0.014044166
         ..

                  $ BUILDING RESOURCES $

BUILDING-RESOURCE
$ schedule and intensity/sq ft. above ground floor from LBL hosp BDL
         V-T-SCH          =  EQP-SCHED
         VERT-TRANS-KW    =    32.665718079
         HW-SCHEDULE = OCC-SCHED
         HOT-WATER    =   39184.78125
         ..

$ File loads_rep.inc
$ (08/25/89)

                    $ LOADS REPORT DATA FOR $
                    $     ALL BUILDINGS     $


$ Space peak loads summary, Building peak load components
LOADS-REPORT     S (LS-C,LS-F)  ..


END  ..

COMPUTE LOADS  ..
$ File system.inc
$ (03/22/90)

                   $ SYSTEMS DATA FOR $
                   $   LARGE OFFICE   $

INPUT SYSTEMS  ..



$ system schedules
$ 2/93
$ file sys_sch.inc

                  $ SYSTEM SCHEDULES $

FAN-SCHED SCHEDULE THRU DEC 31
    (WD)
   $ HVAC schedules
```

```
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (0.)
   (7,18) (1.)
   (19,24) (0.)

    (WEH)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (0.)
   (7,13) (1.)
   (14,24) (0.)

    ..

CLG-SCHED SCHEDULE
   THRU DEC 31
   (WD)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (90)
   (7,18) (75)
   (19,24) (90)

   (WEH)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (90)
   (7,13) (75)
   (14,24) (90)

   ..

HTG-SCHED SCHEDULE
   THRU DEC 31
   (WD)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (55)
   (7,18) (70)
   (19,24) (55)

   (WEH)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,6) (55)
   (7,13) (70)
   (14,24) (55)

   ..


ZNAIR = ZONE-AIR
        OA-CFM/PER 15.
  ..

ZNCON = ZONE-CONTROL
        DESIGN-HEAT-T 70
```

```
        DESIGN-COOL-T 75
        HEAT-TEMP-SCH HTG-SCHED
        COOL-TEMP-SCH CLG-SCHED
        THERMOSTAT-TYPE PROPORTIONAL
        ..

PER-1T ZONE
      ZONE-TYPE CONDITIONED
      ZONE-AIR ZNAIR
      ZONE-CONTROL ZNCON
      ..

PER-2T ZONE  LIKE  PER-1T   ..
PER-3T ZONE  LIKE  PER-1T  ..
PER-4T ZONE  LIKE  PER-1T   ..
COR-1T ZONE  LIKE  PER-1T  ..
PER-1F ZONE  LIKE  PER-1T   ..
PER-2F ZONE  LIKE  PER-1T   ..
PER-3F ZONE  LIKE  PER-1T  ..
PER-4F ZONE  LIKE  PER-1T   ..
COR-1F ZONE  LIKE  PER-1T  ..
PER-1I ZONE LIKE  PER-1T  FLOOR-MULTIPLIER 5 ..
PER-2I ZONE  LIKE  PER-1I   ..
PER-3I ZONE  LIKE  PER-1I   ..
PER-4I ZONE  LIKE  PER-1I   ..
COR-1I ZONE  LIKE  PER-1I   ..
BASE-1 ZONE
       ZONE-TYPE UNCONDITIONED ..

            $Large Office System Types$
SYS1     SYSTEM
         SYSTEM-TYPE      SUM
         OA-CONTROL       TEMP
         FAN-SCHEDULE     FAN-SCHED
         MIN-CFM-RATIO    0.5
         RETURN-AIR-PATH  DUCT
         ZONE-NAMES       (COR-1T,COR-1F,COR-1I,
                           PER-1I,PER-2I,PER-3I,PER-4I,
                           PER-1F,PER-2F,PER-3F,PER-4F,
                           PER-1T,PER-2T,PER-3T,PER-4T,BASE-1)
         ..



##defl sys_rep[] 1

PLT-1     PLANT-ASSIGNMENT   SYSTEM-NAMES (SYS1)  ..

$ File system_rep.inc
$ (11/21/90)

                   $ SYSTEM REPORT DATA FOR $
                   $     ALL BUILDINGS      $

SYSTEMS-REPORT

   ..

$ this removes systems reports
$ ##setl sys_rep 0

##list
```

```
END  ..

COMPUTE SYSTEMS  ..
$ File plant.inc
$ (08/22/89)

                      $ PLANT DATA FOR $
                      $  LARGE OFFICE $

INPUT PLANT  ..


PLT-1     PLANT-ASSIGNMENT  ..

DHW       P-E TYPE DHW-HEATER  SIZE -999  ..

$ no plant

$ File plant_rep.inc
$ (01/30/90)

                   $ PLANT REPORT DATA FOR $
                   $     ALL BUILDINGS     $

PLANT-REPORT

     S (BEPS)  ..

##list

END  ..

COMPUTE PLANT  ..

STOP ..
```

```
$ File: SofNDCOH0cR0.inp Created: Fri Apr 30 23:20:21 PDT 1993
$ DOE-2.1D BDL Input for Small_Office
$ COMMEND input data runs

##show
##setl vintage   old
##setl hvactype hvac0c
##setl condition basecase
##setl location  washingtonwyec
##setl region    North
##setl comp      plant
##setl report    none
##fileprefix     /icl/emfbca/D2/Commercial/SmOffInc/

POST-PROCESSOR  PARTIAL  ..
INPUT LOADS  ..



TITLE LINE-1 *COMMEND input data runs*
      LINE-2 *Small_Office in WashDCN basecase condition*
      LINE-3 *Pre_1980 construction characteristics*
      LINE-4 *No_HVAC_fans_on *
      ..

RUN-PERIOD  JAN 1 1991 THRU DEC 31 1991  ..

$ File location.inc
$ (01/05/90)

               $ LOCATION SPECIFIC DATA $
               $    FOR ALL BUILDINGS   $


   BUILDING-LOCATION  LAT 38.1  LON 87.00  ALT   14  T-Z 5


$ defaults for all locations:
   AZIMUTH 0
   HOLIDAY YES
   DAYLIGHT-SAVINGS YES
   ..

ABORT ERRORS  ..
LIST WARNINGS  ..
PARAMETER  CREDIT-DAYLTG NO  ..
$ File const.inc
$ (02/93)

                    $ CONSTRUCTION DATA FOR $
                    $     SMALL OFFICE     $

$ Region Non-specific Data $
##setl aspect_ratio 0.67
##setl wall_height 10.
##setl perim_width 15.
$natural inf based on cfm = ACH*(Vol/AREA)*1hour/60min; no wind effect consider

##setl ach .40
##setl inf_cfm  #[ach[] * #[wall_height[] / 60] ]
$system outdoor air; 0 infil while fans are operating except with no system
##setl oa_cfm/per 15.
##setl system0_inf_ratio 0.
##setl equip_load .50
```

```
$ DHW use (btu/hr/person)
##setl hot_water 50.

