PNL-7974
UC-350

Construction Cost Impact Analysis of the U.S. Department of Energy Mandatory Performance Standards for New Federal Commercial and Multi-Family, High-Rise Residential Buildings

F. V. Di Massa
D. L. Hadley
M. A. Halverson

December 1993

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

Summary

In accordance with federal legislation, the U.S. Department of Energy (DOE) has conducted a project to demonstrate use of its Energy Conservation Voluntary Performance Standards for Commercial and Multi-Family High-Rise Residential Buildings; Mandatory for New Federal Buildings; Interim Rule (referred to in this report as DOE-1993). A key requisite of the legislation requires DOE to develop commercial building energy standards that are cost effective. During the demonstration project, DOE specifically addressed this issue by assessing the impacts of the standards on 1) construction costs, 2) builders (and especially small builders) of multi-family, high-rise buildings, and 3) the ability of low-to moderate-income persons to purchase or rent units in such buildings.

For the demonstration, the DOE selected four prototypical buildings located in two different climates for a total of eight test cases. These four buildings were part of a larger sample of buildings used in a prior analysis to determine the DOE-1993 standards' impact on building energy efficiency. As part of the energy efficiency analysis, the energy performance characteristics of the original buildings were modified through computer simulation to comply with ASHRAE Standard 90A-1980: Energy Conservation in New Building Designs. The original computer simulations were also revised to meet the minimum performance requirements of DOE-1993. The two sets of building energy performance characteristics that resulted were used to establish the energy-related building components of this comparative construction cost impact analysis. Incremental cost estimates were developed for those energy-related building components that varied between the ASHRAE-1980 and DOE-1993 building configurations.

Findings from the construction cost impact analysis indicate that although the energy-efficiency requirements of DOE-1993 are, in general, more demanding than ASHRAE-1980, they do not necessarily result in higher construction costs. Rather, the DOE-1993 compliance methodologies' flexibility allows designers to economically use the wide range of lighting and heating, ventilation, and air-conditioning (HVAC) equipment and envelope component materials currently available to design buildings with energy-related components of equivalent or lower construction cost than those designed to the ASHRAE-1980 standard.

In six of the eight cases studied, the total cost of the energy-related building components evaluated was slightly lower under DOE-1993 than under the ASHRAE-1980 standard. A portion of the construction cost savings resulted from the lower lighting power levels allowed under DOE-1993. These lighting power levels were assumed to be achievable with currently available and recommended lighting technologies, such as T-8 fluorescent lamps and electronic or hybrid ballasts. Higher fixture efficacy (greater lumen output and/or lower power requirements) and lower allowable lighting levels permit design alternatives using fewer fixtures, thereby reducing material and labor costs while reducing the installed watts per square foot to meet the lighting power allowance.

Fewer and more efficient fixtures also result in lower building internal heat gain which reduces air conditioning loads, but increases heating demand. The effect of lower internal heat gain, when coupled with the minor increases in envelope and glazing thermal efficiency performance and slightly higher efficiency HVAC equipment required

by DOE-1993, produced some small changes in HVAC equipment capacity requirements. In half the cases studied, these changes were large enough to allow the slight downsizing of cooling equipment resulting in additional cost savings. Because the DOE-1993 standard appears to result in relatively small changes in energy-related building component costs, the impacts of the standard on small builders of multi-family, high-rise residential buildings are expected to be minimal.

It is anticipated that DOE-1993 will have no impact on the ability of low-to-moderate-income people to rent or purchase a unit in a multi-family, high-rise complex for three reasons. First, the standard does not appear to lead to higher construction costs. Second, findings demonstrate that very small changes in HVAC equipment sizing and efficiency will be required under DOE-1993 relative to ASHRAE-1980 and the number of lighting fixtures may be reduced, indicating a potential reduction in maintenance costs. Finally, a previous study evaluating the energy efficiency of the standard found that overall energy use should be reduced; therefore, DOE-1993 should have no impact on rent or purchase prices.

Several additional findings pertaining to the study methodology, made during the course of the demonstration, have led to the following series of recommendations.

The findings of this analysis have revealed the limitations of using theoretical building simulation output data to define the energy-related building components used in a comparative construction cost study.

