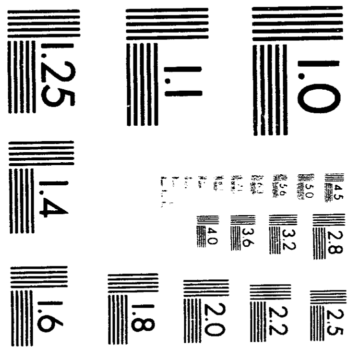

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Energy Conservation Potential of the U.S. Department of Energy Interim Commercial Building Standards

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Summary

Pacific Northwest Laboratory (PNL) conducted this study for the U.S. Department of Energy (DOE). The purpose of this study was to assess the impacts of the DOE Interim Energy Conservation Performance Standards for New Commercial and Multi-Family High Rise Residential Buildings on the energy performance of commercial buildings.

Several energy conservation standards for new commercial buildings were compared on a whole-building energy-use basis. The basic methodology used for this analysis determined standards requirements for building energy simulation input, performed building energy simulations, and compared simulation results. Four building standards, seven distinct building types, two to four heating, ventilating, and air-conditioning (HVAC) systems, and six climate locations were selected for this analysis. Energy consumption results for different HVAC systems in each building type and the impact across climate locations and building types were averaged to summarize the data. This data was then compared to obtain an evaluation of equity of the standards for application in the United States, across a variety of HVAC systems and climates.

The results of this analysis indicate that significant reductions in whole-building energy use are possible with full implementation of the DOE standards. The main conclusions from this study are as follows:

- The energy impacts of building standards changes can be estimated by comparing a building that just complies with one standard to the same building modified to comply with the other standard. This technique ensures that any differences in building energy performance are solely because of changes in the standards.
- Some of the buildings simulated for this analysis met and, in fact, greatly exceeded the performance requirements of the standards, even with uninsulated walls. That fact, as well as the impact of current construction practice on buildings standards comparisons (are any buildings really built to "just" comply with the standard?) can significantly affect energy usage and construction cost.
- Using the 90A-1980 standard as the base building configuration, an average 18% reduction in energy use is predicted with the DOE-93 standard.
- The greatest potential reduction in energy use is in retail buildings and in the coldest climate locations.
- In all climate locations and most building types, the greatest single source of the potential reduction is from reductions in lighting energy use.
- The reduced lighting loads interact with the HVAC system, resulting in reduced cooling loads but increasing heating loads. The net impact on the HVAC system is an overall reduction in HVAC requirement, resulting in possible downsizing of the HVAC equipment.

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1.0 Introduction

This report describes a project conducted to demonstrate the whole-building energy conservation potential achievable from full implementation of the U.S. Department of Energy (DOE) Interim Energy Conservation Performance Standards for New Commercial and Multi-Family High Rise Residential Buildings. DOE's development and implementation of energy performance standards for commercial buildings were established by the Energy Conservation Standards for New Buildings Act of 1976, as amended, Public Law (PL) 94-385, 42 USC 6831 *et seq.*, hereinafter referred to as the Act. In accordance with the Act, DOE was to establish performance standards for both federal and private sector buildings "to achieve the maximum practicable improvements in energy efficiency and use of non-depletable resources for all new buildings..." (42 USC 6831).

The Act was amended in 1980. Section 326, 94 Stat. 1649 of the Housing and Community Development Act of 1980 (PL 399, 42 USC 6833) required DOE to undertake a three-stage process in the development of the standards: promulgate interim standards; conduct a demonstration project; and develop and issue the final standards. DOE is also required to "review the standards on a non-specific periodic basis and revise according to more recent information and research . . . " (42 USC 6833). The Act was amended again by the Omnibus Reconciliation Act of 1981, making the standards mandatory for federal buildings and voluntary for all others.

Following promulgation of the interim commercial standards in January 1989, DOE was required to

> *undertake a demonstration project that will at minimum include an analysis of the impact of the standards on the design, construction costs, and the energy savings, including the types of energy to be realized from utilizing the energy standards...conduct the demonstration project in at least two geographical areas...analyze the impact of the standards on residential builders, especially small builders, and the impact of construction costs on the ability of low- and moderate-income persons to purchase or rent units in such buildings...the demonstration project shall have a duration of one year and that within 180 days of its completion, a report of the results from the demonstration program be sent to Congress...(42 USC 6833).*

Chapter 1 of this report continues with a summary of the historical development of building energy conservation standards (Section 1.1). Section 1.2 provides an explanation of how the body of this report is organized.

1.1 Energy Conservation Standards Development

In 1975, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), in cooperation with the Illuminating Engineering Society of North America (IES) and under procedures approved by the American National Standards Institute (ANSI), approved and published ANSI/ ASHRAE/IES Standard 90-75 (hereinafter called Standard 90-75), "Energy Conservation in New Building Design." The standard provided minimum criteria for designing energy-conserving buildings. Shortly thereafter, the Energy Production and Conservation Act (PL 94-163) was passed. The Act held out federal financial support for state energy programs based, in part, on their adoption of energy standards no less stringent than Standard 90-75. An opportunity for the states was created. Beginning in 1975, many states passed legislation and adopted regulations making energy standards part of the building design and construction process. Concurrently, DOE (formerly the Energy Research and Development Administration [ERDA]) began developing programs to assist the states with energy standards implementation.

Standard 90-75 was revised in 1980 and became, in part, ANSI/ASHRAE/IES Standard 90A-1980. Soon thereafter, the Council of American Building Officials (CABO) sponsored updates to the Model Energy Conservation Code, MECC-77. The first update was in 1983 when the MECC-77 was updated to include requirements in Standard 90A-80. Since then, the CABO process has allowed consideration of proposed changes, resulting in annual revisions to the code. Concurrent with these national voluntary standards and model codes initiatives, DOE remained active in energy standards work, in response to PL 94-385.

Two major initiatives sponsored by DOE during the 1980s on building energy standards development, and in response to PL 94-385, were special projects coordinated by ASHRAE. One of the projects, Special Project 41 (SP 41), brought together experts in the design, construction, and estimating fields to determine what revisions to Standard 90A-80 were feasible and cost-effective. Through the use of energy consumption simulations, sample buildings were designed, modified, and redesigned with a view toward the energy use reduction attributable to different product and systems strategies. The costs associated with the products and systems were reviewed as well, and decisions were made concerning what design strategies were cost-effective. The results of this effort were evaluated and provided a basis for a series of recommendations on how Standard 90A-80 could be revised to more effectively address energy conservation in new buildings. These recommendations were used in the ASHRAE/IES process for developing consensus standards. The most recent is ASHRAE/IES Standard 90.1-1989, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings" (hereinafter referred to Standard 90.1-89).

Using Standard 90.1-89 as a basis, DOE developed interim energy conservation standards for federal buildings. These federal standards were promulgated in 1989 as 10 CFR 435, Subpart A, *Energy Conservation Voluntary Performance Standards for Commercial and Multi-Family High Rise Residential Buildings; Mandatory for New Federal Buildings; Interim Rule*. The federal standards include performance requirements for new construction starting in 1989 and more stringent performance requirements for construction starting in 1993. In the remainder of this report, the 1989 performance requirements are referred to as DOE-89; likewise, the 1993 performance requirements are termed DOE-93.

1.2 Report Organization

In Chapter 2, the basic analysis methodology used to derive the energy conservation impact of the standards is described. The energy conservation by building type, climate location, and system component is summarized in Chapter 3. The conclusions reached are presented in Chapter 4.

2.0 Methodology

Energy conservation standards provide design requirements for building systems that affect energy consumption. The intent of the standards is to improve energy efficiency in buildings at a reasonable cost. Advances in building systems since 1975 justified the development of standards that specified increased energy efficiency in buildings. The rising cost of energy over the same period forced organizations to adjust patterns of energy consumption. Standards have continually been revised to meet these changes.

In this study, we compared several energy conservation standards for new commercial buildings on a whole-building energy-use basis. Although efficiency improvements in individual components of buildings are understood, the impact of these improvements on whole-building performance is not widely known. Whole-building performance is stressed in this analysis because the key to further reductions in building energy consumption is understanding how whole buildings perform and how the envelope, lighting, and equipment interact.

The basic methodology used for this analysis involved three steps:

1. determination of standards requirements for building energy simulation input
2. performance of building energy simulations
3. comparison of simulation results.

Ten building types were modeled with a building energy simulation tool, DOE-2.1C (Lawrence Berkeley Laboratory [LBL] 1984), in six different locations spanning the range of the climates in the United States. The chosen measure of standards effectiveness was annual energy consumption. Comparisons of energy consumption under the requirements of each standard were made within building types.

2.1 Sample Selection

Before any analysis of the impacts of building energy standards begins, four fundamental questions must be answered:

- How many standards will be compared?
- How many building types will be modeled?
- How many different heating, ventilating, air-conditioning (HVAC) systems will be modeled for each building type?
- How many building locations will be used?

These questions are critical because the answers to them have a direct influence on the size of the analysis activity. The number of combinations that must be examined is the multiplicative product of the answers to each of the above questions. For example, if a comparison is desired for 5 building standards, 15 building types (each with 2 HVAC systems), and 50 locations, then a total of 7500 combinations of standard/building/location must be examined. If only 10 locations are chosen, the total number of combinations drops to 1500.

2.1.1 Building Standards Selection

The building standards chosen for our analysis were as follows:

- ANSI/ASHRAE/IES Standard 90A-1980 (ASHRAE 1980) - a nationwide standard that replaced ANSI/ASHRAE/IES 90-75 (referred to as 90A-1980 in the remainder of this report)

- U.S. Department of Energy Interim Standard (DOE 1989) - a voluntary performance standard for commercial and multi-family high rise residential buildings; mandatory for new federal buildings (referred to as DOE-89 in the remainder of this report)

- U.S. Department of Energy Non-Residential Standard (DOE 1989) - a new standard to replace the previously mentioned Interim Standard in 1993 (referred to as DOE-93 in the remainder of this report).

Standards that were not included in this analysis are ANSI/ASHRAE/IES Standard 90-75 (ASHRAE 1975), the first energy conservation standard developed for nationwide use; and ANSI/ASHRAE/IES Standard 90.1P (ASHRAE 1987), the replacement for ANSI/ASHRAE/IES Standard 90A-1980. Standard 90-75 was not included in this analysis because comparisons between 90-75 and later standards have been previously published. ANSI/ASHRAE/IES Standard 90.1P was not included because it is functionally equivalent to DOE-89.

2.1.2 Building Characteristics

Seven distinct building types were selected for analysis in this study. Several models were included for the two major types--office and retail--making the number of study buildings equal to 10. These building types represent large fractions of both the existing building stock and new construction in the United States. These building types also represent large fractions of the total commercial buildings energy use and the total commercial floor area. The building types represented in this report cover 81% of the existing building stock square footage, 69% of the existing building stock energy usage[(a)] and 79% of the existing stock number by number of buildings (Energy Information Administration 1991). The buildings were constructed between 1973 and 1982. The building characteristics are summarized in Table 2.1. More detailed descriptions of the buildings are included in Appendix A.

The 10 buildings were originally simulated as part of a program to develop the 1989 DOE standard for new commercial buildings (10 CFR 435). The standards development program was known informally as SP 41, for ASHRAE Special Project 41, and was managed by Pacific Northwest Laboratory (PNL). The report of the program (referred to as the SP 41 report from now on) was a four-volume series entitled *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings* issued as 40 documents (PNL 1983).

2.1.3 Climate Locations

The six climate locations used in this study are listed in Table 2.2. These locations span the range of climates typical of the country.

Building energy simulations were conducted with DOE-2.1C (LBL 1984) using the Weather Year for Energy Calculations (WYEC) data set for each of the selected locations.

2.1.4 HVAC Systems Selection

Two to four HVAC systems were studied for each building type. The systems are basically those chosen for the SP 41 analysis.

(a) Based on 1979 data.

Table 2.1. Building Description Summary

Building	Area, gross ft²	Basement	Stories	Glazing, percent
Apartment	495,886	Yes	9	30
Small Office	2,250	No	1	36
Medium Office	48,664	No	3	40
Large Office	797,124	Yes	38	35
Church	12,920	No	1	20
School	112,747	No	2	16
Hotel	250,244	No	10	72
Anchor Retail	159,134	No	2	7
Strip Shopping	11,760	No	1	24
Warehouse	43,002	No	1	1

Table 2.2. Characteristics of Selected Climate Locations

Location (ID)	Heating Degree Days	Cooling Degree Days
El Paso, Texas (ELP)	2677	2097
Lake Charles, Louisiana (LCH)	1433	2889
Madison, Wisconsin (MAD)	7729	459
Los Angeles, California (LAX)	1818	614
Seattle, Washington (SEA)	5184	128
Washington, D.C. (WDC)	5008	940

Complete descriptions of each system for specific building types are found in Appendix A.

2.2 Comparison of Buildings Across Building Standards

The impact of building energy standard changes on whole-building energy usage is commonly analyzed by selecting a group of buildings and a number of different locations in the United States and then modeling the buildings, using an accepted building simulation tool, as they would have been built under each standard. Implicit in this analysis is the assumption that any changes in building energy usage are the result of changes made to the buildings to enable them to comply with the standards. To ensure that this assumption is valid, two conditions must be met. First, Building A as modeled under Standard 1 must be as close as possible to Building A as modeled under Standard 2. Second, Building A should be modeled to comply as closely as possible with the different standards.

The first condition, which basically calls for uniformity in modeling assumptions, ensures that any assumptions not directly related to building standards are consistent from standard to standard for a specific building. For example, the number of occupants in the building and the schedules associated with those occupants are important modeling assumptions that are not specified in building energy standards. If Building A built to Standard 1 is modeled using one set of occupants and schedules, and Building A built to Standard 2 is modeled with another set of occupants and schedules, then the apparent changes in whole-building energy usage between Standard 1 and 2 could be caused solely by the changes in occupancy.

The second condition, requiring that the building be made to comply as closely as possible to the applicable standard, is also vital if Building A is going to be modeled under two different standards. If Building A is made to comply exactly with Standard 1 and then made to exceed the requirements of Standard 2, then comparison of the two standards will be distorted by the fact that the building was overdesigned under Standard 2. A building is said to be in minimal compliance if the building as designed just meets the requirements of the standard. All buildings modeled in this study were minimally compliant with the appropriate standards.

Note that the condition of minimal compliance does have some implications when applied to real buildings. Suppose that a building requires exactly 2.6 in. of a specific type of wall insulation to minimally comply. If that insulation is commonly available in 2-, 3- or 4-in. thicknesses, common practice would call for the use of 3 in. of insulation because that is the least amount of insulation (and presumably lowest cost) that will allow the building to meet the standard. The building would no longer be minimally compliant, however, because the insulation levels are 0.4 in. thicker than necessary. If Building A required 2 in. of insulation to meet Standard 1 and 2.6 in. of insulation to meet Standard 2, then common practice would use 2 in. for Standard 1 and 3 in. for Standard 2. Comparison of Building 2 under Standard 1 with Building A under Standard 2 would then show that Building A built to Standard 2 used less energy, but part of the energy savings would be the result of the excess 0.4 in. of insulation.

An even worse situation could occur if Standard 1 called for 2.6 in. of insulation and Standard 2 called for 2.9 in. of insulation. Common practice here might be to use 3 in. of insulation for each standard. In this case, modeling of the building built to these two standards would show that the standards gave the same whole-building energy usage. This is definitely not the correct result, and the distortion of the results is caused entirely by common practice. The role of common practices as they affect building energy standards is beyond the scope of this report, and the remainder of this work will focus on minimally compliant buildings.

An interesting exception to the minimally compliant condition occurs when the building is sub-minimally compliant. A building is said to be sub-minimally compliant if it exceeds performance specified by the building standard. If the building exceeds the performance required by the standard even with little or no insulation and low-performance glass, then there is not much to be done to the building that will make it minimally compliant short of increasing the amount of window area in the building. If, as in this study, the geometry and physical characteristics of the building are maintained from location to location and standard to standard, changing the window area is not acceptable, and the analyst is left with a sub-minimally compliant building. In this case, it is important that the building be either sub-minimally compliant under both standards or that the effect of the superior performance be factored into the comparison of the standards.

In this study, attempts were made to keep the degree of sub-minimal compliance the same across standards. However, comparisons of sub-minimally compliant buildings across standards should be considered to be not quite as accurate as comparisons of minimally compliant buildings. In this study, the apartment building was sub-minimally compliant in warmer climates, the school was sub-minimally compliant in cooler climates, and the retail building was sub-minimally compliant in all climates. This should be kept in mind when evaluating the performance of these buildings across building standards.