$ Region and Vintage Specific Construction Data
$ File north_const.inc
$ (02/93)

                $ NORTHERN US DATA FOR $
                $     SMALL OFFICE     $
$ common values for both office vintages
##setl floors 2.
##setl slab_u 1.67
##setl fuel_use 79
$ values for old offices
  ##setl area 5500.
  ##setl sqft_person 420.
  ##setl glass_ratio 0.20
  ##setl wall_r 4.9
  ##setl window_r 1.76
  ##setl window_sc .79
  ##setl roof_r 11.9
  $ Intensities
  ##setl light_load 2.2
  $ Schedules
  ##setl wd_start 9
  ##setl wd_stop  18
  ##setl we_start 9
  ##setl we_stop  13


$ Run Parameter Evaluation
$   base condition evaluated


$ System and Plant Assignment for HVAC systems

##setl baseboards no

    ##setl systemtype system0c
$ Include Outdoor air Load in Building Load Calc through Infiltration Schedule
    ##setl system0_inf #[oa_cfm/per[] / sqft_person[]]
    ##setl system0_inf_ratio #[system0_inf[] / inf_cfm[]]
    ##setl planttype  plant0


$ File loads.inc
$ (03/22/90)

                   $ LOADS DATA FOR $
                   $  SMALL OFFICE $

$ Load Schedules
$ File loads_sch.inc
$ (08/25/89)

                   $ LOADS SCHEDULE DATA FOR $
                   $      SMALL OFFICE      $
  $SCHEDULE MACROS

##def occ_sched [start, stop, low, high]
   $ Occupant schedules
   $ 2 hour ramp up, 1 hour ramp down

   (1,#[start - 1]) (low)
```

```
      (start) (#[low + #[#[high - low] / 3]])
      (#[start + 1]) (#[high - #[#[high - low] / 3]])
      (#[start + 2],#[stop - 1]) (high)
      (stop) (#[high - #[#[high - low] / 2]])
      (#[stop + 1],24) (low)

   ##enddef

   ##def lit_sched [start, stop, low, high]
      $ Lighting schedules
      $ no ramping

      (1,#[start - 1]) (low)
      (start,#[stop - 1]) (high)
      (stop,24) (low)

   ##enddef

   ##def eqp_sched [start, stop, low, high]
      $ Equipment schedules
      $ no ramping

      (1,#[start - 1]) (low)
      (start,#[stop - 1]) (high)
      (stop,24) (low)

   ##enddef

   ##def hvac_sched [start, stop, low, high]
      $ HVAC schedules
      $ no ramping, on 1 hour early, off 1 hour late

      (1,#[start - 2]) (low)
      (#[start - 1],stop) (high)
      (#[stop + 1],24) (low)

   ##enddef


                  $ STANDARD OPERATION $
   $ OCC $
   OCCDAY-1    DAY-SCHEDULE

      $ Occupant schedules
      $ 2 hour ramp up, 1 hour ramp down

      (1,8) (0.00)
      (9) ( 0.333333343)
      (10) ( 0.666666627)
      (11,17) (1.00)
      (18) ( 0.500000000)
      (19,24) (0.00)

         ..
   OCCDAY-2    DAY-SCHEDULE

      $ Occupant schedules
      $ 2 hour ramp up, 1 hour ramp down

      (1,8) (0.00)
      (9) ( 0.066666670)
      (10) ( 0.133333325)
      (11,12) (0.20)
      (13) ( 0.100000001)
```

```
      (14,24) (0.00)

         ..
   OCC-SCHED SCHEDULE THRU DEC 31
           (WD) OCCDAY-1 (WEH) OCCDAY-2
         ..

   $ LIT $
   LITDAY-1    DAY-SCHEDULE

      $ Lighting schedules
      $ no ramping

      (1,8) (0.20)
      (9,17) (0.90)
      (18,24) (0.20)

         ..
   LITDAY-2    DAY-SCHEDULE

      $ Lighting schedules
      $ no ramping

      (1,8) (0.20)
      (9,12) (0.20)
      (13,24) (0.20)

         ..
   LIT-SCHED SCHEDULE THRU DEC 31
           (WD) LITDAY-1 (WEH) LITDAY-2  ..

   $ EQP $
   EQPDAY-1    DAY-SCHEDULE

      $ Equipment schedules
      $ no ramping

      (1,8) (0.17)
      (9,17) (1.00)
      (18,24) (0.17)

         ..
   EQPDAY-2    DAY-SCHEDULE

      $ Equipment schedules
      $ no ramping

      (1,8) (0.17)
      (9,12) (0.17)
      (13,24) (0.17)

         ..
   EQP-SCHED SCHEDULE THRU DEC 31
           (WD) EQPDAY-1 (WEH) EQPDAY-2  ..

   $ INFILTRATION $
   INFIL-1    DAY-SCHEDULE

      $ HVAC schedules
      $ no ramping, on 1 hour early, off 1 hour late

      (1,7) (1.)
      (8,18) (0.535714269)
      (19,24) (1.)
```

```
         ..
INFIL-2    DAY-SCHEDULE

   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,7) (1.)
   (8,13) (0.535714269)
   (14,24) (1.)

         ..
INF-SCHED SCHEDULE THRU DEC 31
        (WD) INFIL-1 (WEH) INFIL-2  ..


$ BASEMENT SOURCE $
ALLWAYSON SCHEDULE THRU DEC 31 (ALL) (1,24) (1) ..

$ Exterior Surfaces
$ Wall - stone,insulation,air-space,gyp-board
IN-W MATERIAL  RES = 4.9 ..
WALLR LAYERS   MAT = (ST01,IN-W,AL21,GP02) ..
WALL-1 CONSTRUCTION LAYERS = WALLR ..

$ Roof - built-up roofing,4" conc.,insulation,air-space,accoustic tile
IN-R MATERIAL  RES = 11.9 ..
ROOFR LAYERS   MAT = (BR01,CC24,IN-R,AL33,AC02) ..
ROOF-1 CONSTRUCTION  LAYERS = ROOFR ..

$ Floor - 4" light-weight conc., pad, carpet
FLOORR LAYERS MAT = (CC24,CP01) ..
FLOOR-1 CONSTRUCTION LAYERS = FLOORR ..
$ Slab - 6" heavy-weight conc., 2' soil
SOIL MATERIAL  THICKNESS = 2.0  SPECIFIC-HEAT = 0.26
               CONDUCTIVITY = 1.0  DENSITY = 115  ..
SLABL LAYERS  MAT = (SOIL,CC15)  ..
SLAB-1 CONSTRUCTION LAYERS = SLABL  ..

$ Glass
COMPOSITE GLASS-TYPE PANES = 1
       SHADING-COEF = .79
       GLASS-CONDUCTANCE =  0.568181813
       ..


$ Zone Calculations for a two zone building
##set1 flr_area #[area[] / floors[]]
##set1 long_len #[SQRT OF #[flr_area[] / aspect_ratio[]]]

$ Average zone area
##set1 zone_area #[flr_area[] / 2]

$ Average perimeter leg length
##set1 zone_len #[#[long_len[] * #[aspect_ratio[] + 1]] / 2]

                        $ GENERAL SPACE CHARACTERISTICS $

SPACE-1   SPACE-CONDITIONS
          ZONE-TYPE          = CONDITIONED
          TEMPERATURE        = (73)
          PEOPLE-SCHEDULE    = OCC-SCHED    P-H-S = 255  P-H-L = 255
                                            $ ASHRAE Fund. 26.21
```

```
          LIGHTING-SCHEDULE = LIT-SCHED   L-W = 2.2
          LIGHT-TO-SPACE    = 1.00
          EQUIP-SCHEDULE    = EQP-SCHED   E-W = .50
          INF-SCHEDULE      = INF-SCHED
          INF-METHOD        = AIR-CHANGE
          INF-CFM/SQFT      = 0.066666670
          FLOOR-WEIGHT      = 70.
          ..