Recommendation 1: Within the next year DOE should begin the development of a methodology to link energy-related construction cost database information with building simulation programs to allow the effects of energy-efficient design alternatives to be measured and evaluated directly in terms of both energy and cost performance.

This comparative construction cost impact analysis represents only a small fraction of the possible design and equipment selection permutations that may result from the implementation of the DOE-1993 standard.

Recommendation 2: During the next year, DOE should expand its construction cost impact analysis efforts to include a cost-sensitivity analysis which examines design alternatives that reflect 1) average, low-cost construction practice; 2) above-average, moderate-cost construction; and 3) advanced, high-cost construction practices which make full use of current materials, equipment, and technologies. The sensitivity analysis will allow DOE to more clearly define the bounds of the cost impacts possible under the DOE-1993 standard.

It was noted that this study used buildings that do not accurately reflect the significant advancements and changes in design practice that came about in the 1980s as a basis for analysis.

Recommendation 3: Within the next year, DOE should perform an assessment of current industry design and construction practice. The assessment should be followed by cooperative working agreements with the design and construction industry to develop practical design alternatives that comply with DOE-1993.

Contents

Tables

1.0 Introduction

The U.S. Department of Energy's (DOE's) mandate to develop and implement energy performance standards for commercial buildings was established by the Energy Conservation Standards for New Buildings Act of 1976, as amended, Public Law 94-385, 42 USC 6831 *et seq.*, hereafter 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 (Public Law 399, 42 USC 6833) required DOE to use a three-stage process in developing the standards: promulgate interim standards, conduct a demonstration project, and develop and issue the final standards at a future date. DOE was assisted in the demonstration project by Pacific Northwest Laboratory (PNL).[a] 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 these energy savings, including the types of energy to be realized from utilizing these 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).

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

1.1 Development of Energy Conservation Standards

In 1975 the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), in cooperation with the Illuminating Engineering Society (IES) and under procedures approved by the American National Standards Institute (ANSI), approved and published ANSI/ASHRAE/IES 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 (Public Law 94-63) 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. Beginning in 1975, many states passed legislation and adopted regulations making energy standards part of the building design and construction process. Concurrently, DOE [formerly U.S. Energy Research and Development Administration (ERDA)] began developing programs to assist the states with implementing energy standards.

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 such update was in 1983, at which time the MECC-77 was updated to include requirements in Standard 90A-1980 (hereafter referred to as ASHRAE-1980). Concurrent with these national voluntary standards and model codes initiatives, DOE remained active in energy standards work. This was in response to initiatives outlined in Public Law 94-385.

Two major initiatives sponsored by DOE during the 1980s on building energy standards development, and in response to Public Law 94-385, were Special Projects coordinated by ASHRAE. One of the projects, Special Project 41 (SP41), brought together experts in the design, construction, and estimating fields to determine what revisions to ASHRAE-1980 were feasible and cost effective. By applying the findings of energy consumption simulations, using different product and systems strategies, existing buildings were designed, modified, and redesigned for the purpose of reducing energy. 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 ASHRAE-1980 could be revised to more effectively address energy conservation in new buildings.

These recommendations were used in the ASHRAE/IES process for development of consensus standards. The most recent is ASHRAE/IES Standard 90.1-1989, "Energy Conservation in New Buildings, Except Low-Rise Residential" (Standard 90.1-89).

Using ASHRAE/IES Standard 90.1-89 as a basis, interim standards for federal building have been developed. These federal standards were promulgated in 1989 as 10 CFR 435, "Voluntary Performance Standards for New Commercial and Multi-Family High Rise Residential; Mandatory for Federal Buildings." The federal standards include performance requirements for new construction starting in 1989 and more stringent performance requirements for construction starting in 1993. The 1989 performance requirements are referred to as DOE-1989 and the 1993 performance requirements are referred to as DOE-1993 in the remainder of this report.

1.2 Report Organization

Chapter 2 describes the methodology used in this demonstration project, and the overall findings of the demonstration are presented in Chapter 3. Chapter 4 gives the recommendations based on this demonstration. References are listed in Chapter 5.

2.0 Methodology

For the demonstration, the DOE selected four prototypical buildings in two climate locations. The four buildings are part of a larger sample of buildings used in the ASHRAE SP41 project mentioned above. The SP41 project resulted in a four-volume series entitled, "Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings," issued as 40 documents (PNL 1983a). The report includes complete descriptions, including blueprints and cost estimate data of the original buildings, which were constructed in the late 1970s and early 1980s. Because of the availability of this comprehensive documentation, the SP41 buildings provided an acceptable basis for the comparative construction cost impact analysis presented here.