2.3 Compliance with Building Standards

The examples used in defining minimal compliance and the conditions necessary for accurate standard-to-standard comparisons focused primarily on the building envelope. The issue of compliance goes beyond envelope considerations to include lighting and equipment. Lighting power allowances, the building envelope, and the HVAC equipment all must be compliant for a building to be compliant with all parts of a standard. Lighting power allowances and HVAC system requirements were set to minimally compliant levels for all standards. The problem of sub-minimal compliance, as discussed in Section 2.2, does not affect lighting standards or HVAC system requirements. Early standards (such as Standard 90A-1980) treated the three components of the standard independently. Newer standards have evolved to the point where the interaction between the lighting and envelope components is recognized and quantified in the standard. The impact of lighting and internal building loads as major sources of heat is incorporated in newer standards. HVAC system requirements are based primarily on system efficiency and not on system size, so the interaction between the envelope and HVAC systems is minimal as far as the standards concerned.

2.3.1 Lighting Compliance

Requirements for Standard 90A-1980 are based directly on lighting power density (LPD) values found in the *Illuminating Engineering Society of North America Handbook* (IES 1981). These values were used in previous SP 41 testing (PNL 1983).Requirements for DOE-89 and DOE-93 were calculated using the Lighting Prescriptive and System Performance Compliance Calculation Program, LTGSTD (ASHRAE 1988; Crawley, Riesen, and Briggs 1989). The LTGSTD program is based on Sections 3.3, 3.4, and 3.5 of DOE-89.

2.3.2 Envelope Compliance

Requirements for Standard 90A-1980 are based on the simultaneous solution of Equations 1, 2, and 3 of Section 4 of the Standard. These equations combine the effect of floor, ceiling, and wall insulation levels with glazing characteristics to yield a single solution.

Requirements for DOE-89 and DOE-93 were determined using the Envelope System Performance Compliance Calculation Program, ENVSTD (ASHRAE 1988; Crawley, Riesen, and Briggs 1989). This program is based on Section 5.5 of DOE-89. Floor and ceiling insulation levels are set by a prescriptive method based on the building location. Wall insulation levels, glass transmittance, and shading coefficients were adjusted so that the building just met the requirements of DOE-93. Many possible combinations of wall insulation, glass transmittance, and shading coefficient will yield a compliant building, but we examined only one combination for each building in a specific climate. In most cases, minor changes to the wall insulation or shading coefficients were sufficient to make the buildings comply. Glass transmittance was altered only when necessary.

2.3.3 Equipment Compliance

Requirements for Standard 90A-1980 were taken directly from that standard. Requirements for DOE-89 and DOE-93 were taken directly from those standards.

3.0 Energy Performance of the Standards

An analysis of whole-building energy performance was conducted to compare the energy conservation potential of DOE-89 and DOE-93 commercial building energy conservation standards. The base year construction practice was Standard 90A-1980. Energy end-use data for each of 10 study buildings were predicted through building model simulations using DOE-2.1C for the three building standards for six climate locations.

Summary reports from the model simulations were used to obtain end-use data for the following components: heating, cooling, lights, fans and pumps, service hot water, and miscellaneous (vertical transportation and miscellaneous). In each end-use category, the results of all HVAC systems simulated for each building type were averaged. Tabulated results of individual simulations can be found in Appendix B. Averaging of energy consumption results for different HVAC systems in each building type, followed by a further averaging of the impact of across climate locations and across building type, is done to summarize the data into a concise form for review and to present the results from a national perspective. These comparisons present an evaluation of equity of the standards for application in the United States, across a variety of HVAC systems and climates. Because of uncertainties in the composition and locations of future building stock, no weighing factors were applied in the averaging. The locations used were selected because of their representation of six climates prevalent in the United States. The multiple HVAC systems simulated were selected to represent the typical options available to HVAC designers and building owners.

The metric used to compare the performance of the buildings and the impacts of the standards is energy use intensity--annual energy consumption normalized by gross floor area (kBtu/ft^2/yr) of the building.

3.1 Whole-Building Performance

The annual whole-building energy-use intensities for each building type and climate location are shown in Table 3.1 for the 90A-1980 buildings. As one would expect, there is considerable variation in energy use intensity among the 10 building types and six climate locations. Overall, when averaged across all climate locations, the hotel is the most energy-intensive building type (112 kBtu/ft^2/yr); the warehouse is the least (31 kBtu/ft^2/yr). Not unexpectedly, the average building energy use is most intense in coldest climate locations, represented by Madison, Wisconsin, at 89 kBtu/ft^2/yr and the least intensive in the milder climate locations such as Los Angeles, California, at 57 kBtu/ft^2/yr.

The impacts of the three standards on annual energy use, averaged by building type and by climate location, are shown graphically in Figures 3.1 and 3.2, respectively. At this level of averaging, all building types except the warehouse show energy-conserving trends where total energy consumption decreases when comparing the standards progressively from 90A-1980 to DOE-93. Exceptions to this general energy-conserving trend occur also in some specific building/climate combinations because of the interactions between the lighting energy use and the HVAC load requirements. These are described further in Section 3.3.

The energy savings potential from the two DOE standards compared to the base building configuration, when averaged across all buildings and all climate locations, is 13%

Table 3.1. Energy-Use Intensity (kBtu/ft²/yr) for the 90A-1980 Buildings

Building Type	Building Location						Building
	ELP	LCH	MAD	LAX	SEA	WDC	Average
Small Office	96	89	133	75	106	107	101
Medium Office	80	80	79	68	67	78	75
Large Office	65	65	72	53	58	66	63
Retail	97	99	91	83	74	91	89
Strip Retail	106	109	121	72	85	109	100
Hotel	116	121	123	100	98	116	112
Apartment	64	56	88	39	60	64	62
School	40	32	58	29	42	44	41
Warehouse	25	22	47	20	38	35	31
Church	53	51	77	35	53	62	55
Location Average	**74**	**72**	**89**	**57**	**68**	**77**	**73**

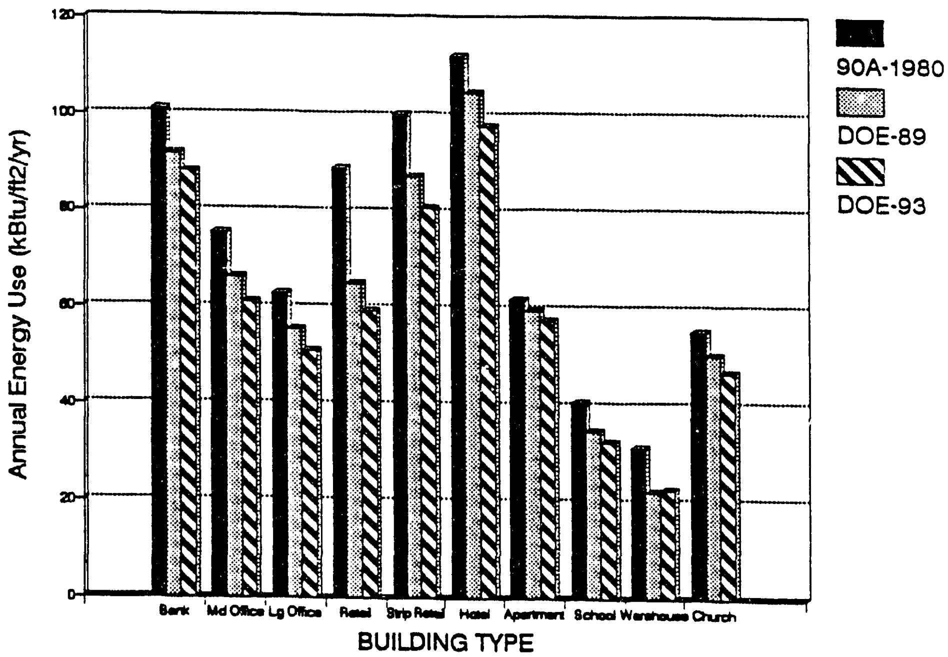

Figure 3.1. Annual Energy Consumption Averaged by Building Type

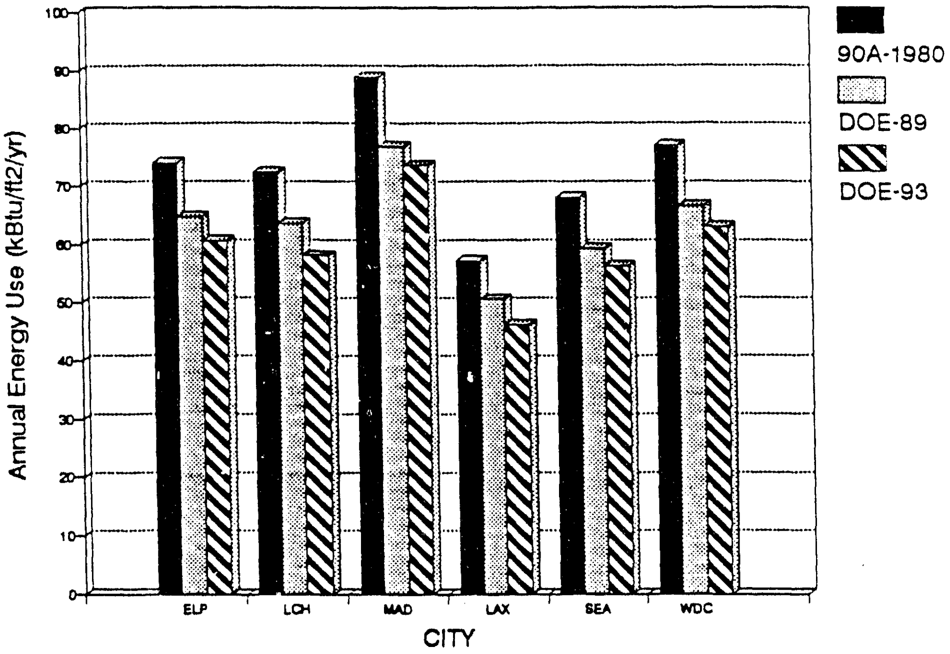

Figure 3.2. Annual Energy Consumption Averaged by Climate Location

for DOE-89 and 18% for DOE-93. The greatest savings occur in the retail building type (see Figures 3.3 and 3.4). The annual whole-building energy conservation potential in the DOE-89 retail building is approximately 27%. An additional 6% savings is possible with implementation of the DOE-93 standard. Energy conservation from the remaining nine buildings ranges from 7% for the apartment to 24% for the warehouse.

The contribution of each of the individual building components toward the conservation of total building energy use was investigated, to assess the relative importance of the energy-efficiency measures in each of the three standards. The annual energy consumption is shown in Figure 3.5 for each end-use component, averaged over all building types and climate l ations. If we consider only the three components that are most directly affected by the standards (heating, cooling, and lighting loads), the most energy-intensive end-use component in the base building is the lighting loads (20 kBtu/ft^2/yr); the least intensive is the cooling loads (14 kBtu/ft^2/yr). The greatest energy conservation potential, in terms of both magnitude of energy saved and percentage reduction from the base buildings, is from a reduction in lighting energy use in response to the reduced lighting power allowance in the standards. So effective are the reduced 1993 lighting power allowances that in the DOE-93 buildings, lighting energy use ranks second to heating energy use (12 kBtu/ft^2/yr compared to 17 kBtu/ft^2/yr).

The relative importance of the heating, cooling, and lighting components varies considerably among the building types and climate locations, depending on building type and climatic conditions.

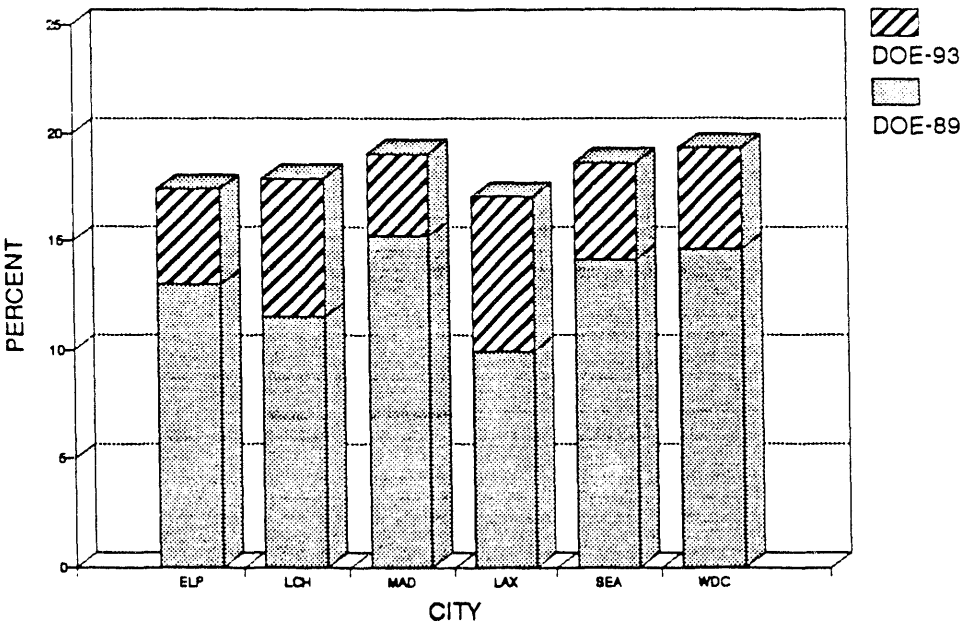

Figure 3.3. Energy Savings Potential from DOE Standards, Averaged Across All Buildings

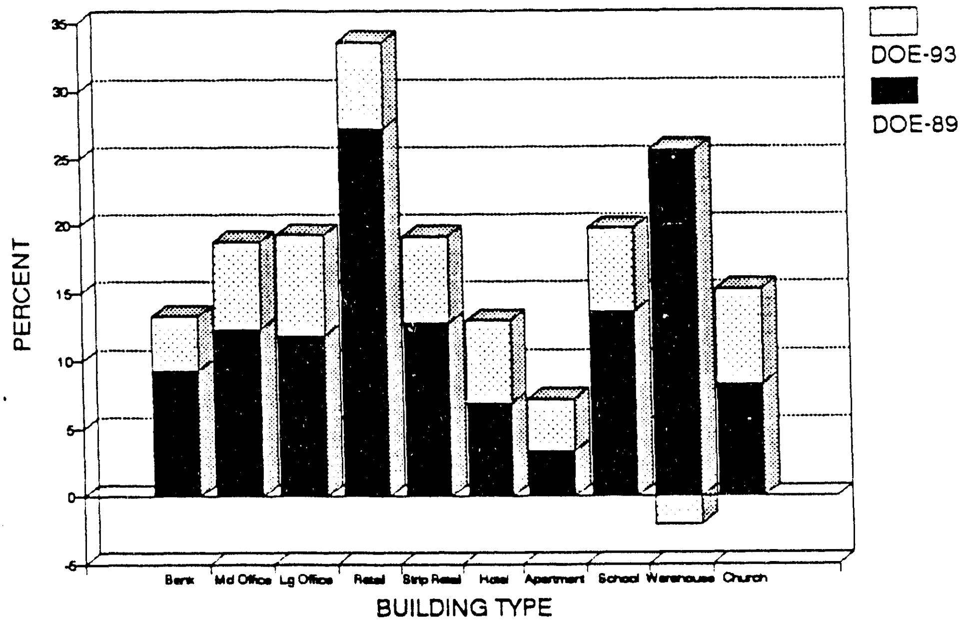

Figure 3.4. Energy Savings Potential from DOE Standards, Averaged Across All Climate Locations

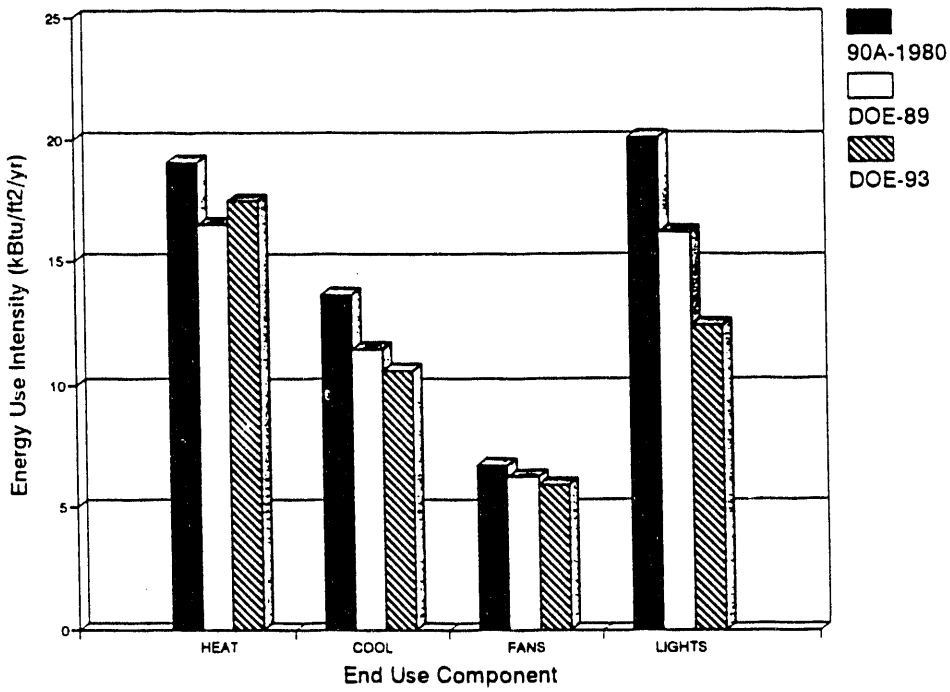

Figure 3.5. Annual Energy Consumption by Building Component

3.2 Energy Savings by Building Type

The annual energy consumption by end-use component, for each building type, aggregated across the six climate locations is shown in Figures 3.6 through 3.15. For each building type, the service hot water (SHW) and miscellaneous categories are identical for all climates and HVAC systems simulated. The SHW and miscellaneous components are set at nominal energy consumption rates in the DOE-2.1C simulation files, while fans and pumps are simulated to work at varying rates for the HVAC systems meeting the space loads. From the averaged and individual simulation results, the fan/pump category varies only slightly among the different HVAC systems within each building type. The miscellaneous category (vertical transportation and miscellaneous) is unaffected by the standards. The SWH component is relatively unaffected.