SPACE-2   SPACE-CONDITIONS  $ Basement
          ZONE-TYPE         = UNCONDITIONED
          INF-METHOD        = AIR-CHANGE
          AIR-CHANGES/HR    = 2            $ Combustion air
          SOURCE-TYPE       = PROCESS
          SOURCE-BTU/HR     =  2476.650146484
                                                     $ 5% Jacket loss
          SOURCE-SCHEDULE   = ALLWAYSON
          FLOOR-WEIGHT      = 130
          ..

                     $ SINGLE FLOOR ZONES $

ZSF1     SPACE
         SPACE-CONDITIONS = SPACE-1
         AREA             = 1375
         VOLUME           =  13750
         NUMBER-OF-PEOPLE =  3.273809433
         ..

EWall    EXTERIOR-WALL CONSTRUCTION = WALL-1
         HEIGHT       = 11
         WIDTH        = 26.747634888
         AZIMUTH      = 90
         ..

EWWndw   WINDOW GLASS-TYPE = COMPOSITE
         HEIGHT =  2.200000048
         WIDTH  = 26.747634888
         ..

SWall    EXTERIOR-WALL CONSTRUCTION = WALL-1
         HEIGHT       = 11
         WIDTH        = 53.495269775
         AZIMUTH      = 180
         ..

NSWndw   WINDOW GLASS-TYPE = COMPOSITE
         HEIGHT =  2.200000048
         WIDTH  = 53.495269775
         ..

WWall    EXTERIOR-WALL LIKE EWall
         AZIMUTH     = 270 ..
         WINDOW LIKE EWWndw ..


ZFloor   INTERIOR-WALL  $ Floor to Basement
         CONSTRUCTION    = FLOOR-1
         AREA            = 1375
         NEXT-TO BASE-1
         ..


ZNF1     SPACE LIKE ZSF1 ..
```

```
        EXTERIOR-WALL LIKE EWall ..
        WINDOW LIKE EWWndw ..

NWall   EXTERIOR-WALL LIKE SWall
        AZIMUTH      = 0 ..
        WINDOW LIKE NSWndw ..

        EXTERIOR-WALL LIKE WWall ..
        WINDOW LIKE EWWndw ..


        INTERIOR-WALL LIKE ZFloor .. $Floor to Basement

                        $ SECOND FLOOR $

ZSF2    SPACE LIKE ZSF1  ..

        EXTERIOR-WALL LIKE EWall ..
        WINDOW LIKE EWWndw ..

        EXTERIOR-WALL LIKE SWall ..
        WINDOW LIKE NSWndw ..

        EXTERIOR-WALL LIKE WWall ..
        WINDOW LIKE EWWndw ..

ZRoof   ROOF  CONSTRUCTION = ROOF-1
        TILT             = 0.0
        GND-REFLECTANCE = 0.0
        HEIGHT           =  25.703207016
        WIDTH            = 53.495269775
        ..

ZNF2    SPACE LIKE ZSF1  ..

        EXTERIOR-WALL LIKE EWall ..
        WINDOW LIKE EWWndw ..

        EXTERIOR-WALL LIKE NWall ..
        WINDOW LIKE NSWndw ..

        EXTERIOR-WALL LIKE WWall ..
        WINDOW LIKE EWWndw ..

        ROOF  LIKE ZRoof ..

                      $ Basement

BASE-1  SPACE
        SPACE-CONDITIONS = SPACE-2
        AREA             = 2750
        VOLUME           = 22000
        ..

SLB-1   UNDERGROUND-FLOOR
        CONSTRUCTION     = SLAB-1
        AREA             = 2750
        U-EFFECTIVE      =    0.129944891
        ..

                     $ BUILDING RESOURCES $

BUILDING-RESOURCE
```

```
$ schedule and intensity/sq ft. above ground floor from LBL hosp BDL
         V-T-SCH          =  EQP-SCHED
         VERT-TRANS-KW    =    1.017500043
         HW-SCHEDULE = OCC-SCHED
         HOT-WATER    =    654.761901855
         ..

$ File loads_rep.inc
$ (08/25/89)

                    $ LOADS REPORT DATA FOR $
                    $      ALL BUILDINGS     $


$ Space peak loads summary, Building peak load components
LOADS-REPORT    S (LS-C,LS-F)  ..


END  ..

COMPUTE LOADS  ..
$ File system.inc
$ (03/22/90)

                    $ SYSTEMS DATA FOR $
                    $   SMALL OFFICE    $

INPUT SYSTEMS  ..



$ system schedules
$ 2/93
$ file sys_sch.inc

                  $ SYSTEM SCHEDULES $

FAN-SCHED SCHEDULE THRU DEC 31
    (WD)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,7) (0.)
   (8,18) (1.)
   (19,24) (0.)

    (WEH)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,7) (0.)
   (8,13) (1.)
   (14,24) (0.)


CLG-SCHED SCHEDULE THRU DEC 31
   (WD)
   $ HVAC schedules
   $ no ramping, on 1 hour early, off 1 hour late

   (1,7) (90)
   (8,18) (75)
   (19,24) (90)
```

```
         (WEH)
         $ HVAC schedules
         $ no ramping, on 1 hour early, off 1 hour late

         (1,7) (90)
         (8,13) (75)
         (14,24) (90)

         ..

      HTG-SCHED SCHEDULE
         THRU DEC 31
         (WD)
         $ HVAC schedules
         $ no ramping, on 1 hour early, off 1 hour late

         (1,7) (55)
         (8,18) (70)
         (19,24) (55)

         (WEH)
         $ HVAC schedules
         $ no ramping, on 1 hour early, off 1 hour late

         (1,7) (55)
         (8,13) (70)
         (14,24) (55)

         ..

      ALWAYSOFF SCHEDULE
         THRU DEC 31
         (ALL) (1,24) (0)
         ..

      ALWAYSON SCHEDULE
         THRU DEC 31
         (ALL) (1,24) (1)
         ..

      VENT-SCHED SCHEDULE
         THRU DEC 31
         (WD)
         $ Equipment schedules
         $ no ramping

         (1,8) (0)
         (9,17) (-1)
         (18,24) (0)

         (WEH)
         $ Equipment schedules
         $ no ramping

         (1,8) (0)
         (9,12) (-1)
         (13,24) (0)

         ..

                  $ SYSTEM PERFORMANCE CURVES $

      IDEAL  CURVE-FIT
             TYPE = LINEAR
```

```
              COEFFICIENTS = (1,0)
   ..

$Zone definitions
     ##def zone_like_list
ZNF1   ZONE  LIKE  ZSF1   ..
ZSF2   ZONE  LIKE  ZSF1   ..
ZNF2   ZONE  LIKE  ZSF1   ..
     ##enddef
     ##defl north_zones ZNF1 ZNF2
     ##defl south_zones ZSF1 ZSF2
     ##defl hvac6a_list SYS1 SYS2 SYS3 SYS4 SYSH1 SYSH2 SYSH3 SYSH4
     ##def  system_like_list
SYS2 SYSTEM LIKE SYS1
     ZONE-NAMES (ZNF2) ..
SYS3 SYSTEM LIKE SYS1
     ZONE-NAMES (ZSF1) ..
SYS4 SYSTEM LIKE SYS1
     ZONE-NAMES (ZSF2) ..
     ##enddef
     ##def  heat_like_list
SYSH2 SYSTEM LIKE SYSH1
     ZONE-NAMES (ZNF2) ..
SYSH3 SYSTEM LIKE SYSH1
     ZONE-NAMES (ZSF1) ..
SYSH4 SYSTEM LIKE SYSH1
     ZONE-NAMES (ZSF2) ..
     ##enddef


ZNAIR = ZONE-AIR
        OA-CFM/PER 15. ..