Through computer simulation, the energy performance characteristics of the four original buildings were revised to comply to ASHRAE-1980 and revised a second time to meet the minimum performance requirements of the DOE-1993 standard. Elements of the original building that were modified include the energy performance characteristics of the ceiling, walls, and floor; glazing thermal transmittance and shading coefficients; lighting power allowances; and heating, ventilation, and air-conditioning (HVAC) equipment capacities and efficiencies. The original building's architectural features, such as the window-to-wall ratio, were not altered.

When applicable, incremental construction cost estimates were developed for those energy-related building components that varied between the ASHRAE-1980 and DOE-1993 simulations. Engineering judgment was used to identify energy-related building components and equipment which provided the most realistic method of compliance. In many instances, several options were available, and the option likely to produce the lowest life-cycle cost was selected. Cost estimates were based on data from *MEANS Building Construction Cost Data 1991*, *MEANS Electrical Cost Data 1991*, *MEANS Mechanical Cost Data 1991* (R. S. Means 1990a,b,c). Additional information on product cost and availability was obtained from manufacturers, distributors, and retailers of glass and glazing products, HVAC, and lighting equipment in various locations in the United States.

2.1 Selection of Prototype Buildings and Climate Locations

A multi-family, high-rise building was one of the four buildings selected because it was specified in the federal legislation. A small office (bank), a retail anchor store, and a strip mall retail building were chosen because they represented the full range of estimated annual energy savings from the DOE-1993 standard. The buildings were modeled for two different climate zones: Madison, Wisconsin, and Los Angeles, California. Madison was selected because it is the climate location that had the greatest annual energy use averaged across all building types. Los Angeles was selected for the opposite reason--the least annual energy use across all building types.

2.2 Building Simulation Input Description

Building envelope characteristics for buildings being modeled under ASHRAE-1980 were developed through simultaneous solution of a series of equations in the ASHRAE 90A-1980 Standard. These equations combine the effects of floor, ceiling, and wall insulation with glazing characteristics to yield a single solution. Lighting levels for buildings being modeled under ASHRAE-1980 were developed through the use of the lighting power density values found in the Illuminating Society of North America Lighting Handbook (IES 1981). HVAC equipment efficiencies were taken directly from the ASHRAE 90A-1980 Standard.

Building envelope characteristics for buildings being modeled under DOE-1993 were developed through use of the ENVSTD program. [ENVSTD is a software program developed to facilitate use of those portions of the DOE standard related to the building envelope (Crawley, Riesen, and Briggs 1989)]. Floor and ceiling insulation levels are set by a prescriptive method based on the local climate. Wall insulation levels, glass thermal transmittance, and shading coefficients were adjusted so that the building just met the requirements of the DOE-1993 Standard. Lighting levels for buildings being modelled under DOE-1993 were developed through the use of the LTGSTD program. [LTGSTD is a software program developed to facilitate use of those portions of the DOE Standard related to lighting systems (Crawley, Riesen, and Briggs 1989)]. HVAC equipment efficiencies were taken directly from DOE-1993.

2.3 Small Office Building - Bank

The small office building selected is a single-floor, 2500-ft^2 branch bank, constructed in 1981 in Guilderland, New York. It has a floor-to-roof height of 16 feet and is of wood-frame construction with brick veneer. The building is roughly 50% glass on the north and south sides, with 10% glass on the west and 3% on the east. The entire building is served by a single variable air volume (VAV), direct-expansion rooftop cooling unit. The estimated total original construction cost of the bank was $301,000.