A decrease in energy consumption in the cooling and lighting components when averaged over all building types and locations is evident when progressively moving from 90A-1980 to DOE-93.

Evidence of thermal interaction between building systems can be found in a closer look at individual building types. Heating, cooling, and lighting interact throughout the different seasons of a year as zone loads are met by the HVAC systems. The progressive reduction of the maximum allowed lighting power from 90A-1980 to the DOE-93 standard causes an increase in space-heating energy consumption because of less lighting heat energy in the heating season. If the reduction in lighting

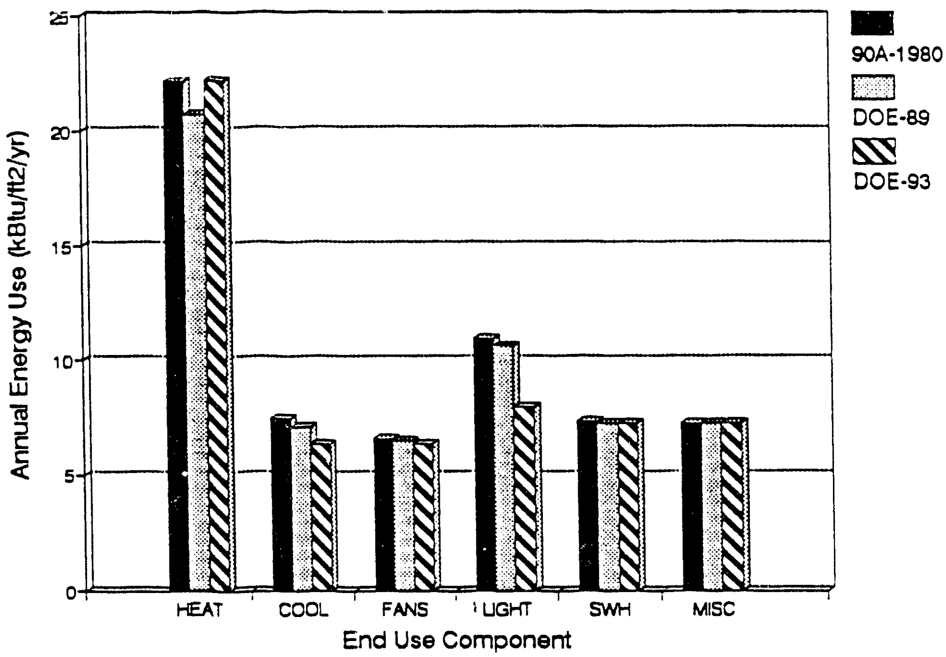

Figure 3.6. Apartment Building Annual Energy Consumption by End-Use Component

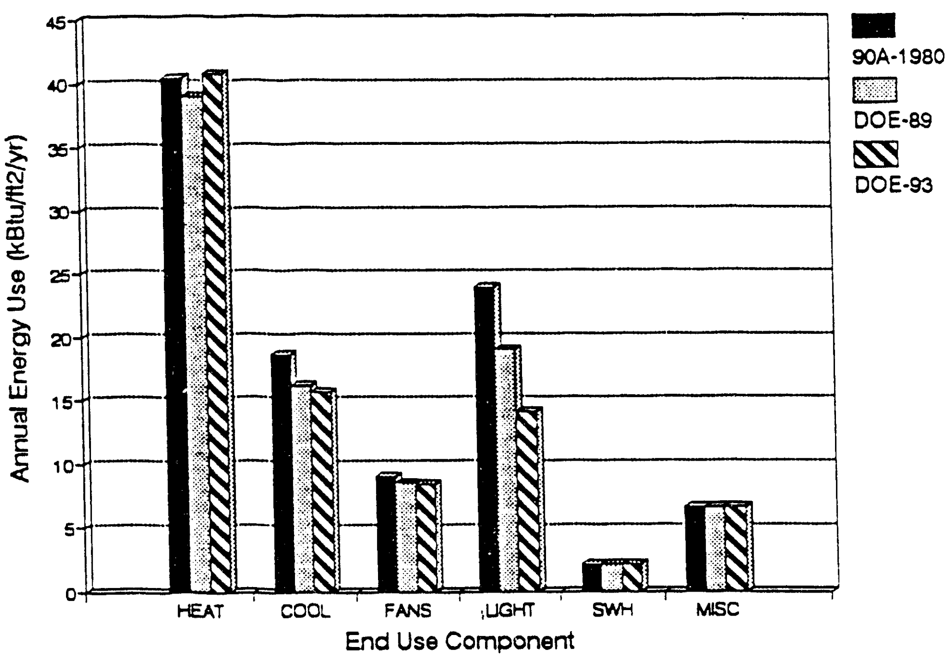

Figure 3.7. Small Office Building Annual Energy Consumption by End-Use Component

power allowance is significant, the increase in heating energy requirement exceeds the energy savings gained from improved equipment efficiency. This results in a net heating energy increase. There is also a reduction in space cooling energy because of less lighting heat energy in the summer.

The hotel, large office, medium office, and anchor retail store buildings (see Figures 3.8 through 3.11) best illustrate this phenomenon. However, each of these buildings still exhibits a net reduction in whole-building energy consumption because of the magnitude of the savings from the reduced lighting and cooling energy requirements.

The results of the model simulations, aggregated by building, are described in detail in the following paragraphs. The descriptions are ordered from the most energy-intensive building (energy consumption per square foot) to the least.

Hotel

When averaged across all climate locations, the hotel is the most energy-intensive building type simulated. For the base building (90A-1980 standard), the whole-building energy consumption is 112 kBtu/ft^2/yr. The largest single end use in the hotel building is the miscellaneous category (approximately 24% of the total for the base case building). The second biggest end use is the cooling loads at 22% of the building total.Total whole-building energy consumption decreases to 98 kBtu/ft^2/yr for DOE-93, a 13% energy savings. By end use, the greatest energy savings are from a reduction in lighting power allowance (a 38% lighting energy savings) and a reduction in cooling energy consumption 27%). There is a small (13%) increase in heating energy consumption from 90A-1980 to DOE-93, because of the interaction of the heating loads and the reduced lighting power allowance specified in the 1993 standard.

Small Office (Bank)

Total building energy consumption for the small office building is 101 kBtu/ft^2/yr for the base building. This decreases to 92 kBtu/ft^2/yr for DOE-89 and to 88 kBtu/ft^2/yr for DOE-93. The largest single energy end use is the heating loads, accounting for more than 40% of the annual building total. Lighting and cooling loads are a distant second and third at approximately 24% and 18%, respectively.

Annual energy use in the small office building decreases to 88 kBtu/ft^2/yr with DOE-93. The lower lighting levels in DOE-93 account for 41% of the total energy savings.

Strip Retail

The strip retail store is the third most energy-intensive building simulated. Total annual energy consumption is 100 kBtu/ft^2/yr. Averaged over all locations, the annual heating and cooling loads are almost identical (27% and 25%, respectively). The largest single energy end use, however, is the lighting load at 32% of the total.

Energy conservation potential in the strip retail store is greatest in the heating and lighting end-use loads, representing 30% and 19% savings, respectively, for the DOE-93 building over the base building. Annual whole-building energy consumption decreases by 13% with the DOE-89 building and an additional 7% with the DOE-93 building.

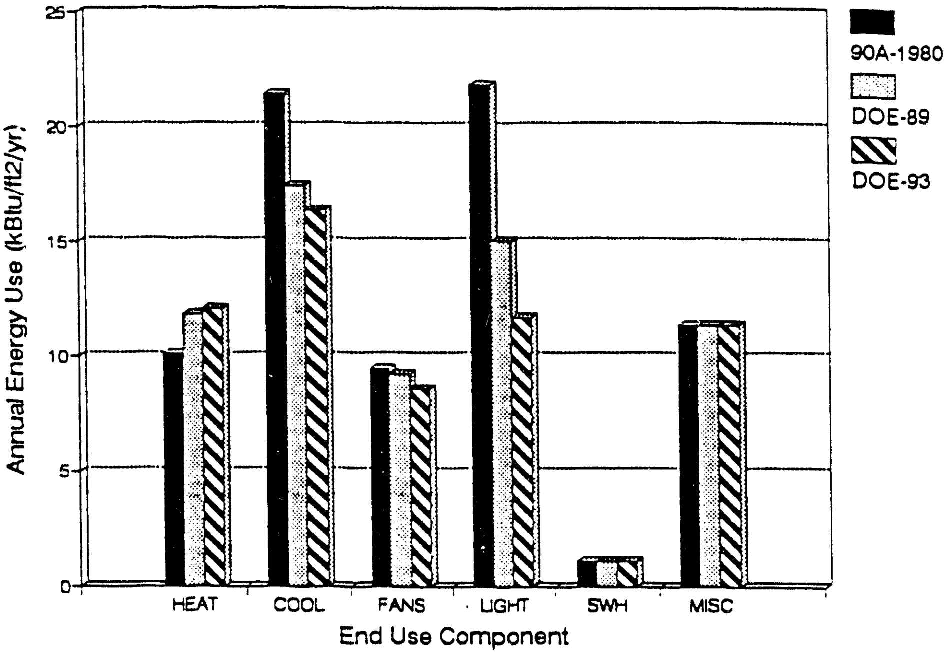

Figure 3.8. Medium Office Building Annual Energy Consumption by End-Use Component

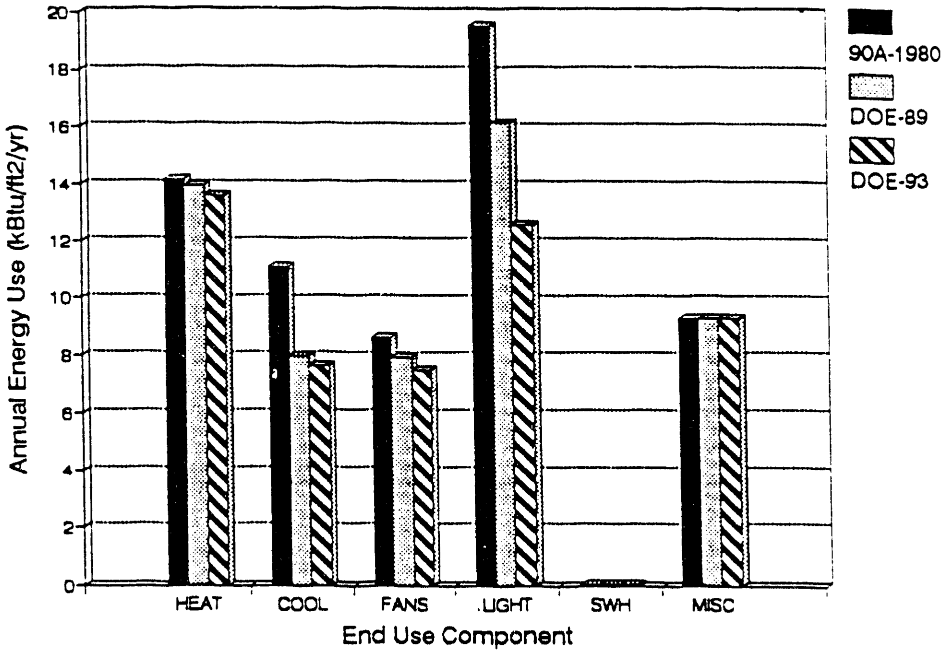

Figure 3.9. Large Office Building Annual Energy Consumption by End-Use Component

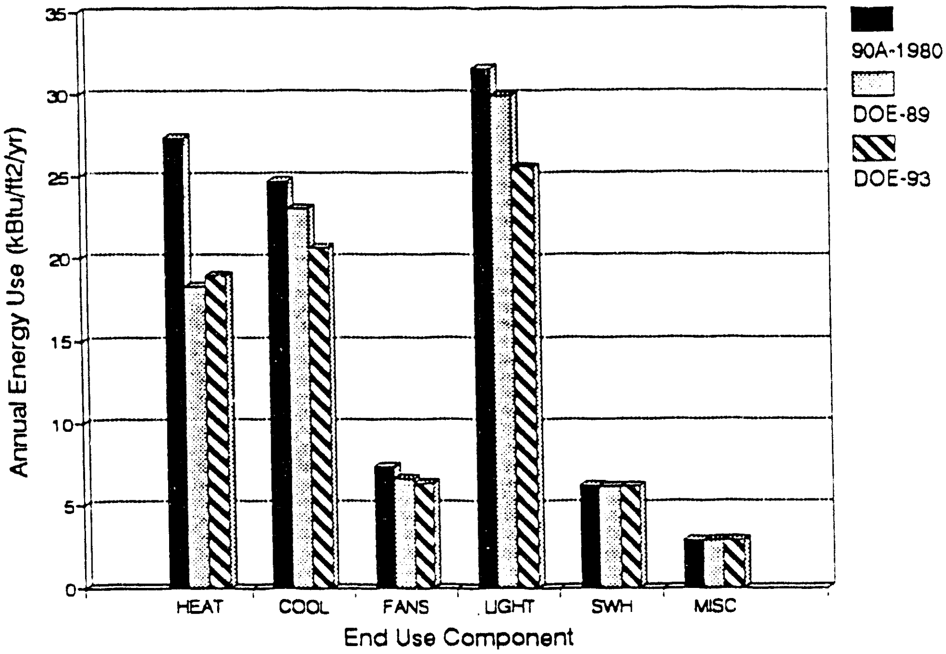

Figure 3.10. Strip Retail Building Annual Energy Consumption by End-Use Component