ZNCON = ZONE-CONTROL
        DESIGN-HEAT-T 70
        DESIGN-COOL-T 75
        HEAT-TEMP-SCH HTG-SCHED
        COOL-TEMP-SCH CLG-SCHED
        THERMOSTAT-TYPE PROPORTIONAL
        BASEBOARD-CTRL THERMOSTATIC ..


ZSF1  ZONE
      ZONE-TYPE CONDITIONED
      ZONE-AIR ZNAIR
      ZONE-CONTROL ZNCON
      ..

zone_like_list[]
ZNF1   ZONE  LIKE  ZSF1   ..
ZSF2   ZONE  LIKE  ZSF1   ..
ZNF2   ZONE  LIKE  ZSF1   ..

BASE-1 ZONE
       ZONE-TYPE UNCONDITIONED ..
            $Small Office System Types$
$no system
##defl sys_list SYS1

SYS1     SYSTEM
         SYSTEM-TYPE      SUM
         FAN-SCHEDULE     ALWAYSON
         ZONE-NAMES       (ZNF1 ZNF2,ZSF1 ZSF2,BASE-1) ..
```

```
##defl sys_rep[] 1

PLT-1     PLANT-ASSIGNMENT   SYSTEM-NAMES (SYS1)  ..

$ File system_rep.inc
$ (11/21/90)

                    $ SYSTEM REPORT DATA FOR $
                    $     ALL BUILDINGS      $

SYSTEMS-REPORT

   ..

$ this removes systems reports
$ ##setl sys_rep 0

##list

END  ..

COMPUTE SYSTEMS  ..
$ File plant.inc
$ (08/22/89)

                       $ PLANT DATA FOR $
                       $  SMALL OFFICE $

INPUT PLANT  ..


PLT-1     PLANT-ASSIGNMENT  ..

$ domestic hot water only
DHW       P-E TYPE DHW-HEATER SIZE -999 I-N 1  ..
PLANT-PARAMETERS
          DHW-HEATER-FUEL NATURAL-GAS  ..


$ File plant_rep.inc
$ (01/30/90)

                    $ PLANT REPORT DATA FOR $
                    $     ALL BUILDINGS     $

PLANT-REPORT

     S (BEPS)  ..

##list

END  ..

COMPUTE PLANT  ..