2.3.1 Bank - Los Angeles, California Simulation

The bank was simulated using Los Angeles weather data. A ceiling insulation level of R-6.73 was required to comply with ASHRAE-1980, while DOE-1993 required a slightly lower level of R-5.43. Several ceiling insulation options exist which could meet the requirements of both standards. Given the bank is of wood-frame construction, it is most likely that a 3.5-in. fiberglass batt (R-11) would have been specified to provide compliance in both cases, resulting in no incremental costs. The lighting power allowances (LPA) under ASHRAE-1980 were 2.77 Watts per ft^2 (W/ft^2) in the main business area and 2.13 W/ft^2 in the lounge area. Under DOE-1993, the LPA requirement was approximately 40% less (1.68 W/ft^2 in the main business area, 0.56 W/ft^2 in the lounge area). Cost estimates were performed assuming T-8 fluorescent fixtures with electronic ballasts. These high-performance fixtures have a greater initial cost than those used in the ASHRAE-1980 scenario; however, fewer fixtures (and related wiring) are required to meet the lower LPA under DOE-1993. As a result, material and labor costs for lighting were $876 lower under DOE-1993 than ASHRAE-1980.

HVAC capacity requirements also decreased as a result of the lighting modifications, but the drop was not large enough to result in a change in equipment sizing. Therefore, there were no HVAC cost impacts.

(a) Many possible combinations of wall insulation and glass transmittance and shading coefficients will yield a minimally compliant building. However, only one combination was examined for each building in a particular climate location.

In total, use of the DOE-1993 standards relative to ASHRAE-1980 resulted in a negative increment of $876.

2.3.2 Bank - Madison, Wisconsin Simulation

Ceiling R-values went from R-11.88 under ASHRAE-1980 to R-15.96 under DOE-1993. A 6-in. fiberglass batt (R-19) was used to satisfy both standards and resulted in no net cost change. Floor slab insulation values were R-5.56/ASHRAE-1980 and R-7.69/DOE-1993. Smooth-cell polystyrene slab insulation of 1.5-in. thickness met the ASHRAE requirements, but a 2-in. thickness was needed to comply with DOE-1993 resulting in a cost increase of $320.

Double glazing was used in both the DOE and ASHRAE cases; however, the shading coefficient under the DOE standard (0.576) as greater than the ASHRAE level (0.391) and, as a result, tinted glass could be used in place of a reflective coating. This resulted in a negative increment of $1338.

Lighting cost savings are identical to those in the Los Angeles simulation ($876), so overall, DOE-1993 allowed for a construction cost savings of $1,894.

Table 2.1 compares the bank building's energy performance characteristics required for minimal compliance under DOE-1993 and ASHRAE-1980.

Table 2.1. Energy-Related Building Characteristics for the Bank Building

	Madison		Los Angeles	
	ASHRAE-1980	DOE-1993	ASHRAE-1980	DOE-1993
Building Component				
Roof insulation	R-11.9	R-16.0	R-6.7	R-5.4
Wall insulation	R-8.3	R-8.3	R-1.1	R-1.1
Floor insulation	R-5.6	R-7.7	R-2.5	R-2.5
Glazing thermal transmittance	0.595	0.595	0.595	0.595
Glazing shading coefficient	0.391	0.576	0.476	0.583
Window/wall ratio	0.36	0.36	0.36	0.36
Power Allowance				
Lighting (W/ft^2)	2.1-2.8	0.6-1.7	2.1-2.8	0.6-1.7
Equipment Efficiencies				
Cooling (EIR)[(a)]	0.248	0.193	0.248	0.192
Heating (HIR)[(b)]	1.33	1.25	1.33	1.25

(a) Electric Input Ratio.
(b) Heat Input Ratio.

2.4 Multi-Story, Multi-Family Apartment Building

The multi-family building selected for analysis was built in Edina, Minnesota, in 1977. It is a 9-story structure built in the shape of an "H", with an underground garage. It consists of 416,776 gross square feet (GSF) (excluding parking), of which 362,736 GSF are residential living quarters, and 54,040 GSF are composed of public areas and corridors. The building is constructed of cast-in-place concrete columns and flats slabs with post-tensioned steel reinforcing. North and south exposures have about 27% glass; east and west exposures have about 20% glass. Multiple HVAC system types were used for this building. The apartments are supplied with four-pipe fan coil units. The ventilation air in the apartments for make-up to the kitchen and bathroom exhausts is furnished from the corridor, supplied with a 100% make-up air variable-temperature, constant-volume (VTCV) direct expansion rooftop unit. The rooftop unit is also furnished with a hot water heating coil, whereas the cooling is done with a direct expansion coil, reciprocating compressor, and air-cooled condenser. The public and recreation areas are furnished with VTCV air-handling units. Two hermetic centrifugal chillers provide the chilled water, and two gas-fired, hot water boilers the hot water. A single, gas-fired hot water heater is also furnished for domestic hot water.