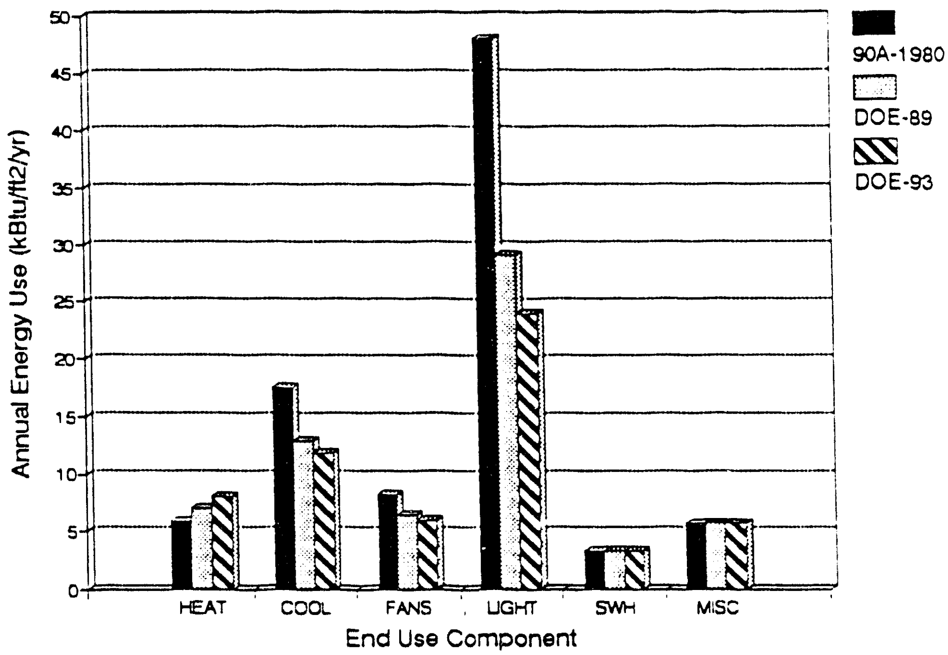

Figure 3.11. Retail Building Annual Energy Consumption by End-Use Component

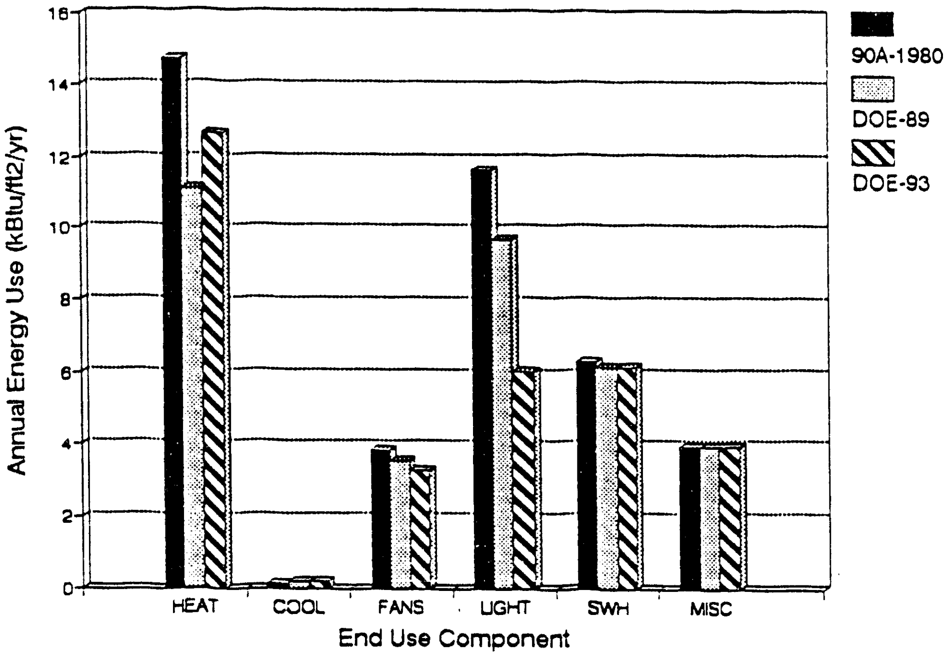

Figure 3.12. School Building Annual Energy Consumption by End-Use Component

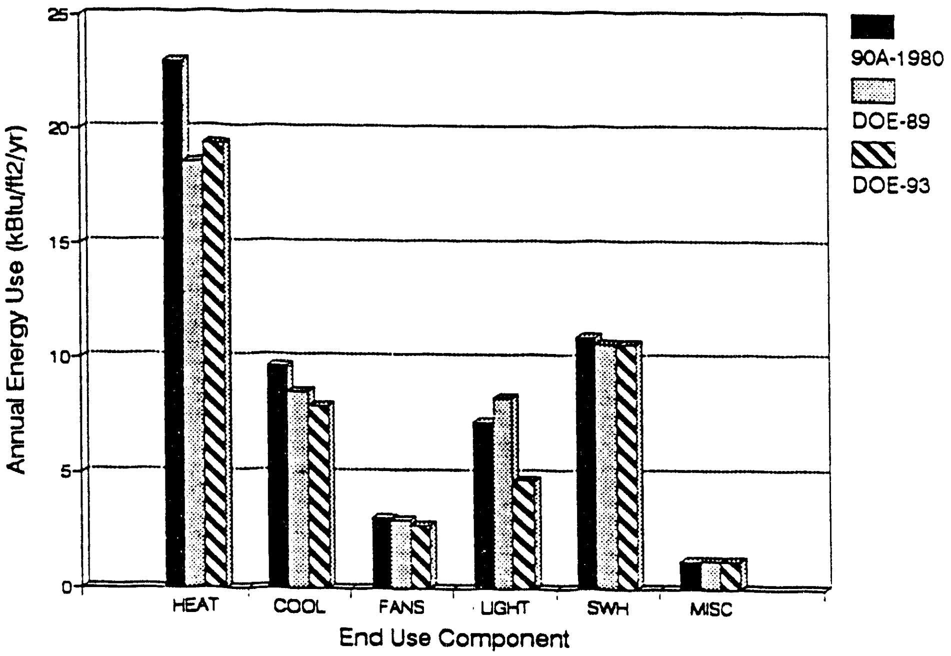

Figure 3.13. Church Building Annual Energy Consumption by End-Use Component

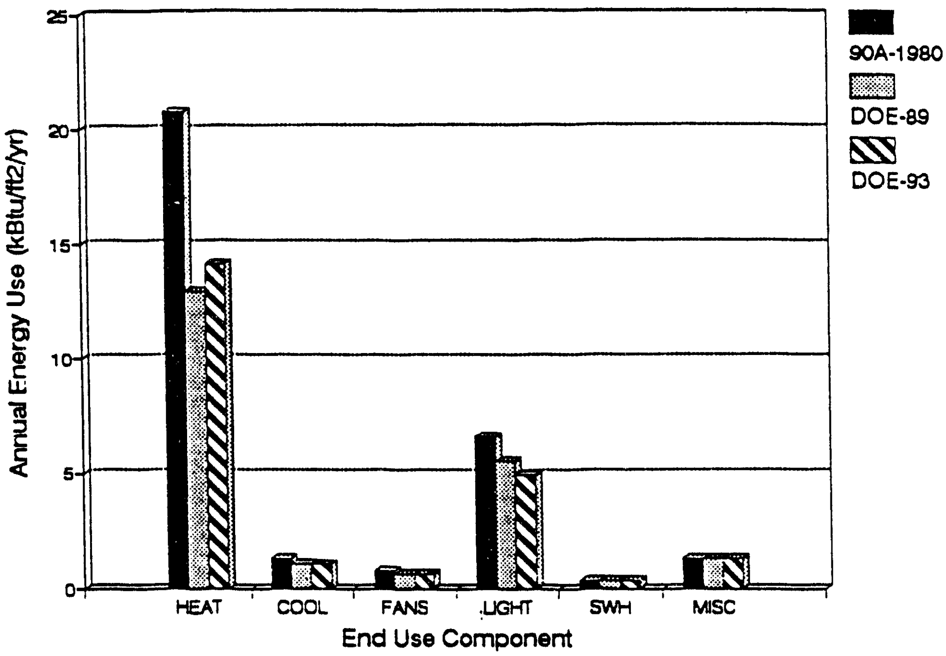

Figure 3.14. Warehouse Building Annual Energy Consumption by End-Use Component

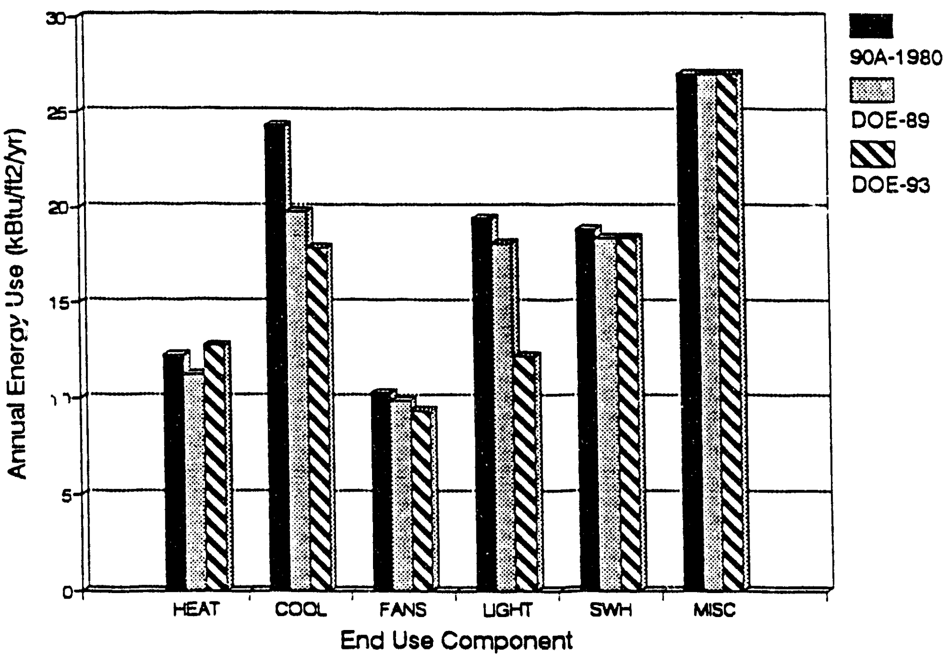

Figure 3.15. Hotel Building Annual Energy Consumption by End-Use Component

Retail

Annual energy consumption for the base retail store is 89 kBtu/ft^2/yr. Lighting loads represent the single most intensive end use at almost 54% of the annual building total. Heating and cooling energy use are only 7% and 20% of the annual total.

Although this building is only the fourth most energy-intensive building type, implementation of the DOE standards generates the greatest energy conservation of the 10 building types simulated. Full implementation of the two standards results in savings of 27% for DOE-89 and an additional 6% for DOE-93.

The most significant energy conservation occurs in the lighting end use as energy use drops from 48 kBtu/ft^2/yr to 29 kBtu/ft^2/yr with the DOE-89 building and to 24 kBtu/ft^2/yr with the DOE-93 building. Heating load energy use goes up by 33% (6 kBtu/ft^2/yr to 8 kBtu/ft^2/yr) with the DOE-93 standard because of the interaction between the HVAC system and the reduced lighting energy use.

Medium Office

Annual energy use in the medium office building is approximately 75 kBtu/ft^2/yr in the base building. Lighting and cooling loads energy use are nearly equal at 29% and 28%, respectively, of the annual total building energy use. Annual heating load energy use makes up approximately 13% of the building total.

Overall, a 19% reduction in whole-building energy use is achievable with implementation of the DOE-93 standard. At the end-use level, the largest energy savings are from the reduction in lighting power allowance. In the DOE-89 building, the lighting load energy use drops 31%; it drops another 16% with the DOE-93 standard. This represents a savings of 113% of the annual whole-building energy use.

Heating load energy use increases 20% in response to the significant reduction in lighting power allowance. Cooling load energy use decreases progressively with the DOE-89 and DOE-93 standards to 77% of the base building cooling energy use.

Large Office

The large office building is the single biggest total energy consumer of the 10 buildings simulated, at an estimated 50,000 million Btu/yr. However, when normalized by building gross area, its energy use intensity ranks sixth at approximately 63 kBtu/ft^2/yr. Lighting energy use is approximately 31% of the annual total for the base building. Heating and cooling load energy uses are 23% and 18%, respectively.

Lighting energy use drops significantly (17%) because of the decrease in lighting power allowance with the DOE-89 standard and an additional 18% with the progression to the DOE-93 standard. Cooling load energy use decreases 31% for the DOE-93 standard. Heating energy use decreases by 4% with DOE-93.

Apartment

The annual energy use intensity for the apartment building is estimated to be approximately 62 kBtu/ft^2/yr. Heating load energy use is the single dominant end use at 36% of the annual total. Lighting and cooling energy use follow with 18% and 12% of the annual building total.

Overall, the apartment building showed the least energy savings potential of the 10 buildings simulated. Implementation of the DOE-89 standards would result in energy savings of less than 4%, with just under 8% achievable with the DOE-93 standard.

Church

The assembly building type, represented by a church, is estimated to use 55 kBtu/ft²/yr for the base condition building. The two largest end-users of energy are the heating and cooling loads--42% and 18%, respectively. Service hot water makes up another 20% of the building total. Lighting energy use is 13% of the building total.

Annual energy savings from implementing the DOE-89 and DOE-93 standards were 9% and 16%, respectively. Greatest savings are from a overall reduction in heating loads--a 16% reduction in energy use.

School

Annual energy use in this base building is 41 kBtu/ft²/yr. The two biggest end-use categories of energy use are heating loads (36% of building total) and lighting loads (29%). Cooling loads are essentially zero because of the operating schedule imposed in DOE-2.

Potential energy savings from implementing the two DOE standards are achieved primarily from a reduction in the lighting power allowance that results in a 50% reduction in lighting energy use. There is also a net decrease in heating load energy use (14%), although progressing from the DOE-89 to the DOE-93 standard, there is a small increase in heating energy use.

Warehouse

The warehouse is the least energy-intensive building simulated. Annual energy consumption is 31 kBtu/ft²/yr. Because of the unique operating constraints of this building type, the only significant end-use loads are from heating (67% of building total) and lights (21% of building total).

A potential energy savings of approximately 28% is achievable with full implementation of the DOE-89 standard, but there is a net increase (<2%) in building total energy consumption in progressing from the DOE-89 to the DOE-93 standard because of the increase in heating loads.

3.3 Energy Savings by Climate Location

The annual component energy use by climate location averaged across the 10 building types is summarized in Table 3.2 and illustrated in the bar charts shown in Figures 3.16 through 3.21. When aggregated across the 10 building types to the climate location, the lighting and miscellaneous components of energy use are the same. It was also assumed that the SWH efficiencies were unchanged between the standards and that the energy consumption remained constant. The most energy-intensive buildings are located in Madison, the coldest climate location modeled. The least energy-intensive is Los Angeles. The impact of climate on the relationship between the heating and cooling loads is evident. The buildings in the three coldest locations with more than 5000 heating degree days--Madison, Seattle, and Washington, D.C.--can be characterized as heating-load-dominated. Buildings in Lake Charles (2889 cooling degree days) characteristically are dominated by significant cooling loads. El Paso is in the middle with nearly equal heating and cooling loads.

On average, the cooling loads decrease progressively from the 90A-1980 to the DOE-89 and DOE-93 standards in all of the climate locations, in response to the decrease in lighting loads. The greatest reductions occur in Lake Charles, the site with the greatest cooling loads. The heating loads decrease with

Table 3.2. Building Energy Consumption (kBtu/ft^2/yr) by End-Use Component, Averaged Across All Building Types

Location	Standard	End-Use Component Consumption Heat	Cool	Fans	Light	Swh	Misc	Total
El Paso, Texas	90A-1980	17	16	7	20	6	8	74
	DOE-89	15	14	7	16	6	8	65
	DOE-93	16	13	6	12	6	8	61
Lake Charles, Louisiana	90A-1980	8	24	7	20	6	8	72
	DOE-89	7	21	7	16	6	8	64
	DOE-93	7	19	6	12	6	8	58
Los Angeles, California	90A-1980	5	12	6	20	6	8	57
	DOE-89	5	10	6	16	6	8	51
	DOE-93	6	9	5	12	6	8	46
Madison, Wisconsin	90A-1980	40	9	7	20	6	8	89
	DOE-89	34	8	6	16	6	8	77
	DOE-93	35	7	6	12	6	8	74
Seattle, Washington	90A-1980	22	6	6	20	6	8	68
	DOE-89	19	5	6	16	6	8	59
	DOE-93	21	4	6	12	6	8	56
Washington, D.C.	90A-1980	22	14	7	20	6	8	77
	DOE-89	19	12	6	16	6	8	67
	DOE-93	20	11	6	12	6	8	63

DOE-89 over 90A-1980, but a slight increase with DOE-93. However, there is still net decrease in the heating loads between 90A-1980 and DOE-93, for all locations except Los Angeles, which shows a slight increase over 90A-1980.

The energy use patterns and savings for the six locations are briefly described in the following paragraphs.

Madison, Wisconsin

Madison represents a cold climate region, with a dominant heating load (45% of building total) and a relatively small cooling requirement (10% of total). Lighting makes up approximately 22% of the total. Madison represents the climate region with the greatest overall building energy use intensity at 89 kBtu/ft^2/yr for the 90A-1980 standard. This decreases to 74 kBtu/ft^2/yr for DOE-93, a 17% savings in total energy consumption.