STOP ..
```

Tables C.1 - C.12
Office Building Loads

Office Building Loads (1)

Southern Large Office in Washington DC							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-2.05	7.18	7.55	-1.96	6.23	5.45
high window R	2.80	-1.05	7.64	7.55	-1.07	6.66	5.45
low window R	1.10	-2.55	7.03	7.55	-3.06	5.91	5.45
high shading coef.	0.90	-1.93	7.54	7.55	-1.74	6.93	5.45
low shading coef.	0.60	-2.22	6.73	7.55	-2.09	5.84	5.45
high wall R	11.00	-1.37	7.37	7.55	-1.75	6.28	5.45
low wall R	0.01	-3.21	6.99	7.55	-3.37	5.99	5.45
high roof R	19.00	-2.01	7.24	7.55	-1.91	6.26	5.45
low roof R	7.00	-2.11	7.14	7.55	-2.04	6.19	5.45
high air changes	0.50	-2.29	6.66	7.55	-2.24	5.75	5.45
low air changes	0.10	-1.85	7.79	7.55	-1.74	6.79	5.45
high window/wall ratio	0.75	-2.79	8.41	7.55	-2.53	7.07	5.45
low window/wall ratio	0.25	-1.74	6.65	7.55	-1.38	5.38	5.45
high internal gains (W/ft2)	1.20	-1.81	8.36	7.55	-1.69	7.38	5.45
low internal gains (W/ft2)	0.50	-2.2	6.54	7.55	-2.12	5.61	5.45
high occupancy (ft2/person)	200.00	-2.27	7.27	7.55	-2.17	6.29	5.45
low lighting power density (W/ft2)	0.70	-2.93	4.23	2.94	-2.45	4.62	2.94

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Large Office in Pasadena							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-0.29	8	7.55	-0.26	7.03	5.45
high window R	2.80	-0.06	8.93	7.55	-0.06	7.91	5.45
low window R	1.10	-0.43	7.68	7.55	-0.6	6.36	5.45
high shading coef.	0.90	-0.24	8.52	7.55	-0.18	8.06	5.45
low shading coef.	0.60	-0.37	7.34	7.55	-0.32	6.46	5.45
high wall R	11.00	-0.11	8.47	7.55	-0.2	7.17	5.45
low wall R	0.01	-0.68	7.51	7.55	-0.75	6.41	5.45
high roof R	19.00	-0.28	8.06	7.55	-0.25	7.08	5.45
low roof R	7.00	-0.29	7.94	7.55	-0.26	6.96	5.45
high air changes	0.50	-0.35	7.43	7.55	-0.32	6.47	5.45
low air changes	0.10	-0.24	8.58	7.55	-0.21	7.66	5.45
high window/wall ratio	0.75	-0.45	9.46	7.55	-0.39	8	5.45
low window/wall ratio	0.25	-0.22	7.37	7.55	-0.13	6.07	5.45
high internal gains (W/ft2)	1.20	-0.22	9.37	7.55	-0.19	8.41	5.45
low internal gains (W/ft2)	0.50	-0.34	7.25	7.55	-0.3	6.28	5.45
high occupancy (ft2/person)	200.00	-0.33	8.2	7.55	-0.3	7.19	5.45
low lighting power density (W/ft2)	0.70	-0.64	4.45	2.94	-0.42	5.05	2.94

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Northern Large Office in Washington DC							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-2	7.41	7.55	-1.76	6.14	5.45
high window R	2.80	-1.04	7.88	7.55	-1.02	6.48	5.45
low window R	1.10	-2.58	7.23	7.55	-2.78	5.86	5.45
high shading coef.	0.90	-1.9	7.7	7.55	-1.55	6.8	5.45
low shading coef.	0.60	-2.2	6.87	7.55	-1.86	5.87	5.45
high wall R	11.00	-1.3	7.63	7.55	-1.49	6.21	5.45
low wall R	0.01	-3.19	7.2	7.55	-2.9	5.95	5.45
high roof R	19.00	-1.94	7.48	7.55	-1.69	6.19	5.45
low roof R	7.00	-2.03	7.39	7.55	-1.8	6.13	5.45
high air changes	0.50	-2.23	6.89	7.55	-2.01	5.62	5.45
low air changes	0.10	-1.8	8.03	7.55	-1.56	6.75	5.45
high window/wall ratio	0.75	-2.69	8.76	7.55	-2.21	6.85	5.45
low window/wall ratio	0.25	-1.7	6.83	7.55	-1.32	5.43	5.45
high internal gains (W/ft2)	1.20	-1.75	8.6	7.55	-1.52	7.33	5.45
low internal gains (W/ft2)	0.50	-2.14	6.77	7.55	-1.91	5.5	5.45
high occupancy (ft2/person)	200.00	-2.21	7.5	7.55	-1.95	6.19	5.45
low lighting power density (W/ft2)	0.70	-2.87	4.43	2.94	-2.21	4.46	2.94

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Large Office in Chicago							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-3.5	6.4	7.55	-3.06	5.22	5.45
high window R	2.80	-2.07	6.91	7.55	-1.97	5.59	5.45
low window R	1.10	-4.36	6.2	7.55	-4.54	4.92	5.45
high shading coef.	0.90	-3.39	6.66	7.55	-2.81	5.83	5.45
low shading coef.	0.60	-3.75	5.92	7.55	-3.18	4.98	5.45
high wall R	11.00	-2.48	6.65	7.55	-2.66	5.31	5.45
low wall R	0.01	-5.25	6.15	7.55	-4.71	4.99	5.45
high roof R	19.00	-3.4	6.48	7.55	-2.94	5.27	5.45
low roof R	7.00	-3.55	6.38	7.55	-3.12	5.21	5.45
high air changes	0.50	-3.88	5.8	7.55	-3.48	4.65	5.45
low air changes	0.10	-3.18	7.09	7.55	-2.75	5.93	5.45
high window/wall ratio	0.75	-4.65	7.55	7.55	-3.78	5.82	5.45
low window/wall ratio	0.25	-3.01	5.91	7.55	-2.35	4.62	5.45
high internal gains (W/ft2)	1.20	-3.18	7.52	7.55	-2.75	6.34	5.45
low internal gains (W/ft2)	0.50	-3.69	5.8	7.55	-3.25	4.62	5.45
high occupancy (ft2/person)	200.00	-3.86	6.33	7.55	-3.39	5.15	5.45
low lighting power density (W/ft2)	0.70	-4.59	3.58	2.94	-3.63	3.64	2.94

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Large Office in Minneapolis							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-5.11	5.69	7.55	-4.47	4.57	5.45
high window R	2.80	-3.21	6.16	7.55	-3.03	4.92	5.45
low window R	1.10	-6.23	5.5	7.55	-6.37	4.28	5.45
high shading coef.	0.90	-4.97	5.93	7.55	-4.16	5.13	5.45
low shading coef.	0.60	-5.42	5.24	7.55	-4.62	4.35	5.45
high wall R	11.00	-3.73	5.93	7.55	-3.94	4.66	5.45
low wall R	0.01	-7.43	5.44	7.55	-6.65	4.34	5.45
high roof R	19.00	-4.96	5.76	7.55	-4.29	4.62	5.45
low roof R	7.00	-5.19	5.67	7.55	-4.55	4.56	5.45
high air changes	0.50	-5.66	5.06	7.55	-5.1	4.01	5.45
low air changes	0.10	-4.65	6.46	7.55	-4.01	5.35	5.45
high window/wall ratio	0.75	-6.71	6.74	7.55	-5.46	5.12	5.45
low window/wall ratio	0.25	-4.44	5.25	7.55	-3.49	4.03	5.45
high internal gains (W/ft2)	1.20	-4.72	6.74	7.55	-4.08	5.62	5.45
low internal gains (W/ft2)	0.50	-5.35	5.13	7.55	-4.71	4.01	5.45
high occupancy (ft2/person)	200.00	-5.64	5.5	7.55	-4.97	4.43	5.45
low lighting power density (W/ft2)	0.70	-6.45	3.06	2.94	-5.19	3.12	2.94

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Large Office in Charleston							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-0.72	8.79	7.55	-0.67	7.82	5.45
high window R	2.80	-0.3	9.35	7.55	-0.29	8.35	5.45
low window R	1.10	-0.95	8.61	7.55	-1.19	7.43	5.45
high shading coef.	0.90	-0.66	9.25	7.55	-0.55	8.72	5.45
low shading coef.	0.60	-0.82	8.21	7.55	-0.75	7.33	5.45
high wall R	11.00	-0.42	9.04	7.55	-0.58	7.89	5.45
low wall R	0.01	-1.28	8.56	7.55	-1.35	7.52	5.45