2.4.1 Apartment Building - Los Angeles

Ceiling insulation values dropped from R-8.41/ASHRAE-1980 to R-7.11/DOE-1993. This small difference in thermal resistance values did not provide enough change to result in an incremental insulation thickness.

Lower lighting power allowances under DOE-1993 provide for cost savings of almost $14,000 in the apartment building. In the parking garage, high-pressure sodium fixtures were used in the DOE-1993 scenario, to replace high-output fluorescent fixtures used under the ASHRAE-1980 scenario. High efficiency fluorescent fixtures replaced incandescents to achieve the DOE-1993 lighting power allowances in lobbies and storage areas.

Heating requirements increased as a result of the slight drop in ceiling thermal resistance values mentioned above in combination with the reduced internal heat gain achieved through the lower LPA. The slightly larger boiler needed to meet the increased heating requirement resulted in a cost increase of $3,600. Conversely, cooling requirements dropped slightly under DOE-1993; however, not enough to result in equipment downsizing.

The overall cost impact of DOE-1993 relative to ASHRAE-1980 was a negative increment of $10,161.

2.4.2 Apartment Building - Madison

Ceiling, wall, and floor insulation values all increased under DOE-1993. However, the increases were small, and only floor insulation incremented to the next greater thickness material. Extruded polystyrene slab insulation of 1.5-in. met the ASHRAE-1980 floor insulation requirements of R-5.55, but a 2-in. thickness of the same material was needed to meet the R-7.69 required to comply with DOE-1993. The incremental cost amounted to $1,600.

As was the case in the Los Angeles simulation, lighting power requirements were significantly lower under DOE-1993, and the associated lighting cost savings were $13,761. Heating and cooling requirements were slightly lower, and downsizing of boilers, chillers, and cooling towers was possible. The change in capacities was enough to result in a construction cost savings of $15,140.

The overall cost reduction under the DOE-1993 scenario was approximately $27,000.

Table 2.2 compares the apartment building's energy performance characteristics required for minimum compliance under DOE-1993 and ASHRAE-1980.

2.5 Retail (Anchor) Store

The retail store selected, a high-quality department store that serves as an anchor store for a mall shopping center, was built in Atlanta, Georgia, in 1975. The building is a 2-story structure with an average floor-to-floor height of 19 feet. Its 164,200-ft^2 area is divided into merchandising and office, 82%, and stock and storage, 18%. Construction is steel frame with masonry skin. The building has very little glass: no display windows, only 8-foot-wide glass entrance doors and a strip of small windows on the second floor office area. Each floor of the building is served by two constant-volume variable temperature air-handling units. There are no return fans; each unit has a drybulb-activated economizer. The air-handling units have electric-resistance heating coils. The cooling coils are supplied by chilled water from a single, hermetic centrifugal chiller with condensing water from a cooling tower.

Table 2.2. Energy-Related Building Characteristics for the Multi-Family, High-Rise Building

	Madison		Los Angeles	
	ASHRAE-1980	DOE-1993	ASHRAE-1980	DOE-1993
Building Component				
Roof insulation	R-13.6	R-17.6	R-8.4	R-7.1
Wall insulation	R-0.5	R-2.0	R-0.0	R-0.0
Floor insulation	R-5.5	R-7.7	R-2.5	R-2.5
Glazing thermal transmittance	0.595	0.595	1.383	1.383
Glazing shading coefficient	0.850	0.850	0.975	0.975
Window/wall ratio	0.13	0.13	0.13	0.13
Power Allowance				
Lighting (W/ft^2)	0.5-1.85	0.14-1.71	0.5-1.85	0.14-1.71
Equipment Efficiencies				
Cooling (EIR)[(a)]	0.248	0.192	0.248	0.192
Heating (HIR)[(b)]	1.33	1.25	1.33	1.25

2.5.1 Retail Store - Los Angeles

The DOE2.1C computer simulation indicated that an insulation value of R-0.98 was required for minimum compliance to ASHRAE-1980, but called for an R-0 under DOE-1993. The built-up roof construction of the retail building lends itself to rigid insulation and, therefore, 0.5-in. polystyrene insulation was estimated for the ASHRAE-1980 case at a cost of $26,172. This condition, where an "odd" R-value is established by a building simulation program, is a good example of one of the drawbacks associated with using theoretical data from an energy simulation program for the purposes of determining cost impacts of energy-efficiency codes and regulations. Ideally, the energy simulation program should default to the nearest value that reflects commonly available components and equipment. In this way, energy savings data would directly correlate with cost impacts.