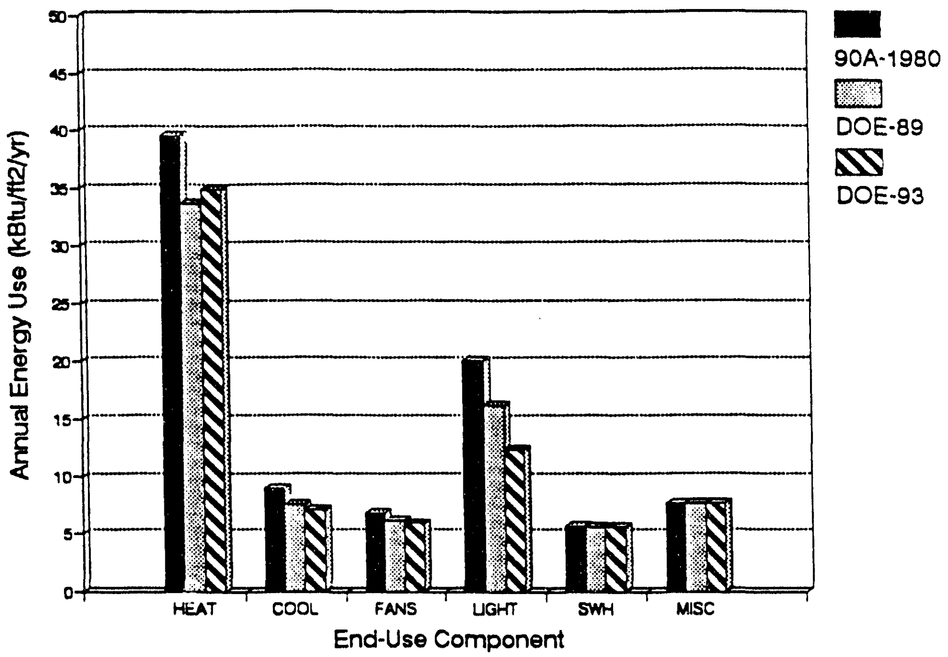

Figure 3.16. Madison, Wisconsin, Annual Energy Consumption by End-Use Component

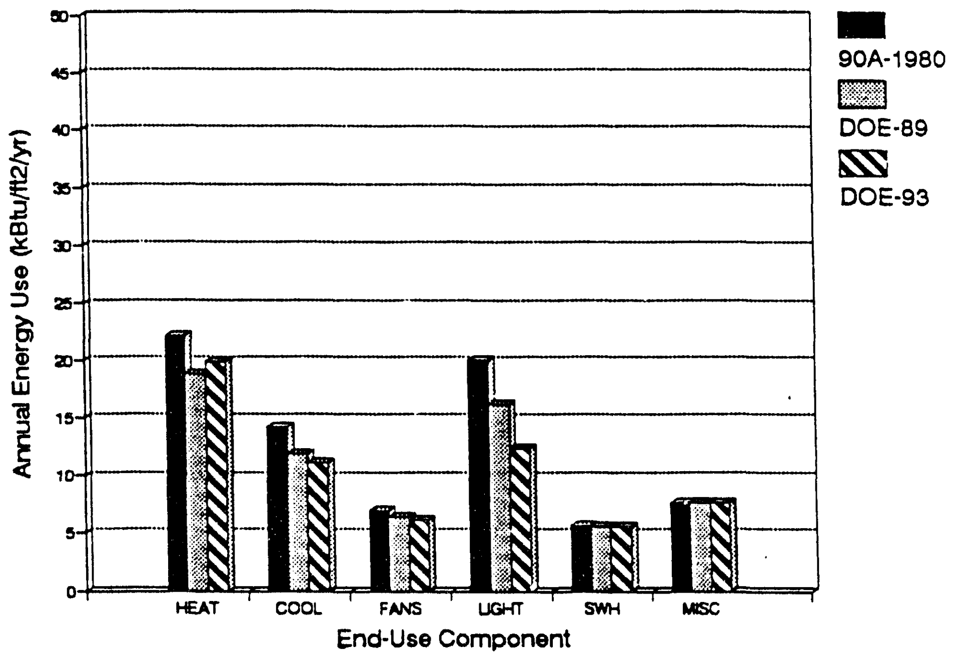

Figure 3.17. Washington, D.C., Annual Energy Consumption by End-Use Component

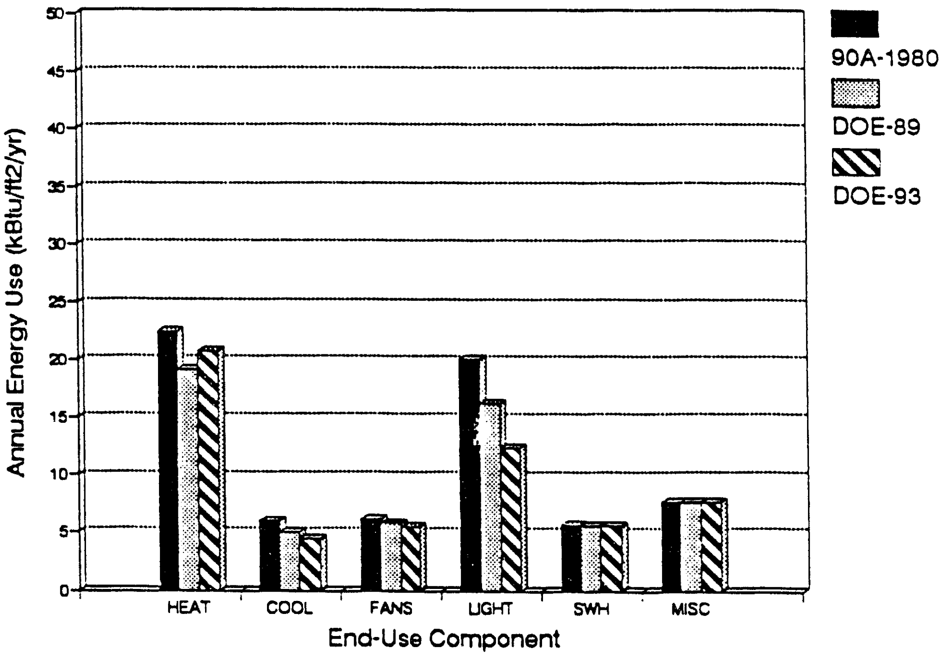

Figure 3.18. Seattle, Washington, Annual Energy Consumption by End-Use Component

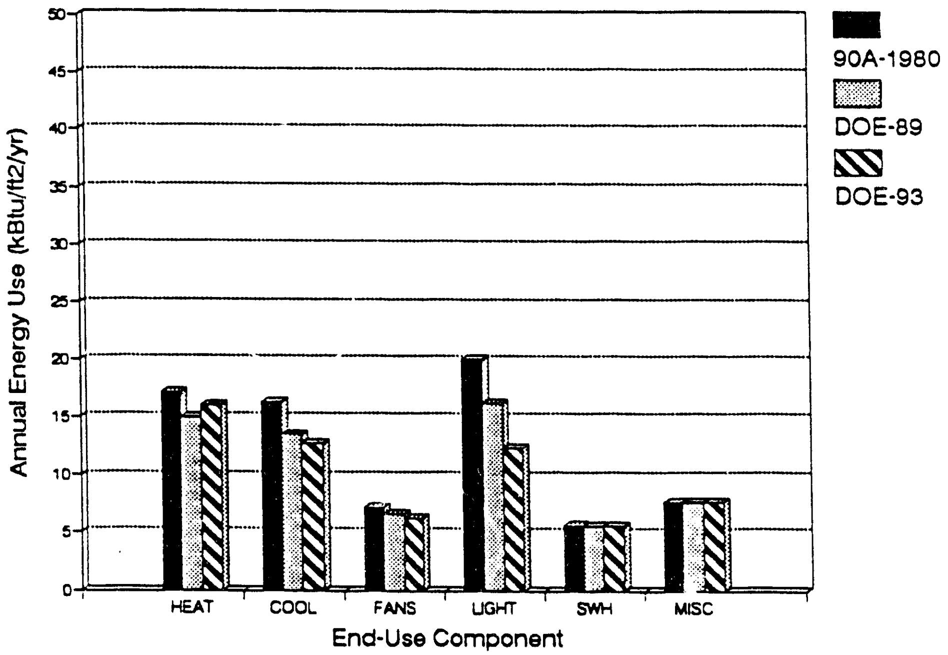

Figure 3.19. El Paso, Texas, Annual Energy Consumption by End-Use Component

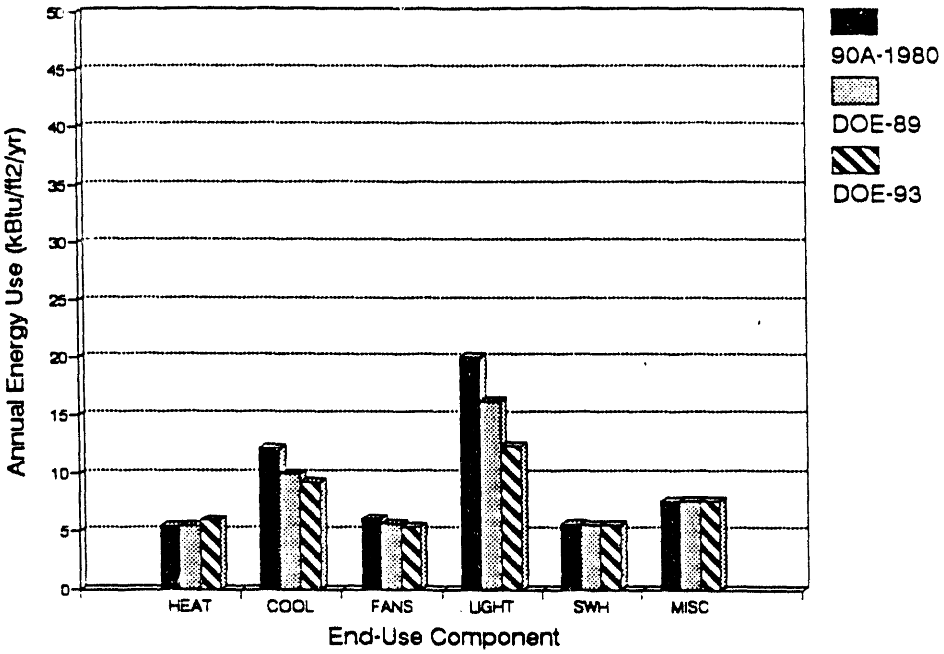

Figure 3.20. Los Angeles, California, Annual Energy Consumption by End-Use Component

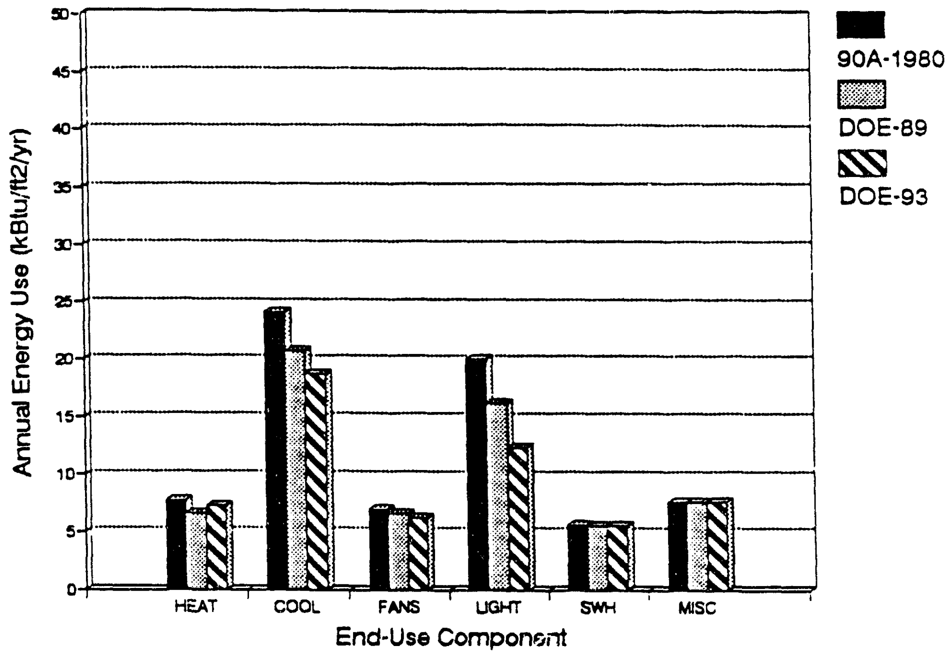

Figure 3.21. Lake Charles, Louisiana, Annual Energy Consumption by End-Use Component

Washington, D.C.

Washington represents a climate region with both a significant heating and cooling requirement. As with the Madison climate, building total energy consumption is dominated by the heating loads (29%), with cooling taking an 18% share of the building total. The lighting end use constitutes approximately 26% of the building total. Total building energy consumption decreases by 17% (77 kBtu/ft^2/yr to 64 kBtu/ft^2/yr) as the full DOE-93 standards are implemented.

El Paso, Texas

El Paso represents a typical hot/dry climate location. It has a small but equal heating and cooling load (24% and 21% share of building total) that is also approximately equivalent to the magnitude of the lighting energy use (25%). The energy savings from implementation of the DOE-89 standard is approximately 13%, with an additional 5% savings from the DOE-93 standard above DOE-89.

Lake Charles, Louisiana

Lake Charles was used to represent a hot and humid climate, with a dominant cooling load requirement. The largest single energy end use, aggregated across all buildings, is the cooling load (approximately 33% of the building total). The lighting end use makes up approximately 28% of the total, with heating loads only 11%. The end-use share does not significantly change between standards. Building total energy consumption decreases from 72 kBtu/ft^2/yr for the 90A-1980 standard to 58 kBtu/ft^2/yr for DOE-93, a 19% change in energy use.

Seattle, Washington

Seattle represents a "neutral" climate region with dominant heating loads. Heating loads decrease from 22 kBtu/ft^2/yr to 19 kBtu/ft^2/yr with DOE-89 (a 14% reduction), but rises up to 21 kBtu/ft^2/yr with DOE-93. Cooling loads are significantly smaller (9%), with lighting making up 29% of the total. Overall building energy consumption decreases from 68 kBtu/ft^2/yr to 56 kBtu/ft^2/yr when progressing from 90A-1980 to DOE-93, a 16% energy savings.

Los Angeles, California

This climate location represents the lowest total building average energy consumption of the six locations simulated. Estimated building energy consumption for the 90A-1980 standard is 57 kBtu/ft^2/yr, decreasing to 46 kBtu/ft^2/yr for the DOE-93 standard. Building end-use energy consumption in Los Angeles is dominated by the lighting loads (35%). Heating and cooling loads are 9% and 21% of the building total, respectively.

In progressing from the base building to the DOE-93 building, the lighting and cooling energy use decreased by 8 kBtu/ft^2/yr and 4 kBtu/ft^2/yr, respectively. Heating energy use increased by 1 kBtu/yr/ft^2 because of the interaction of the decrease in lighting energy use and the HVAC system loads.

4.0 Conclusions

This study was undertaken to assess the impacts of the DOE commercial building standards on the energy performance of commercial buildings. The results indicate that significant reductions in whole-building energy use are possible with full implementation of the DOE standards. The main conclusions from this study are highlighted below.

- The energy impacts of building standards changes can be estimated by comparing a building that just complies with one standard to the same building modified to comply with the other standard. This technique ensures that any differences in building energy performance are due solely to changes in the standards.

- Some of the buildings simulated for this analysis met and, in fact, greatly exceeded the performance requirements of the standards, even with uninsulated walls. That fact, as well as the impact of current construction practice on building standards comparisons (are any buildings really built to "just" comply with the standard?) can significantly affect energy usage and construction cost.

- Using the 90A-1980 standard as the base building configuration, an average 18% reduction in energy use is predicted with the DOE-93 standard.

- The greatest potential reduction in energy use is in retail buildings and in the coldest climate locations.

- In all climate locations and most building types, the greatest single source of the potential reduction is from reductions in lighting energy use.

- The reduced lighting loads interact with the HVAC system, resulting in reduced cooling loads but increasing heating loads. The net impact on the HVAC system is an overall reduction in HVAC requirement, resulting in possible downsizing of the HVAC equipment.

5.0 References

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Appendix A

Building Type Descriptions

Appendix A

Building Type Descriptions

The building types used in the analysis are described and illustrated in this appendix. The three main building components--envelope, lighting, and HVAC systems--are also described. For each envelope and lighting configuration in the building types, two, three, or four HVAC systems are described.

Apartment

Building Description

The multifamily building selected for project testing was built in Edina, Minnesota, in 1977. It is a nine-story structure with underground parking built in the shape of an H with the long sides facing east and west. It consists of 416,686 gross square feet (GSF) excluding parking, which is 79,200 GSF. Residential living quarters occupy 362,736 GSF; 53,950 GSF comprise public areas and corridors. The building illustrated in Figure A.1, is constructed of cast-in-place concrete columns and 4-in. face brick. The building is approximately 13% glass, fairly evenly distributed on all sides. Six electric-traction passenger elevators are installed in the building.

The building schedules were modeled using the Standard 90.1p Section 13 residential schedules. Setpoints were modeled at 75°F cooling and 70°F heating. The night and weekend heating setback was 55°F. As a consequence of the shape and size of the building, zoning is complicated. For HVAC purposes, the apartment zones may be grouped together. Individual zones exist for dining, lobby, recreation, and crafts areas, as well as for the corridors and the garage.

HVAC Systems Descriptions

HVAC Case 1

All apartment zones are served by a four-pipe fan coil system (FPFC). Public areas (except the corridors) are served by individual variable-temperature constant-volume air-handling units (SZRH w/o RH). The corridors and the garage are each served by a packaged rooftop unit (PSZ). The corridors have DX cooling; no cooling is available to the garage. Heat for all zones is provided by hot water coils served by two gas-fired hot water boilers. Two hermetic centrifugal chillers provide chilled water for the FPFC and SZRH systems. Dry-bulb economizers were modeled in each unit for those standards and locations where required. Return fans were not modeled.

HVAC Case 2

All apartment zones are served by air-to-air heat pumps with electric resistance backup heaters (PSZ). All public areas are served by variable-temperature constant-volume direct expansion units with electric resistance heat (PSZ). No cooling is available to the garage. Dry-bulb economizers were modeled in each unit for those standards and locations where required. Return fans were not modeled.