high roof R	19.00	-0.71	8.83	7.55	-0.66	7.85	5.45
low roof R	7.00	-0.74	8.76	7.55	-0.7	7.79	5.45
high air changes	0.50	-0.83	8.34	7.55	-0.79	7.38	5.45
low air changes	0.10	-0.64	9.34	7.55	-0.58	8.32	5.45
high window/wall ratio	0.75	-1.01	10.4	7.55	-0.9	8.92	5.45
low window/wall ratio	0.25	-0.61	8.1	7.55	-0.45	6.71	5.45
high internal gains (W/ft2)	1.20	-0.62	10.14	7.55	-0.56	9.15	5.45
low internal gains (W/ft2)	0.50	-0.79	8.06	7.55	-0.74	7.1	5.45
high occupancy (ft2/person)	200.00	-0.81	9.16	7.55	-0.75	8.11	5.45
low lighting power density (W/ft2)	0.70	-1.18	5.43	2.94	-0.91	5.96	2.94

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Southern Small Office in Washington DC							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-4.02	6.24	7.34	-4.58	3.68	5.67
high window R	2.80	-2.82	6.74	7.34	-4.07	3.77	5.67
low window R	1.10	-4.49	6.08	7.34	-5.03	3.6	5.67
high shading coef.	0.90	-3.87	6.62	7.34	-4.4	3.98	5.67
low shading coef.	0.60	-4.49	5.23	7.34	-4.77	3.38	5.67
high wall R	11.00	-2.78	6.5	7.34	-3.98	3.69	5.67
low wall R	0.01	-8.06	5.93	7.34	-8.04	3.7	5.67
high roof R	19.00	-3.77	6.26	7.34	-4.19	3.64	5.67
low roof R	7.00	-4.24	6.22	7.34	-5.26	3.75	5.67
high air changes	0.70	-4.68	5.99	7.34	-5.38	3.53	5.67
low air changes	0.20	-3.57	6.42	7.34	-3.99	3.79	5.67
high window/wall ratio	0.40	-4.48	9.26	7.34	-4.79	5.82	5.67
high internal gains (W/ft2)	1.00	-3.5	7.05	7.34	-3.98	4.37	5.67
low internal gains (W/ft2)	0.25	-4.3	5.85	7.34	-4.89	3.34	5.67
high occupancy (ft2/person)	200.00	-4.31	6.45	7.34	-4.85	3.92	5.67
low lighting power density (W/ft2)	1.00	-5.41	4.55	3.34	-5.45	2.82	3.34

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Small Office in Pasadena							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-0.34	7.86	7.34	-0.54	3.92	5.67
high window R	2.80	-0.15	9.03	7.34	-0.4	4.2	5.67
low window R	1.10	-0.44	7.51	7.34	-0.67	3.71	5.67
high shading coef.	0.90	-0.3	8.55	7.34	-0.45	4.47	5.67
low shading coef.	0.60	-0.51	6.05	7.34	-0.65	3.4	5.67
high wall R	11.00	-0.13	8.65	7.34	-0.38	4.1	5.67
low wall R	0.01	-1.38	6.65	7.34	-1.65	3.44	5.67
high roof R	19.00	-0.3	7.99	7.34	-0.44	3.98	5.67
low roof R	7.00	-0.39	7.77	7.34	-0.73	3.84	5.67
high air changes	0.70	-0.5	7.3	7.34	-0.79	3.54	5.67
low air changes	0.20	-0.25	8.3	7.34	-0.39	4.22	5.67
high window/wall ratio	0.40	-0.33	12.74	7.34	-0.4	7.45	5.67
high internal gains (W/ft2)	1.00	-0.25	9.12	7.34	-0.36	5.01	5.67
low internal gains (W/ft2)	0.25	-0.41	7.26	7.34	-0.67	3.42	5.67
high occupancy (ft2/person)	200.00	-0.39	8.07	7.34	-0.61	4.18	5.67
low lighting power density (W/ft2)	1.00	-0.77	5.29	3.34	-0.95	2.69	3.34

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Northern Small Office in Washington DC							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-3.17	6.59	7.34	-3.01	4.72	5.67
high window R	2.80	-2.5	6.93	7.34	-2.65	4.85	5.67
low window R	1.10	-4.18	6.21	7.34	-3.92	4.45	5.67
high shading coef.	0.90	-2.98	7.17	7.34	-2.75	5.38	5.67
low shading coef.	0.60	-3.54	5.64	7.34	-3.18	4.35	5.67
high wall R	11.00	-2.26	6.86	7.34	-2.38	4.83	5.67
low wall R	0.01	-7.6	6.12	7.34	-7.97	4.49	5.67
high roof R	19.00	-2.98	6.63	7.34	-2.86	4.73	5.67
low roof R	7.00	-3.44	6.56	7.34	-3.35	4.71	5.67
high air changes	0.70	-3.81	6.3	7.34	-3.72	4.49	5.67
low air changes	0.20	-2.74	6.82	7.34	-2.51	4.91	5.67
high window/wall ratio	0.40	-3.34	9.89	7.34	-3.16	8.09	5.67
high internal gains (W/ft2)	1.00	-2.71	7.47	7.34	-2.5	5.55	5.67
low internal gains (W/ft2)	0.25	-3.42	6.18	7.34	-3.29	4.33	5.67
high occupancy (ft2/person)	200.00	-3.45	6.79	7.34	-3.31	4.96	5.67
low lighting power density (W/ft2)	1.00	-4.47	4.8	3.34	-3.81	3.71	3.34

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Small Office in Chicago							
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-5.69	5.46	7.34	-5.26	3.81	5.67
high window R	2.80	-4.67	5.82	7.34	-4.73	3.95	5.67
low window R	1.10	-7.21	5.05	7.34	-6.6	3.52	5.67
high shading coef.	0.90	-5.42	6.01	7.34	-4.9	4.44	5.67
low shading coef.	0.60	-6.2	4.57	7.34	-5.48	3.47	5.67
high wall R	11.00	-4.31	5.78	7.34	-4.32	3.96	5.67
low wall R	0.01	-12.27	4.8	7.34	-12.54	3.4	5.67
high roof R	19.00	-5.41	5.52	7.34	-5.04	3.84	5.67
low roof R	7.00	-6.08	5.4	7.34	-5.75	3.77	5.67
high air changes	0.70	-6.65	5.17	7.34	-6.29	3.57	5.67
low air changes	0.20	-5.02	5.69	7.34	-4.51	4.01	5.67
high window/wall ratio	0.40	-6.07	8.55	7.34	-5.63	6.96	5.67
high internal gains (W/ft2)	1.00	-5.09	6.24	7.34	-4.62	4.55	5.67
low internal gains (W/ft2)	0.25	-6	5.09	7.34	-5.59	3.47	5.67
high occupancy (ft2/person)	200.00	-6.11	5.61	7.34	-5.71	3.99	5.67
low lighting power density (W/ft2)	1.00	-7.27	3.88	3.34	-6.21	2.93	3.34

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

Small Office in Minneapolis							
		Pre 1980			1980-1989		
Condition	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
Condition on Parameter		-8.54	4.63	7.34	-7.73	3.16	5.67
	2.80	-7.16	4.96	7.34	-7.03	3.29	5.67
basecase (2)	1.10	-10.55	4.24	7.34	-9.49	2.89	5.67
high shading coef.	0.90	-8.21	5.13	7.34	-7.3	3.74	5.67
low shading coef.	0.60	-9.15	3.81	7.34	-8	2.85	5.67
high wall R	11.00	-6.62	4.94	7.34	-6.46	3.31	5.67
low wall R	0.01	-17.42	3.92	7.34	-17.43	2.67	5.67
high roof R	19.00	-8.15	4.68	7.34	-7.43	3.19	5.67
low roof R	7.00	-9.08	4.57	7.34	-8.4	3.11	5.67
high air changes	0.70	-9.85	4.36	7.34	-9.13	2.94	5.67
low air changes	0.20	-7.63	4.84	7.34	-6.74	3.34	5.67
high window/wall ratio	0.40	-9.3	7.46	7.34	-8.52	6.05	5.67
high internal gains (W/ft2)	1.00	-7.8	5.31	7.34	-6.97	3.81	5.67
low internal gains (W/ft2)	0.25	-8.92	4.31	7.34	-8.13	2.86	5.67
high occupancy (ft2/person)	200.00	-9.17	4.74	7.34	-8.42	3.3	5.67
low lighting power density (W/ft2)	1.00	-10.41	3.23	3.34	-8.86	2.39	3.34

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Office Building Loads (1)

		Small Office in Charleston					
		Pre 1980			1980-1989		