The DOE-1993 lighting power allowance for the retail store was 1.20 W/ft^2. The LPA under ASHRAE-1980 was 3.25 W/ft^2. The building was actually constructed to 1.70 W/ft^2, significantly exceeding the performance requirements of the ASHRAE-1980 standard. Because the ASHRAE LPA appeared to be unreasonably high, savings were estimated relative to the as-built conditions. The lower LPA from DOE-1993 relative to the as-built condition yielded a total savings potential of $8,495. Meeting the standard of 1.20 W/ft^2 was easily accomplished by using the T-8 fluorescent lamp and electronic ballast technologies.

The cooling requirements of the building decreased by approximately 25% under DOE-1993, and cost estimates performed on a smaller chiller and cooling tower revealed a cost reduction potential of approximately $22,000. Overall, the negative cost increment as a result of the DOE-1993 standard was $56,567.

2.5.2 Retail Store - Madison

Ceiling and floor insulation requirements were tighter under the DOE-1993 scenario resulting in a cost increase of over $21,000. These cost increases were partially offset by savings from lighting reduction ($8,445) and from the specification of a smaller cooling tower ($7,400). The total cost increment of the DOE-1993 version of the retail store versus the ASHRAE-1980 case was $5,297.

Table 2.3 compares the retail building's energy performance characteristics required for minimal compliance under DOE-1993 and ASHRAE-1980.

2.6 Strip Mall Store

The small retail store selected was composed of two units (end and adjacent unit) of a strip shopping center built in Multnomah County, Oregon in 1978. The units are single-story (18 ft floor to ceiling) with a GSF area of 11,760 ft^2, and are wood-frame construction with cedar siding. The southern and western exposures are about 35% glass, with no glass on the eastern and northern sides. Each unit is served by a separate packaged rooftop variable-temperature, constant-volume direct expansion unit. Each unit has a drybulb-activated economizer. The heating is by gas-fired heat exchangers and the refrigeration compressors are the reciprocating-type with air-cooled condensers. Estimated total original building construction cost was $620,000.

Table 2.3. Energy-Related Building Characteristics for the Anchor Retal Building

	Madison		Los Angeles	
	ASHRAE-1980	DOE-1993	ASHRAE-1980	DOE-1993
Building Component				
Roof insulation	R-6.1	R-10.2	R-1.0	R-0.0
Wall insulation	R-1.3	R-0.8	R-0.0	R-0.0
Floor insulation	R-5.6	R-7.7	R-2.5	R-2.5
Glazing thermal transmittance	1.383	1.383	1.383	1.383
Glazing shading coefficient	0.975	0.975	0.975	0.975
Window/wall ratio	0.07	0.07	0.07	0.07
Power Allowance				
Lighting (W/ft^2)	3.25	1.2	3.25	1.2
Equipment Efficiencies				
Cooling (EIR)[(a)]	0.248	0.192	0.248	0.192
Heating (HIR)[(b)]	1.33	1.25	1.33	1.25

2.6.1 Strip Mall Store - Los Angeles

This is the only simulation where the DOE-1993 standard resulted in an increase in glazing efficiency resulting in an increment from single- to double-pane glass. The use of double-pane windows resulted in a cost increase of $10,602.

The building was built to a lower LPA than that required by either standard and, therefore, lighting did not result in incremental cost changes. The cooling requirements went down as a result of the increased insulating qualities of the glass but not enough to increment the HVAC system to the next smaller unit.

2.6.2 Strip Mall Store - Madison

Costs related to increases in the thermal efficiency of the ceiling ($1,171), wall ($926), and floor ($1,100) characteristics of the strip mall under the DOE-1993 standard simulation were completely offset by savings from a slightly lower capacity HVAC system ($9,400). The total negative increment equaled $6,204.

Table 2.4 compares the strip mall building's energy performance characteristics required for minimal compliance under DOE-1993 and ASHRAE-1980.