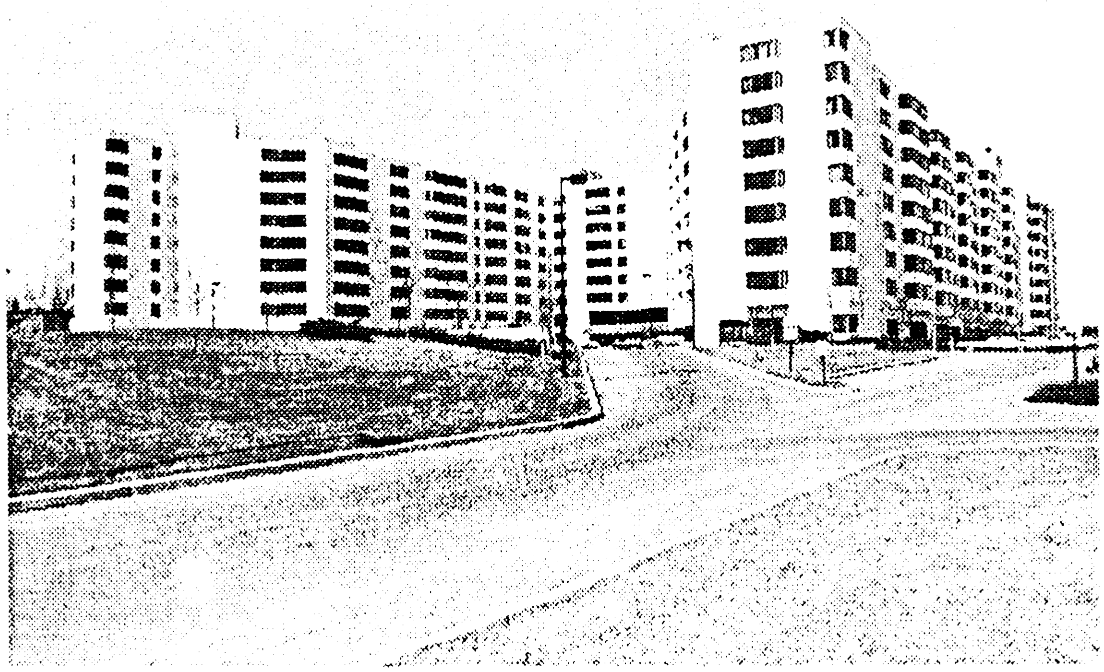

Figure A.1. Apartment Building

HVAC Case 3

All apartment zones and public areas (except corridors and garage) are served by water-source heat pumps (HP). The corridors and the garage are each served by a packaged rooftop unit (PSZ). The corridors have DX cooling; no cooling is available to the garage. The hot-water loop for the HP system and the coils for PSZ systems are served by two gas-fired hot-water boilers. Dry-bulb economizers were modeled in each unit for those standards and locations where required. Return fans were not modeled.

Small Office

Building Description

The small office building selected for testing is a single-floor 2500-ft^2 branch bank (50 ft x 50 ft), constructed in Guilderland, New York, in 1981. The building as modeled is only 2250 ft^2 because a vault occupies the northwest corner (approximately 11 ft x 15 ft), which was not included in the DOE-2 input file. The building was modeled with a floor-to-roof height of 10 ft and a wood frame construction with brick veneer. The building is 45% glass on the north side, 60% on the south, 5% on the east, and 15% on the west. A large overhang on the east side covers the drive-up teller's window and shades one-third of the wall. The structure, shown in Figure A.2, is of above-average construction quality and houses a maximum of 19 occupants.

The building schedules were modeled using the Standard 90.1p Section 13 office schedules. Setpoints were modeled at 75°F cooling and 70°F heating. The night and weekend heating setback was 55°F. The

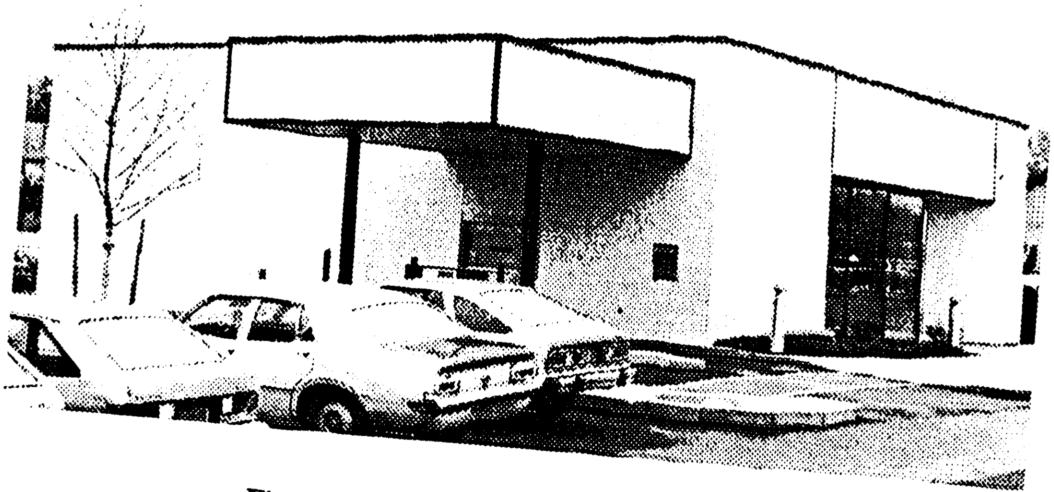

Figure A.2. Small Office Building

building was divided into four HVAC zones for the testing: east-side, south-side, center, and lounge.

HVAC Systems Descriptions

HVAC Case 1

All zones are served by a single packaged rooftop variable-air-volume direct expansion unit (PVAV). The VAV unit heats only to prevent supply temperatures below 55°F. Space heat is provided by electric baseboards. Dry-bulb economizers were modeled in each zone for those standards and locations where required. Return fans were not modeled.

HVAC Case 2

All zones are served by a single packaged rooftop variable-air-volume direct expansion unit (PVAV). The VAV unit heats only to prevent supply temperatures below 55°F. Space heat is provided by hot-water baseboards supplied by a gas-fired hot-water generator. Dry-bulb economizers were modeled in each zone for those standards and locations where required. Return fans were not modeled.

HVAC Case 3

All zones are served by a single packaged rooftop constant-volume, direct expansion, multizone unit equipped with condenser heat recovery. Heating is electric resistance. Economizers were modeled in each zone for those standards and locations where required. Return fans were not modeled.

Church

Building Description

The assembly building selected for modeling in this project was a community center/church, whose basic floor plan is being replicated at various sites across the country. The center is a low-cost, one-floor building of 12,920 GSF. About 12% of the area is chapel, 29% cultural center, and 59% offices and meeting rooms. The building is wood-framed with a trussed roof; the floor-to-roof height is 12.5 ft (average) in the office and meeting rooms and 21 ft in the chapel and cultural center. The building, illustrated in Figure A.3, has approximately 20% glass fairly evenly distributed across all sides.

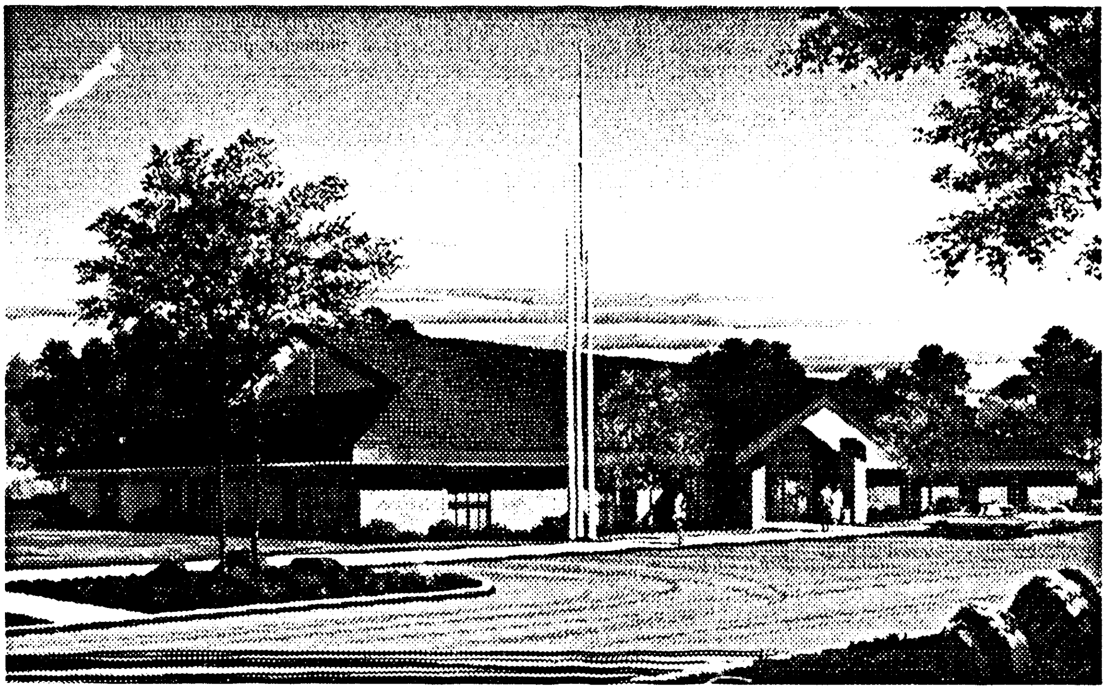

Figure A.3. Church Building

The Standard 90.1P assembly schedules were not used for this building because they represent a schedule more in keeping with a movie theater. Instead, a schedule characterized by heavy use on Sundays (daytime) and on Saturday and weekday evenings for the church and cultural center was used. The offices schedules modeled are those from Standard 90.1P Section 13. Setpoints were modeled at 75°F cooling and 70°F heating and a setback of 55°F. The building was divided into nine zones covering five areas: the chapel, cultural center, hallways, classrooms, and offices.

HVAC Systems Descriptions

HVAC Case 1

Systems serving the chapel, cultural center, hallways and classrooms are variable-temperature, constant-volume direct expansion units with air-cooled condensers (PSZ). Heating is provided by gas-fired heat exchangers. Units serving the offices are through-the-wall packaged heat pumps (PTAC) with electric resistance booster coils and no economizers (economizers are not an applicable option for PTAC systems in DOE-2.1C). Dry-bulb economizers were modeled in the chapel, cultural center, hallways, and classrooms for those standards and locations where required. All systems were modeled without return fans.

HVAC Case 2

Systems serving the chapel, cultural center, and hallways are variable-temperature, constant-volume units with chilled and hot-water coils (SZRH). The classrooms are served by four-pipe fan coil units (FPFC). Hot water is provided by a gas-fired boiler; chilled water is provided by a reciprocating air-cooled chiller. Units serving the offices are through the wall packaged heat pumps (PTAC) with electric resistance booster coils. Dry-bulb

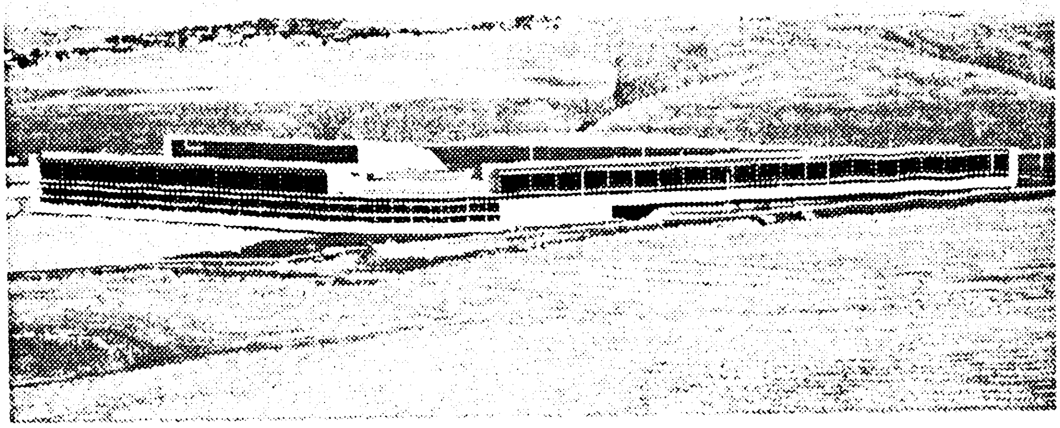

Figure A.4. School Building

economizers were modeled in the chapel, cultural center, and hallways for those standards and locations where required. Economizers are not an applicable option for PTAC and FPFC systems in DOE-2.1C. All systems were modeled without return fans.

School

Building Description

The school building selected for project testing is a junior-high school, built in 1982 in Pendleton, Oregon. It is a modern two-story solar building, constructed in a boomerang shape, with the convex side to the south (see Figure A.4). It has an active hot-air solar system on the south side and roof monitors for illumination of the classroom areas. For this project, the building was modeled without the active solar system and with a flat roof. Skylights were modeled instead of the roof monitors. Construction is metal siding over wood framing. Floor-to-ceiling height is 10.5 ft for classrooms and offices and 20 ft for the gymnasium.

The building has 112,747 GSF, apportioned to classrooms (47%), gymnasium and student center (45%), offices (5%), and food service (3%). Occupancy is 2161 people over nine winter months following the school schedule form Standard 90.1P. The building is closed down (except for the administrative offices) during the summer months.

HVAC Systems Descriptions

HVAC Case 1

Units serving the classrooms and administration are four-pipe fan coil (FPFC). The student center is served by a variable-temperature constant-volume unit (SZRH). The shop, gym, kitchen, and music rooms are served by a separate system of variable-temperature constant-volume units (SZRH). Hot and chilled water coils are supplied by two gas-fired boilers and two hermetic centrifugal chillers. Dry-bulb economizers and return fans were modeled in the student center, shop, gym, kitchen, and music rooms for those standards and locations where required. Classrooms and administration were not modeled with economizers (not an applicable option with FPFC in DOE-2.1C).

HVAC Case 2

All zones are served by a central variable-air-volume system (VAVS). Hot and chilled water coils are supplied by two gas-fired boilers and two hermetic centrifugal chillers. Dry-bulb economizers and return fans were modeled in all zones for those standards and locations where required. Reheat is available.

HVAC Case 3

All zones are served by a central variable-air-volume system (VAVS) with baseboard heat. Hot and chilled water coils are supplied by two gas boilers and two hermetic centrifugal chillers. Dry-bulb economizers and return fans were modeled in all zones for those standards and locations where required. Reheat is not available.

Hotel

Building Description

The hotel selected for project testing is a large convention-type hotel built in Bellevue, Washington, in 1981. The ten floors include 315,000 GSF dedicated to public areas (36%), guest rooms (58%), and service areas (6%). It is built on a long north/south axis with large eastern and western exposures. The building is 82% glass on the west (including a large sloped atrium/lobby), 90% glass on the east, and 21% glass on the northern exposure. There is no glass facing directly south. The construction is reinforced concrete frame with a 9 ft floor-to-floor height. The dining and lounge areas have a 20 ft height; the lobby/atrium (visible in Figure A.5) has a 45 ft average height. The building has seven electric and hydraulic elevators.

Building schedules were modeled using the Standard 90.1p Section 13 hotel schedules in the guest rooms and office schedules for the office. The remainder of the zones were modeled using the inverse of the hotel schedules. Setpoints were modeled at 75°F cooling and 70°F heating. The night and weekend heating setback was 55°F. As a consequence of the shape and size of the building, zoning is complicated. For HVAC purposes, the guest rooms may be grouped together. Individual zones exist for corridors, lobby-atrium, dining-lounge, lobby-corridor, meeting, banquet, office, kitchen, and laundry areas.

HVAC Systems Descriptions

HVAC Case 1

All guestrooms are served by four-pipe fan coil units (FPFC). The corridors are served by a variable-temperature constant-volume unit (SZRH). The lobby-atrium and kitchen/laundry are also served by variable-temperature constant-volume units (SZRH). The dining, meeting, banquet, office, and lobby-corridor spaces are served by a central variable-air-volume system (VAVS) with minimum stops on the VAV boxes of 30%. In the summer, chilled water is supplied by one hermetic centrifugal chiller and supplemented by one double-bundle heat-recovery chiller. In the winter, the double-bundle is base loaded with the centrifugal chiller providing backup as needed. Two gas-fired boilers supplement the heat recovery. Domestic hot water is also gas. Dry-bulb economizers were modeled in each unit for those standards and locations where required. Return fans were not modeled.