Condition on Parameter	Parameter Value	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)	Htg Load (kWh/ft2)	Clg Load (kWh/ft2)	Lighting (kWh/ft2)
basecase (2)		-1.29	8.38	7.34	-1.62	5.08	5.67
high window R	2.80	-0.8	9.02	7.34	-1.39	5.2	5.67
low window R	1.10	-1.48	8.18	7.34	-1.83	4.99	5.67
high shading coef.	0.90	-1.21	8.87	7.34	-1.5	5.48	5.67
low shading coef.	0.60	-1.54	7.07	7.34	-1.74	4.7	5.67
high wall R	11.00	-0.78	8.75	7.34	-1.34	5.12	5.67
low wall R	0.01	-3.09	7.93	7.34	-3.26	5.1	5.67
high roof R	19.00	-1.18	8.42	7.34	-1.44	5.05	5.67
low roof R	7.00	-1.38	8.35	7.34	-1.94	5.15	5.67
high air changes	0.70	-1.59	8.03	7.34	-2.01	4.87	5.67
low air changes	0.20	-1.09	8.65	7.34	-1.34	5.25	5.67
high window/wall ratio	0.40	-1.37	12.27	7.34	-1.53	7.9	5.67
high internal gains (W/ft2)	1.00	-1.07	9.5	7.34	-1.29	6.04	5.67
low internal gains (W/ft2)	0.25	-1.41	7.84	7.34	-1.8	4.63	5.67
high occupancy (ft2/person)	200.00	-1.4	8.7	7.34	-1.72	5.44	5.67
low lighting power density (W/ft2)	1.00	-2	6.06	3.34	-2.17	3.93	3.34

(1) Heating/cooling loads are the loads which have to be added/removed to/from the space to maintain the space temperatures at specified levels. The effects of temperature setback/setup are built in to these numbers. Lighting loads are the amount of heat added to the space because of the operation of lighting equipment.

(2) Basecase conditions are given in Table 17.

Tables C.13 - C.24
Office Building HVAC System Loads and System Electric Energy Use

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Northern Large Office in Washington DC						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)
Hydronic	2.4	0	0.18	2.13	0	0.15
CV Reheat	6.62	16.86	3.58	5.76	14.39	3.08
CV Reheat with economizer	7.94	11.09	3.64	6.88	9.65	3.12
Multizone	4.53	14.29	3.17	4.01	12.19	2.73
Multizone with economizer	7.57	9.81	3.24	6.56	8.51	2.77
VAV with reheat	3.95	12.72	2.33	3.38	10.74	1.99
VAV with reheat and economize	4.33	8.43	2.22	3.73	7.37	1.9
Fan Coil -	2.17	8.31	0.46	1.94	6.97	0.4
Heat Pump Loop	0.41	0	0.2	0.49	0	0.17

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Northern Large Office in Chicago						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)
Hydronic	4.05	0	0.18	3.58	0	0.16
CV Reheat	9.02	16.67	3.84	7.8	14.03	3.27
CV Reheat with economizer	10.67	8.61	3.82	9.17	7.41	3.25
Multizone	6.25	13.37	3.35	5.5	11.26	2.85
Multizone with economizer	10.2	7.51	3.36	8.76	6.48	2.85
VAV with reheat	6.46	12.72	2.54	5.52	10.55	2.15
VAV with reheat and economize	6.12	6.6	2.24	5.23	5.74	1.91
Fan Coil	3.73	7.05	0.49	3.33	5.79	0.42
Heat Pump Loop	1.13	0	0.22	1.24	0	0.19

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Northern Large Office in Minneapolis						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)
Hydronic	5.79	0	0.21	5.11	0	0.18
CV Reheat	10.56	15.61	3.82	9.15	13.05	3.25
CV Reheat with economizer	12.28	7.44	3.75	10.58	6.43	3.19
Multizone	7.47	12.06	3.33	6.63	10.11	2.84
Multizone with economizer	11.81	6.42	3.28	10.17	5.53	2.79
VAV with reheat	9.02	13.18	2.91	7.73	10.84	2.44
VAV with reheat and economize	7.43	5.58	2.2	6.38	4.86	1.88
Fan Coil	5.36	6.22	0.48	4.8	5.03	0.41
Heat Pump Loop	2.08	0	0.23	2.16	0	0.2

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Southern Large Office in Washington DC						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)
Hydronic	2.48	0	0.18	2.39	0	0.16
CV Reheat	6.63	16.47	3.51	6.54	15.34	3.32
CV Reheat with economizer	7.93	10.82	3.57	7.8	10.3	3.37
Multizone	4.55	13.93	3.12	4.57	12.87	2.94
Multizone with economizer	7.55	9.59	3.18	7.43	9.05	2.99
VAV with reheat	4	12.39	2.28	3.75	11.12	2.09
VAV with reheat and economize	4.34	8.19	2.17	4.23	7.73	2.02
Fan Coil	2.24	8.04	0.45	2.19	7.06	0.43
Heat Pump Loop	0.43	0	0.19	0.62	0	0.18

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant; and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

	Southern Large Office in Charleston					
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)
Hydronic	0.93	0	0.19	0.87	0	0.18
CV Reheat	4.16	17.78	3.5	4.14	16.77	3.32
CV Reheat with economizer	4.89	16.05	3.7	4.87	15.29	3.51
Multizone	2.79	15.83	3.1	2.82	14.81	2.93
Multizone with economizer	4.44	14.08	3.27	4.4	13.31	3.09
VAV with reheat	1.71	13.65	2.28	1.57	12.53	2.12
VAV with reheat and economize	2.26	11.85	2.32	2.2	11.19	2.16
Fan Coil	0.81	10	0.44	0.76	9.02	0.43
Heat Pump Loop	0.08	0	0.19	0.12	0	0.18

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Southern Large Office in Pasadena						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	System Electr. (kWh/ ft2)
Hydronic	0.41	0	0.15	0.37	0	0.13
CV Reheat	3.73	16.35	3.42	3.64	15.21	3.26
CV Reheat with economizer	4.71	11.52	3.51	4.62	10.93	3.35
Multizone	2.25	14	3.01	2.25	12.89	2.84
Multizone with economizer	4.05	9.51	3.05	3.96	8.92	2.88
VAV with reheat	0.8	11.35	2.07	0.72	10.22	1.96
VAV with reheat and economize	1.79	8.99	2.16	1.71	8.43	2.03
Fan Coil	0.34	8.5	0.41	0.31	7.48	0.4
Heat Pump Loop	0	0	0.19	0	0	0.19

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Southern Small Office in Charleston						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)
Hydronic	1.7	0	0.24	2.15	0	0.16
CV Reheat	1.02	11.84	3.54	1.41	7.21	2.21
CV Reheat with economizer	1.01	10.37	3.6	1.4	6.96	2.27
Multizone	4.79	18.37	3.98	3.87	11.46	2.51
Multizone with economizer	7.25	16.83	4.25	5.63	10.83	2.69
VAV with reheat	2.93	14.41	2.67	3.23	9.87	1.8
VAV with reheat and economizer	3.13	12.83	2.66	3.39	8.81	1.81
Fan Coil	1.46	9.27	0.48	1.84	5.71	0.28
Heat Pump Loop	0.7	0	0.24	0.98	0	0.16

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Northern Small Office in Chicago						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)
Hydronic	6.76	0	0.24	6.46	0	0.19
CV Reheat	4.94	7.65	3.58	5.04	5.3	2.62
CV Reheat with economizer	4.93	5.62	3.56	5.02	4.14	2.62
Multizone	9.77	14.85	4.16	8.16	10.45	3.04
Multizone with economizer	15.56	9.04	4.21	12.52	6.68	3.07