Table 2.4. Energy-Related Building Ch racteristics for the Strip Retail Building

	Madison		Los Angeles	
	ASHRAE-1980	DOE-1993	ASHRAE-1980	DOE-1993
Building Component				
Roof insulation	R-11.1	R-15.2	R-5.9	R-4.6
Wall insulation	R-3.2	R-13.3	R-5.3	R-5.3
Floor insulation	R-5.6	R-7.7	R-2.5	R-2.5
Glazing thermal transmittance	0.595	0.595	1.383	1.383
Glazing shading coefficient	0.631	0.745	0.683	0.439
Window/wall ratio	0.24	0.24	0.24	0.24
Power Allowance				
Lighting (W/ft^2)	2.7	2.2	2.7	2.2
Equipment Efficiencies				
Cooling (EIR)[a]	0.248	0.192	0.248	0.192
Heating (HIR)[b]	1.33	1.25	1.33	1.25

3.0 Findings

The results of the case studies of the four buildings indicate that although the energy-efficiency requirements of DOE-1993 are, in general, more demanding than ASHRAE-1980, they do not necessarily result in higher construction costs. Rather, the DOE-1993 compliance methodologies' flexibility allows designers to economically use the wide range of lighting and HVAC equipment and envelope component materials currently available to design buildings with energy-related components of equivalent or lower cost than those designed to the ASHRAE-1980 standard. In six of the eight cases studied, energy-related construction component costs were slightly lower as a result of changes made to comply with DOE-1993 relative to ASHRAE-1980.

A portion of the construction cost savings resulted directly from the lower lighting power levels required under DOE-1993. Higher fixture efficacy (greater lumen output and/or lower power requirements) and lower allowable lighting levels permit design alternatives using fewer fixtures, thereby reducing material and labor costs while reducing the installed watts per square foot to meet the lighting power allowance. The reduction in construction costs for the lighting system ranged from approximately $900 in the bank simulation to $14,000 in the apartment building simulation.

The lower lighting power allowance of DOE-1993 also results in lower internal building heat gain, which reduces air conditioning loads while increasing heating demand. The effect of lower internal heat gain, when coupled with the minor increases in envelope and glazing thermal efficiency performance and slightly higher efficiency HVAC equipment required by DOE-1993, produced some small changes in HVAC equipment capacity requirements. In half the cases studied, these changes were large enough to allow the slight downsizing of cooling equipment resulting in cost savings ranging from $7,400 to $22,000. In the case of the Los Angeles apartment building simulation, heating requirements increased as a result of a slight decrease in ceiling insulation required under DOE-1993, plus reduced internal heat gain due to the lower LPA. In this case, a slightly larger boiler was required at a cost increase of $3,600.

There were no incremental construction costs associated with changes in glazing thermal performance characteristics, except for the strip retail store in Los Angeles. In this particular building, the glazing was changed form clear single-pane, to tinted double-pane, with an increase in construction costs of slightly over $10,000.

The required changes in envelope R-values (insulation levels) to meet the requirements of the standard were for the most part small and construction cost impacts relative to ASHRAE-1980 ranged between a negative increment of $26,000 in the Los Angeles retail store to an incremental cost of $21,000 in the Madison retail store.

3.1 Summary of Costs and Energy Savings

A summary of the DOE-1993 cost increments, estimated original building total construction costs, and the annual energy savings achieved through compliance with DOE-1993 is presented in Table 3.1.

Table 3.1. Estimated Base Building Construction Cost and Incremental Costs for Implementing the DOE-1993 Standards

Location/Building	Estimated Construction Cost Original Building	Incremental Cost (DOE-1993 versus ASHRAE-1980)	Annual Energy Savings (MBtu)
Los Angeles			
Apartment	$36,000,000	-$10,161	1998
Bank	$301,000	-$876	24
Strip Retail	$620,000	$10,602	284
Retail	$10,200,000	-$56,567	5118
Madison			
Apartment	$32,000,000	-$27,301	4950
Bank	$301,000	-$1,893	26
Strip Retail	$600,000	-$6,205	108
Retail	$9,000,000	$5,294	3764

The demonstration project findings also indicate that multi-family, high-rise buildings can be designed to comply with both DOE-1993 and ASHRAE-1980 with minimal differences in overall energy-related component construction cost. Therefore, implementation of DOE-1993 should have little or no effect on the ability of both large or small construction companies to bid on these projects. It should be pointed out, however, that multi-family, high-rise buildings are typically built by larger construction firms and not by small construction companies.