HVAC Case 2

Guestrooms are served by water-source heat pumps (HP). The corridors are served by a variable-temperature constant-volume unit (SZRH). The lobby-atrium and kitchen/laundry are also served by variable-temperature

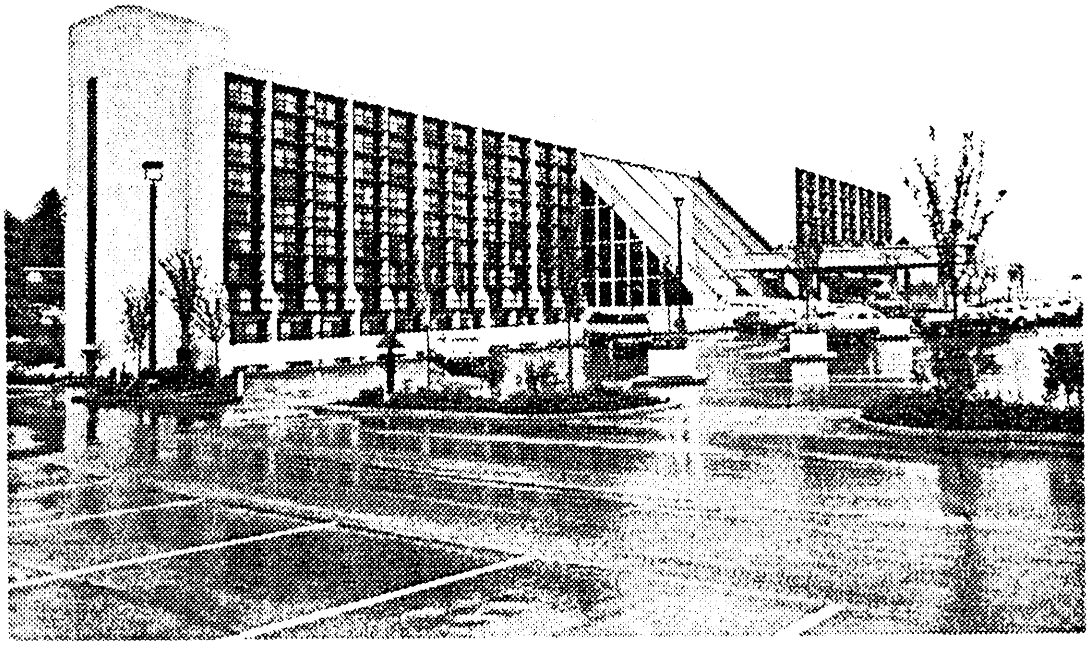

Figure A.5. Hotel Building

constant-volume units (SZRH). The dining, meeting, banquet, office, and lobby-corridor spaces are served by a central variable-air-volume system (VAVS) with minimum stops on the VAV boxes of 30%. Chilled water is supplied by two hermetic centrifugal chillers. Hot water is supplied by two gas-fired boilers. Domestic hot water is also gas. Dry-bulb economizers were modeled in each unit for those standards and locations where required. Return fans were not modeled.

HVAC Case 3

Guestrooms are served by air-to air heat pumps (HP). The corridors are served by a variable-temperature constant-volume unit (SZRH). The lobby-atrium and kitchen/laundry are also served by variable-temperature constant-volume units (SZRH). The dining, meeting, banquet, office, and lobby-corridor spaces are served by a central variable-air-volume system (VAVS) with minimum stops on the VAV boxes of 30%. Chilled water is supplied by two hermetic centrifugal chillers. Hot water is supplied by two gas-fired boilers. Domestic hot water is also gas. Dry-bulb economizers were modeled in each unit for those standards and locations where required. Return fans were not modeled.

Large Office

Building Description

The large office building selected for testing was built in Indianapolis, Indiana, in 1981. As constructed, it is part of a larger complex that included attached low-level retail stores and an underground garage. For this effort only the office tower shown in Figure A.6 was modeled. The tower is a 36-story flattened hexagon in cross section, with 19,740 ft^2 per floor, that flares out to a larger base of 29,650 ft^2 per floor for the bottom six floors.

Floor-to-floor height is 13 ft 6 in. everywhere except in the lobby, where it is 27 ft. The building is constructed of steel frame with a 4-in. lightweight concrete skin and is of above average-quality construction. The tower is about 25% glass, equally spaced around the six sides.

Building schedules were modeled using the Standard 90.1p Section 13 office schedules. Setpoints were modeled at 75°F cooling and 70°F heating. The night and weekend heating setback was 55°F. Because of the building's shape and size, zoning is complicated. For HVAC purposes, the only necessary distinction is between the core and perimeter zones.

HVAC Systems Descriptions

HVAC Case 1

Perimeter zones are served by a variable-air-volume system (VAVS) with a minimum stop of 30%. Core zones are served by a separate variable-air-volume system with a minimum stop of 1%. Chilled water is provided to both systems by two hermetic centrifugal chillers and a cooling tower. Heated water is provided by two gas-fired hot-water generators. Dry-bulb economizers and return fans were modeled for all zones in those standards and locations where required.

HVAC Case 2

Perimeter zones are served by variable-air-volume units with chilled and heated water coils (VAVS). A separate variable-air-volume system (VAVS) serves the core zones. Chilled water is provided by two hermetic centrifugal chillers and a cooling tower during the summer. In the winter, a double bundle chiller is base loaded and a single centrifugal chiller provides backup. Heated water is provided by heat recovery from the double bundle chiller and supplemented by two gas-fired hot-water generators. The gas-fired generators are also available for winter morning startup loads. Dry-bulb economizers and return fans were modeled in all zones for those standards and locations where required.

HVAC Case 3

All zones are served by a single variable-air-volume system with chilled and heated water coils. Chilled water is provided by two hermetic centrifugal chillers and a cooling tower. Heated water is provided by two gas-fired hot-water generators. Dry-bulb economizers were modeled for all zones for those standards and locations where required. Return fans were not modeled.

HVAC Case 4

All zones are served by a single variable-air-volume system with parallel power induction units (PIU), which can warm perimeter zones with waste heat from the core zones. Chilled water is provided by two hermetic centrifugal chillers and a cooling tower. Heated water is provided by two gas-fired hot-water generators. Dry-bulb economizers were modeled for all zones for those standards and locations where required. Return fans were not modeled.

Medium Office

Building Description

The medium office building selected for testing is a 49,500-ft^2 office built in Farmington, Connecticut, in 1973. The building as modeled is 48,644 ft^2 on three floors, with a steel superstructure and 4-in. lightweight concrete construction. Floor-to-floor height is 12 ft. There is one hydraulic passenger elevator. The building is 37% glass on the north, south, and east, and 47% on the west. The first floor is partially bermed (see

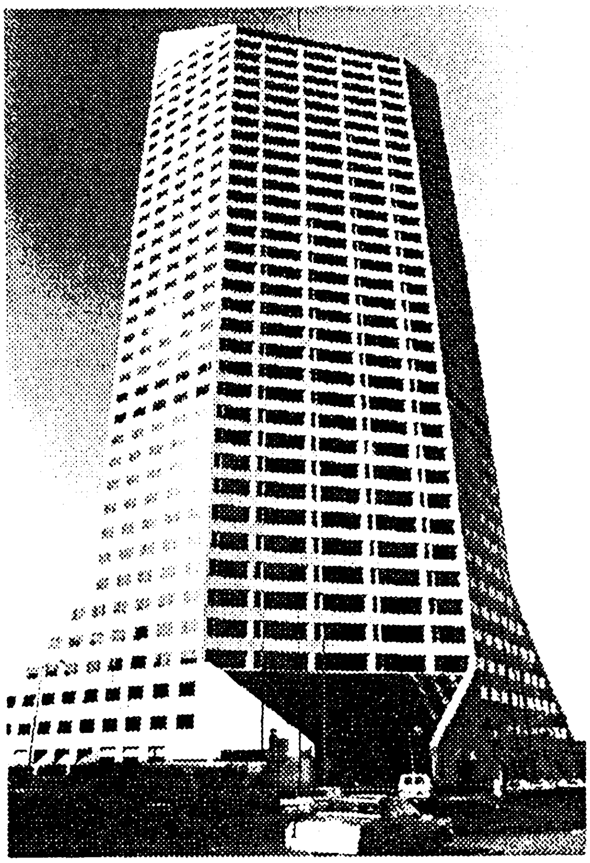

Figure A.6. Large Office Building

Figure A.7) and its windows slopes into the building at 57°. The second-floor windows are shaded by the 5-ft overhang of the top floor. The first floor also receives some shading benefit from the top floor. Aside from this unusual glazing, it is a typical medium-sized office structure, of above-average construction quality, occupied by up to 487 people.

Building schedules were modeled using the Standard 90.1p Section 13 office schedules. Set points were modeled at 75°F cooling and 70°F heating. The night and weekend heating setback was 55°F. The building was divided into five HVAC zones per floor for the testing: north, south, east, west, and core, plus a first-floor north entry, a second-floor west entry, and a plenum zone.

HVAC Systems Descriptions

HVAC Case 1

All zones are served by water-source heat pumps with a single water loop (HP). Heat is added by a gas-fired boiler when the water loop temperature drops below 60°F. Heat is rejected to the atmosphere via a cooling tower when the water loop temperature exceeds 90°F. No economizers are modeled, as they are not an applicable option for the HP system in DOE-2. Return fans were also not modeled.

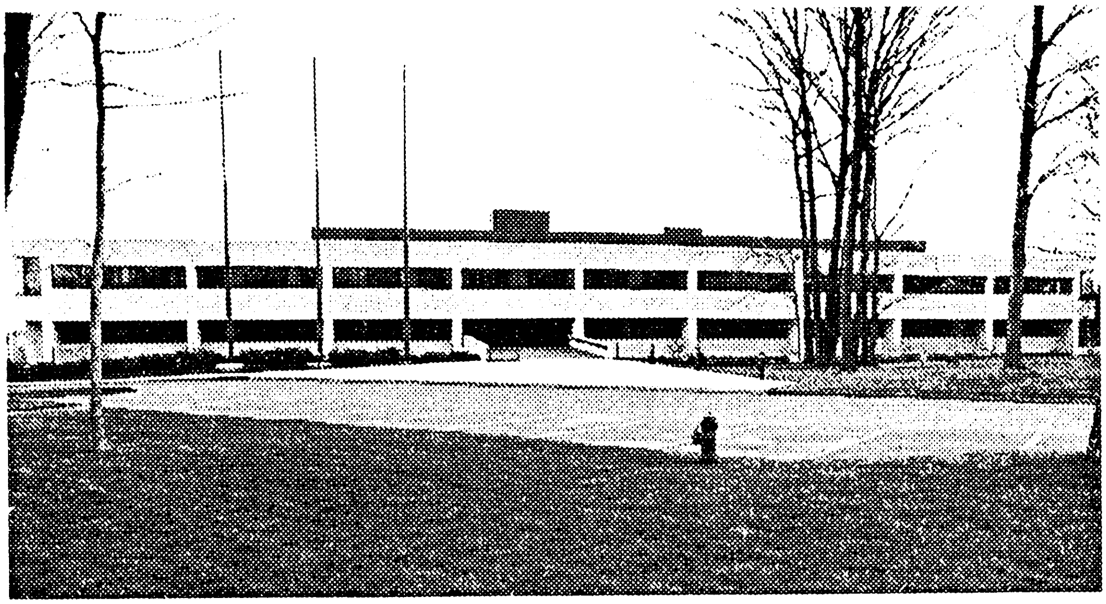

Figure A.7. Medium Office Building

HVAC Case 2

All zones are served by a single dual-duct variable-air-volume system (DDS). Minimum stop on the VAV in the perimeter zones is 50%; minimum stop in core zones is 1%. Chilled water is provided by a reciprocating chiller with air-cooled condenser. Hot water is provided by a gas-fired boiler. Economizers and return fans were modeled for all zones for those standards and locations where required.

HVAC Case 3

All zones are served by a single constant-volume reheat system (RHFS). Chilled water is provided by a double bundle reciprocating chiller with waste heat recovered used to heat the building. When this is insufficient, a gas-fired boiler provides supplemental heat. Economizers and return fans were modeled for all zones for those standards and locations where required.

HVAC Case 4

All zones are served by air-to-air heat pumps with supplemental electric resistance heat (PSZ used to model this system in DOE-2.1C). Economizers were modeled in all zones for those standards and locations where required. Return fans were not modeled.

Anchor Retail Store

Building Description

The retail building used in this analysis is a high-quality department store built in Atlanta, Georgia, in 1975. This building serves as an anchor for a mall shopping center. The building as modeled is 159,134 ft^2 in two stories with a floor-to-floor height of 18 ft and a steel frame construction with 4-in. light-weight concrete and concrete block skin. The building is only 7% glass. There are no display windows, only 8-ft-wide glass entrance doors and a strip of small windows in the second floor office area. There is no glass on the south side, where it opens into the mall area. (Contact with the mall was not simulated.) The building, shown in Figure A.8, is of above-average construction quality.

Building schedules were modeled using the Standard 90.1p Section 13 retail schedules. Setpoints were modeled at 75°F cooling and 70°F heating. The night and weekend heating setback was 55°F. The building was divided into three HVAC zones for the testing: north and south halves of the first floor and the second floor. In addition, there is a plenum above the second floor.

HVAC Systems Descriptions

HVAC Case 1

All zones are served by constant-volume variable-temperature units with electric resistance heating coils and chilled water coils (SZRH). Chilled water is provided by a hermetic centrifugal chiller and cooling tower. Dry-bulb economizers were modeled in each unit for those standards and locations where required. Return fans were not modeled.

HVAC Case 2

All zones are served by rooftop packaged variable-temperature constant-volume direct expansion units equipped with air-cooled condensers and reciprocating compressors (PSZ). Heating is provided by electric resistance. Dry-bulb economizers were modeled in all zones for those standards and locations where required. Return fans were not modeled.

HVAC Case 3

All zones are served by packaged rooftop variable-air-volume direct expansion units (PVAVS) with air-cooled condensers. Heating is electric resistance. Dehumidification is provided by condenser heat recovery. Dry-bulb economizers were modeled for all zones for those standards and locations where required. Return fans were not modeled.

HVAC Case 4

All zones are served by variable-air-volume units (VAVS) with electric resistance heating coils and chilled water coils. Chilled water is provided by a hermetic centrifugal chiller and cooling tower. Dry-bulb economizers were modeled in all zones for those standards and locations where required. Return fans were not modeled.

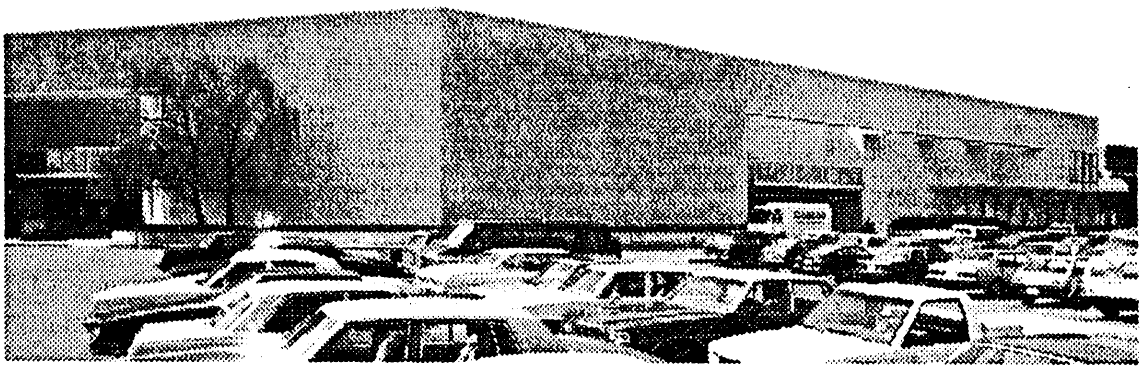

Figure A.8. Retail Building

Strip Shopping Store

Building Description

The small retail store selected for project testing was composed of two units (end plus adjacent unit) of a strip shopping center built in Multnomah County, Oregon, in 1978. The units are single-story (16 ft) with a gross area of 11,760 ft^2, wood-frame construction with cedar siding. Maximum occupancy is 286. There is about 48% glass on the southern exposure, 64% on the western exposure, and no glass on the eastern and northern exposures. The building appears in Figure A.9.

The building schedules were modeled using the Standard 90.1p Section 13 retail schedules. Setpoints were modeled at 75°F cooling and 70°F heating. The night and weekend heating setback was 55°F. The building was divided into two HVAC zones that represent the two business units in the building.

HVAC Systems Descriptions

HVAC Case 1

All zones are served by a separate packaged rooftop variable-temperature, constant-volume direct expansion unit (PSZ). Heat is provided by gas-fired heat exchangers. Refrigeration compressors are reciprocating with air-cooled condensers. All zones are modeled with dry-bulb economizers for those standards and locations where required. Return fans were not modeled.

HVAC Case 2

Each zone is served by a separate packaged rooftop variable-air-volume direct expansion unit (PVAVS) with a minimum stop of 30%. Heat is provided by electric resistance heating coils. Refrigeration compressors are reciprocating with air-cooled condensers and condenser heat recovery. All zones are modeled with dry-bulb economizers for those standards and locations where required. Return fans were not modeled.