VAV with reheat	9.77	13.33	2.88	8.77	10.18	2.23
VAV with reheat and economizer	10.5	7.55	2.72	9.39	5.77	2.11
Fan Coil	6.04	5.89	0.46	5.72	4.14	0.34
Heat Pump Loop	3.35	0	0.27	3.23	0	0.21

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Northern Small Office in Minneapolis						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)
Hydronic	9.83	0	0.26	9.18	0	0.21
CV Reheat	7.52	6.39	3.62	7.37	4.33	2.63
CV Reheat with economizer	7.51	4.61	3.59	7.35	3.35	2.63
Multizone	12.06	13.42	4.24	10.16	9.27	3.09
Multizone with economizer	18.68	7.84	4.21	15.05	5.78	3.07
VAV with reheat	14	14.21	3.28	12.39	11.05	2.67
VAV with reheat and economizer	15.16	6.79	3.1	13.41	5.32	2.54
Fan Coil	8.86	4.97	0.46	8.21	3.41	0.34
Heat Pump Loop	5.06	0	0.29	4.74	0	0.22

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Northern Small Office in Washington DC						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)
Hydronic	4.03	0	0.23	3.96	0	0.17
CV Reheat	2.68	9.11	3.37	2.84	6.51	2.49
CV Reheat with economizer	2.67	7.63	3.36	2.82	5.75	2.5
Multizone	7.09	15.69	3.84	5.92	11.41	2.85
Multizone with economizer	11.48	11.44	3.95	9.28	8.62	2.93
VAV with reheat	5.85	12.89	2.61	5.36	9.85	1.99
VAV with reheat and economizer	6.25	9.24	2.5	5.69	7.06	1.9
Fan Coil	3.49	7.18	0.44	3.42	5.22	0.33
Heat Pump Loop	1.85	0	0.24	1.86	0	0.18

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Southern Small Office in Pasadena						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)
Hydronic	0.55	0	0.18	0.86	0	0.1
CV Reheat	0.27	11.48	3.73	0.38	5.97	2.32
CV Reheat with economizer	0.27	7.16	3.6	0.38	4.13	2.24
Multizone	4.32	18.5	4.14	3.16	10.6	2.59
Multizone with economizer	6.77	13.89	4.26	5	8.13	2.65
VAV with reheat	0.98	11.81	2.5	1.37	7.22	1.55
VAV with reheat and economizer	1.07	10.03	2.49	1.47	6.1	1.54
Fan Coil	0.41	8.32	0.48	0.64	4.16	0.28
Heat Pump Loop	0.11	0	0.25	0.26	0	0.16

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Office Building HVAC System Loads (1) and System Electric Energy Use (2)

Basecase Building

Southern Small Office in Washington DC						
HVAC System	Pre 1980			1980-1989		
	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)	Heat Load (kWh/ ft2)	Cool Load (kWh/ ft2)	HVAC aux (kWh/ ft2)
Hydronic	4.91	0	0.23	5.81	0	0.17
CV Reheat	3.47	8.62	3.49	4.33	5.16	2.26
CV Reheat with economizer	3.46	7.27	3.48	4.31	4.77	2.28
Multizone	8.13	15.75	4	7.03	9.55	2.6
Multizone with economizer	12.89	11.61	4.12	10.59	7.66	2.68
VAV with reheat	7.33	13.33	2.72	7.3	9.08	1.86
VAV with reheat and economizer	7.82	9.31	2.6	7.66	6.31	1.78
Fan Coil	4.41	6.8	0.45	5.13	4.06	0.28
Heat Pump Loop	2.39	0	0.26	2.89	0	0.17

(1) HVAC system loads are the heating/cooling loads which are passed to the HVAC plant, and they include loads added by the distribution system.

(2) This is the electricity used by the components of the distribution system like pumps and fans.

Appendix D - Technology Data Sheets

List of Sheets

Constant-Volume Reheat System

Fan Coil System

Hydronic System

Multi-zone and Dual-Duct Systems

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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 a 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 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: As the name implies, 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 is a unit heater (fan and heating coil hung from the ceiling in the zone being served); the most complex, a single-zone air-handing 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:

Multi-Zone and Dual-Duct Systems

General Description: Multi-zone 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 multi-zone 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 multi-zone 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. Multi-zone systems typically consist of rooftop units with direct expansion cooling and gas heating, serving up to 10 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 multi-zone, 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 multi-zone, 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: Multi-zone 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 to 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 Multi-Zone 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 (VAV) System

General Description: 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, multi-zone, 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 humidities 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 [3]

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

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

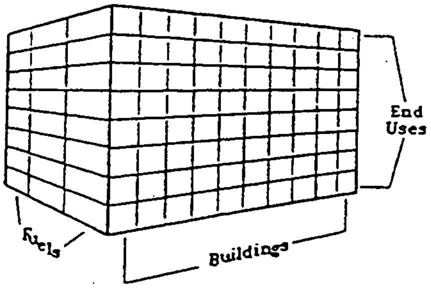
The COMMEND framework segments the commercial market by building type, end use and fuels. The framework is illustrated in Figure E.1. This detailed focus is driven naturally by emerging market issues and analysis needs. For example:

- 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.

Figure E.1

COMMEND Framework



Uses for Market Data

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

BUILDINGS

Small Office
Large Office
Restaurant
Retail
Grocery
Warehouse
Schools
Colleges
Health
Lodging
Miscellaneous

END USES

Space Heat
Cooling
Ventilation
Water Heat
Cooking
Refrigeration
Lighting
Miscellaneous

FUELS

Electricity
Natural Gas
Fuel Oil

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:

$$\text{Annual Energy Use} = \text{EUI} * S * F$$

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.

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:

$$\text{Salesf} = \sum_{v} \text{Ufv} * \text{Efv} * \text{Sfv} * \text{Fv}$$

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.2

COMMEND Framework for Long-Term Forecasting

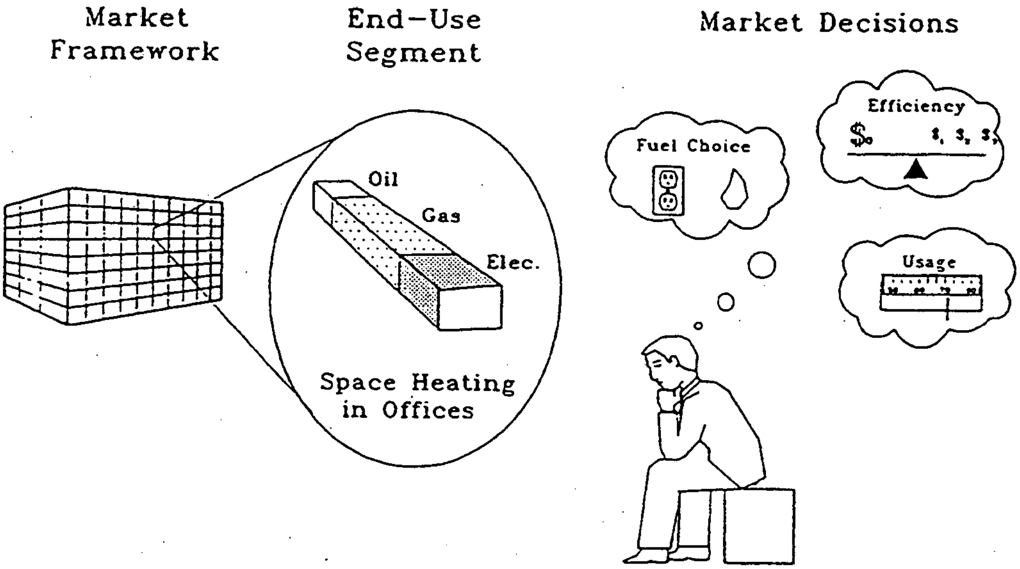
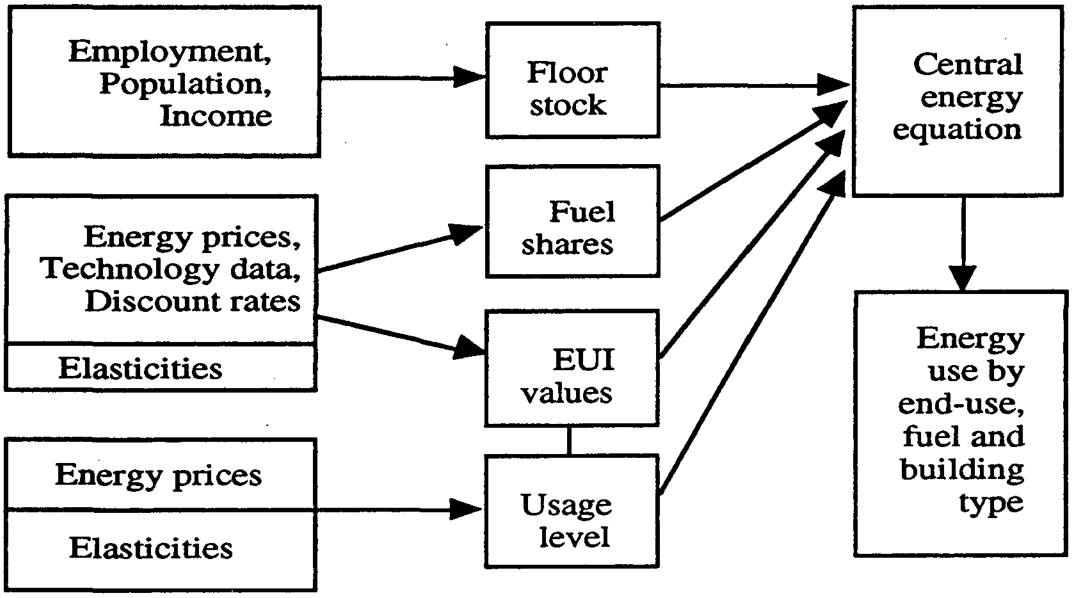


Figure E.3

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.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720