Warehouse

Building Description

The warehouse selected for project testing was built in Tualatin, Oregon, in 1975. It has a gross area of 43,002 ft^2 on one floor, with 38,640 ft^2 of heated-only warehouse, 2,250 ft^2 of lunch and locker area enclosed and conditioned within the warehouse, and 2,112 ft^2 of conditioned office space. The building is constructed of precast concrete tilt-up walls for the warehousing area (25-ft height), and wood-frame/cedar siding for the office spaces (7-ft height). There are nine loading bays on the rear of the building. Only the office space has windows, so total glazing is less than 3% on all exposures.

Building schedules were modeled using the Standard 90.1p Section 13 warehouse and office schedules. Setpoints were modeled at 75°F cooling and 70°F heating in the office and lunchroom. There was essentially no cooling setpoint for the warehouse. The night and weekend heating setback was 55°F. The building was divided into three zones: warehouse, office, and lunchroom/locker room.

HVAC Systems Descriptions

HVAC Case 1

The office and lunchroom zones are served by packaged rooftop variable-temperature, constant-volume direct expansion units (PSZ). Heating is provided by gas-fired heat exchangers. The warehouse is served by a combination heating and ventilating system (UVT) with gas-fired heat exchangers for heat and outdoor air ventilation for space cooling.

Figure A.9 Small Retail Building

Figure A.10 Warehouse

HVAC Case 2

The office and lunchroom zones are served by packaged rooftop variable-temperature, constant-volume direct expansion units (PSZ). Heating is provided by hot-water coils served by a gas-fired boiler. The warehouse is served by a combination heating and ventilating system (UVT) with hot-water coils for heat and outdoor air ventilation for space cooling

HVAC Case 3

The office and lunchroom zones are served by packaged rooftop variable-temperature, constant-volume direct expansion units (PSZ). Heating is provided by hot-water baseboards. The warehouse is served by a combination heating and ventilating system (UVT) with hot-water baseboards for heating and outdoor air ventilation space cooling. A gas boiler supplies hot water to the baseboards.

HVAC Case 4

The office and lunchroom zones are served by packaged rooftop variable-temperature, constant-volume direct expansion units (PSZ). Heating is provided by electric baseboards. The warehouse is served by a combination heating and ventilating system (UVT) with electric baseboards for heating and outdoor air ventilation as a means of space cooling.

Appendix B

Building Energy Performance Summary Tables

Appendix B

Building Energy Performance Summary Tables

Whole-Building Energy Performance (kBtu/ft^2/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
APT S80	21	10	7	11	7	7	64	
APT S89 ELP	20	10	7	11	7	7	61	4.1
	26	9	7	8	7	7	64	-4.9
APT S80	11	13	6	11	7	7	56	
APT S89 LAK	11	12	6	11	7	7	54	3.4
APT S93	11	11	6	8	7	7	51	6.3
APT S80	3	5	5	11	7	7	39	
APT S89 LAX	3	5	6	11	7	7	38	1.2
APT S93	3	4	5	8	7	7	35	9.2
APT S80	50	5	8	11	7	7	88	
APT S89 MAD	44	5	7	11	7	7	81	7.7
APT S93	44	4	7	8	7	7	78	3.6
APT S80	26	3	6	11	7	7	60	
APT S89 SEA	25	3	6	11	7	7	60	0.8
APT S93	26	2	6	8	7	7	57	4.3
APT S80	23	8	7	11	7	7	64	
APT S89 WDC	22	8	7	11	7	7	62	2.6
APT S93	23	7	7	8	7	7	59	4.9
Average 1980	22	8	7	11	7	7	62	
Average 1988	21	7	6	11	7	7	60	3.8
Average 1993	22	6	6	8	7	7	57	3.5

Whole-Building Energy Performance (kBtu/ft^2/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
BAN S80 ELP	28	25	10	24	2	7	96	
BAN S89 ELP	28	20	9	19	2	7	86	10.6
BAN S93 ELP	29	20	8	14	2	7	80	5.6
BAN S80 LAK	14	32	10	24	2	7	89	
BAN S89 LAK	12	29	9	19	2	7	79	11.5
BAN S93 LAK	13	28	9	14	2	7	73	6.0
BAN S80 LOS	17	17	8	24	2	7	75	
BAN S89 LOS	19	15	8	19	2	7	69	7.7
BAN S93 LOS	19	15	8	14	2	7	64	6.5
BAN S80 MAD	80	11	9	24	2	7	133	
BAN S89 MAD	76	10	9	19	2	7	123	7.7
BAN S93 MAD	80	10	9	14	2	7	122	1.0
BAN S80 SEA	56	8	8	24	2	7	106	
BAN S89 SEA	53	8	8	19	2	7	97	8.8
BAN S93 SEA	56	8	8	14	2	7	95	1.7
BAN S80 WAS	46	19	9	24	2	7	107	
BAN S89 WAS	45	15	9	19	2	7	97	9.1
BAN S93 WAS	47	15	9	14	2	7	94	3.3
Average 1980	40	19	9	24	2	7	101	
Average 1988	39	16	9	19	2	7	92	9.2
Average 1993	41	16	8	14	2	7	88	3.7

Whole-Building Energy Performance (kBtu/ft²/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
CHU S80 ELP	19	11	3	7	11	1	53	
CHU S89 ELP	15	10	3	8	11	1	48	9.8
CHU S93 ELP	15	9	2	5	11	1	43	8.0
CHU S80 LAK	9	20	3	7	11	1	51	
CHU S89 LAK	7	18	3	8	11	1	47	7.4
CHU S93 LAK	8	17	2	5	11	1	43	7.7
CHU S80 LOS	6	7	2	7	11	1	35	
CHU S89 LOS	5	6	2	8	11	1	34	1.1
CHU S93 LOS	6	6	2	5	11	1	30	11.1
CHU S80 MAD	48	6	4	7	11	1	77	
CHU S89 MAD	39	5	4	8	11	1	69	11.5
CHU S93 MAD	40	5	4	5	11	1	65	4.7
CHU S80 SEA	28	3	3	7	11	1	53	
CHU S89 SEA	23	2	3	8	11	1	49	8.7
CHU S93 SEA	25	2	3	5	11	1	46	4.8
CHU S80 WAS	28	11	4	7	11	1	62	
CHU S89 WAS	22	9	3	8	11	1	55	11.1
CHU S93 WAS	23	9	3	5	11	1	52	5.4
Average 1980	23	10	3	7	11	1	55	
Average 1988	19	9	3	8	11	1	50	9.0
Average 1993	19	8	3	5	11	1	47	6.5

Whole-Building Energy Performance (kBtu/ft^2/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
HOT S80 ELP	13	26	11	19	19	27	116	
HOT S89 ELP	12	22	11	18	18	27	109	6.3
HOT S93 ELP	13	20	10	12	18	27	101	6.4
HOT S80 LAK	3	41	11	19	19	27	121	
HOT S89 LAK	3	34	11	18	18	27	111	7.8
HOT S93 LAK	4	31	10	12	18	27	103	6.6
HOT S80 LOS	2	24	10	19	19	27	100	
HOT S89 LOS	1	18	9	18	18	27	92	8.2
HOT S93 LOS	2	16	8	12	18	27	84	8.3
HOT S80 MAD	32	16	10	19	19	27	123	
HOT S89 MAD	28	13	9	18	18	27	115	7.0
HOT S93 MAD	31	12	9	12	18	27	109	4.3
HOT S80 SEA	10	13	9	19	19	27	98	
HOT S89 SEA	10	10	9	18	18	27	93	5.3
HOT S93 SEA	13	9	8	12	18	27	87	5.8
HOT S80 WAS	14	26	11	19	19	27	116	
HOT S89 WAS	12	22	11	18	18	27	109	6.4
HOT S93 WAS	15	20	10	12	18	27	102	5.3
Average 1980	12	24	10	19	19	27	112	
Average 1988	11	20	10	18	18	27	105	6.9
Average 1993	13	18	9	12	18	27	98	6.1

Whole-Building Energy Performance (kBtu/ft^2/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
LAR S80 ELP	13	13	10	20	0	9	65	
LAR S89 ELP	15	10	9	16	0	9	59	8.6
LAR S93 ELP	15	9	9	13	0	9	54	7.0
LAR S80 LAK	8	18	10	20	0	9	65	
LAR S89 LAK	8	14	9	16	0	9	57	11.9
LAR S93 LAK	8	14	9	13	0	9	53	6.9
LAR S80 LOS	6	10	8	20	0	9	53	
LAR S89 LOS	6	7	7	16	0	9	46	12.2
LAR S93 LOS	7	7	7	13	0	9	42	8.3
LAR S80 MAD	27	8	8	20	0	9	72	
LAR S89 MAD	27	5	7	16	0	9	65	10.3
LAR S93 MAD	24	5	7	13	0	9	58	8.6
LAR S80 SEA	15	6	8	20	0	9	58	
LAR S89 SEA	13	4	7	16	0	9	50	13.2
LAR S93 SEA	14	4	7	13	0	9	46	7.1
LAR S80 WAS	16	12	9	20	0	9	66	
LAR S89 WAS	15	8	8	16	0	9	56	14.8
LAR S93 WAS	14	8	8	13	0	9	52	6.7
Average 1980	14	11	9	20	0	9	63	
Average 1988	14	8	8	16	0	9	56	11.8
Average 1993	14	8	8	13	0	9	51	7.4

Whole-Building Energy Performance (kBtu/ft²/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
MED S80 ELP	10	26	10	22	1	11	80	
MED S89 ELP	13	22	9	15	1	11	71	11.1
MED S93 ELP	12	20	9	12	1	11	66	6.8
MED S80 LAK	4	33	9	22	1	11	80	
MED S89 LAK	2	30	10	15	1	11	69	13.5
MED S93 LAK	3	28	9	12	1	11	64	7.4
MED S80 LOS	3	21	9	22	1	11	68	
MED S89 LOS	3	17	9	15	1	11	56	17.8
MED S93 LOS	3	16	8	12	1	11	51	7.3
MED S80 MAD	21	15	9	22	1	11	79	
MED S89 MAD	23	11	9	15	1	11	71	9.8
MED S93 MAD	24	10	8	12	1	11	67	4.7
MED S80 SEA	11	12	9	22	1	11	67	
MED S89 SEA	15	8	9	15	1	11	60	10.3
MED S93 SEA	15	8	9	12	1	11	56	6.3
MED S80 WAS	12	22	10	22	1	11	78	
MED S89 WAS	15	17	9	15	1	11	69	11.2
MED S93 WAS	15	16	9	12	1	11	64	6.1
Average 1980	10.1	21.4	9.5	21.8	1.1	11.4	75.3	
Average 1988	11.9	17.4	9.3	15.1	1.1	11.4	66.2	12.2
Average 1993	12.1	16.4	8.6	11.7	1.1	11.4	61.3	6.4

Whole-Building Energy Performance (kBtu/ft^2/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
RET S80 ELP	11	21	9	48	3	6	97	
RET S89 ELP	8	15	7	29	3	6	69	28.9
RET S93 ELP	8	14	6	24	3	6	62	7.4
RET S80 LAK	1	32	9	48	3	6	99	
RET S89 LAK	1	24	7	29	3	6	71	28.6
RET S93 LAK	2	23	7	24	3	6	64	7.0
RET S80 LOS	1	16	8	48	3	6	83	
RET S89 LOS	1	10	6	29	3	6	56	31.6
RET S93 LOS	2	9	6	24	3	6	50	7.3
RET S80 MAD	13	12	8	48	3	6	91	
RET S89 MAD	18	9	6	29	3	6	71	21.2
RET S93 MAD	20	8	6	24	3	6	67	4.8
RET S80 SEA	3	7	8	48	3	6	74	
RET S89 SEA	5	5	6	29	3	6	55	26.5
RET S93 SEA	7	4	5	24	3	6	50	5.7
RET S80 WAS	7	19	8	48	3	6	91	
RET S89 WAS	8	14	7	29	3	6	67	26.4
RET S93 WAS	9	13	6	24	3	6	62	5.8
Average 1980	6.0	17.6	8.3	48.0	3.4	5.8	89.1	
Average 1988	7.0	12.9	6.5	29.1	3.4	5.8	64.9	27.2
Average 1993	8.1	11.9	6.0	24.0	3.4	5.8	59.2	6.4

Whole-Building Energy Performance (kBtu/ft²/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
SCH S80 ELP	14	0	4	12	6	4	40	
SCH S89 ELP	11	0	4	10	6	4	35	11.9
SCH S93 ELP	12	0	4	6	6	4	32	8.1
SCH S80 LAK	6	0	4	12	6	4	32	
SCH S89 LAK	6	0	3	10	6	4	29	10.0
SCH S93 LAK	7	0	3	6	6	4	26	8.6
SCH S80 LOS	3	1	3	12	6	4	29	
SCH S89 LOS	3	1	3	10	6	4	27	7.0
SCH S93 LOS	5	1	3	6	6	4	25	6.1
SCH S80 MAD	32	0	4	12	6	4	58	
SCH S89 MAD	23	0	4	10	6	4	47	19.1
SCH S93 MAD	25	0	4	6	6	4	45	3.0
SCH S80 SEA	16	0	3	12	6	4	42	
SCH S89 SEA	12	0	3	10	6	4	35	16.5
SCH S93 SEA	14	0	3	6	6	4	33	4.6
SCH S80 WAS	18	0	4	12	6	4	44	
SCH S89 WAS	12	0	4	10	6	4	36	17.4
SCH S93 WAS	14	0	3	6	6	4	33	6.5
Average 1980	14.7	0.1	3.9	11.7	6.3	3.9	40.6	
Average 1988	11.1	0.2	3.6	9.7	6.2	3.9	34.7	14.6
Average 1993	12.7	0.2	3.3	6.1	6.2	3.9	32.3	5.9

Whole-Building Energy Performance (kBtu/ft²/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
STR S80 ELP	27	29	9	32	6	3	106	
STR S89 ELP	18	26	7	30	6	3	89	15.7
STR S93 ELP	18	25	7	26	6	3	83	5.5
STR S80 LAK	11	49	8	32	6	3	109	
STR S89 LAK	7	45	7	30	6	3	98	10.1
STR S93 LAK	7	34	7	26	6	3	83	13.7
STR S80 LOS	5	20	7	32	6	3	72	
STR S89 LOS	4	19	6	30	6	3	68	5.7
STR S93 LOS	4	18	6	26	6	3	63	7.1
STR S80 MAD	57	16	7	32	6	3	121	
STR S89 MAD	39	16	6	30	6	3	101	16.6
STR S93 MAD	41	16	6	26	6	3	97	3.4
STR S80 SEA	30	8	6	32	6	3	85	
STR S89 SEA	20	8	6	30	6	3	74	13.3
STR S93 SEA	22	8	6	26	6	3	70	4.3
STR S80 WAS	34	26	8	32	6	3	109	
STR S89 WAS	22	25	7	30	6	3	92	15.1
STR S93 WAS	23	24	6	26	6	3	88	4.1
Average 1980	27	25	7	32	6	3	100	
Average 1988	18	23	7	30	6	3	87	13.2
Average 1993	19	21	6	26	6	3	81	6.3

Whole-Building Energy Performance (kBtu/ft²/yr)

	Heat	Cool	Fans	Light	SWH	Misc	Total	Percent Change
WAR S80 ELP	15	2	1	7	0	1	25	
WAR S89 ELP	10	1	1	6	0	1	19	22.9
WAR S93 ELP	12	1	1	5	0	1	21	-5.6
WAR S80 LAK	11	2	1	7	0	1	22	
WAR S89 LAK	10	2	1	6	0	1	20	10.7
WAR S93 LAK	12	2	1	5	0	1	21	-5.9
WAR S80 LOS	9	1	1	7	0	1	20	
WAR S89 LOS	9	1	1	6	0	1	18	6.8
WAR S93 LOS	10	1	1	5	0	1	18	0.4
WAR S80 MAD	37	1	1	7	0	1	47	
WAR S89 MAD	19	1	1	6	0	1	27	41.8
WAR S93 MAD	19	1	1	5	0	1	27	-0.1
WAR S80 SEA	29	1	1	7	0	1	38	
WAR S89 SEA	15	0	1	6	0	1	23	38.6
WAR S93 SEA	16	0	1	5	0	1	23	0.3
WAR S80 WAS	25	1	1	7	0	1	35	
WAR S89 WAS	15	1	1	6	0	1	24	32.8
WAR S93 WAS	16	1	1	5	0	1	24	-1.4
Average 1980	20.8	1.3	0.8	6.6	0.3	1.3	31.1	
Average 1988	13.0	1.1	0.6	5.6	0.3	1.3	21.9	29.6
Average 1993	14.1	1.1	0.6	5.0	0.3	1.3	22.4	-1.6

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