It is anticipated that DOE-1993 will have no impact on the ability of low-to-moderate-income people to rent or purchase a unit in a multi-family, high-rise complex for three reasons. First, the standard does not appear to lead to higher construction costs. Second, findings demonstrate that very small changes in HVAC equipment sizing and efficiency will be required under DOE-1993 relative to ASHRAE-1980, and the number of lighting fixtures may be reduced, indicating a potential reduction in maintenance costs. Finally, a previous study (Hadley and Halverson 1992) found that overall energy use should be reduced by DOE-1993. Therefore, the DOE-1993 standard should have no impact on rent or purchase prices.

3.1.1 Limitations of the Methodology

The methodology used in this construction cost impact analysis has several limitations. The first pertains to the building energy performance data provided for use in the analysis. The primary intent of the original building model simulations was to develop an energy-use database for estimating the energy-savings potential of minimally compliant prototypical buildings. The methodology used to bring the original buildings' thermal performance into minimal compliance with ASHRAE-1980 and DOE-1993 involved varying the energy efficiency of selected system components until minimum energy performance levels were attained. The process used for selecting system components for modification was somewhat arbitrary.

This approach, although adequate to meet the needs of the energy study (Hadley and Halverson 1992), produced data that do not reflect standard building practice, and therefore, were not entirely compatible with the requirements of the construction cost impact analysis methodology. For example, the thermal resistance values of envelope components derived from the energy analysis required "interpretation" into R-values that are practical from an architectural design and cost-estimating perspective. Some accuracy is lost in the translation because the energy performance characteristics of the theoretical building do not exactly correspond to the performance characteristics of the insulation materials used in the cost study. Ideally, the energy simulation program should provide data which default to the nearest thermal resistance or conductivity value that reflects commonly available components and equipment.

The second limitation is that this construction cost impact analysis represents only a small fraction of the possible design and equipment selection permutations that may result from implementing DOE-1993 and relies on the extensive use of engineering judgment.

Thirdly, this construction cost impact analysis used buildings constructed in the late 1970s and early 1980s as a basis. Buildings constructed during this time period incorporated design techniques common to the 1970s. This somewhat limits the accuracy of the study in that they do not reflect the significant advancements and changes in energy efficiency that came about in the 1980s.

4.0 Recommendations

The results of the case studies performed under this construction cost impact analysis indicate that commercial and multi-family, high-rise buildings can be designed to comply with both DOE-1993 and ASHRAE-1980 with minimal differences in overall construction cost. However, through the course of the demonstration, several limitations to the study methodology were identified. The recommendations which follow are directly associated with these findings.

The findings of this analysis have revealed the limitations of using theoretical building simulation output data to define the energy-related building components used in a comparative construction cost study.

> ***Recommendation 1:*** *Within the next year DOE should begin the development of a methodology to link energy-related construction cost database information with building simulation programs to allow the effects of energy-efficient design alternatives to be measured and evaluated directly in terms of both energy and cost performance.*

This construction cost impact analysis represents only a small fraction of the possible design and equipment selection permutations that may result from the implementation of the DOE-1993 standard.

> ***Recommendation 2:*** *During the next year, DOE should expand its construction cost impact analysis efforts to include a cost-sensitivity analysis which examines design alternatives that reflect 1) average, low-cost construction practice; 2) above-average, moderate-cost construction; and 3) advanced, high-cost construction practices which make full use of current materials, equipment, and technologies. The sensitivity analysis will allow the DOE to more clearly define the bounds of the cost impacts possible under the DOE-1993 standard.*

This construction cost impact analysis used buildings constructed in the late 1970s and early 1980s as a basis.

> ***Recommendation 3:*** *Within the next year, DOE should perform an assessment of current industry design and construction practice using a representative sample of buildings and building types. The assessment should be followed by cooperative working agreements with the design and construction industry to develop practical design alternatives that comply with DOE-1993.*

5.0 References

10 CFR 435. 1989. U.S. Department of Energy, "Energy Conservation Voluntary Performance Standards for New Commercial and Multi-Family High-Rise Residential Buildings; Mandatory for Federal Buildings." *U.S. Code of Federal Regulations.*

American National Standards Institute (ANSI). 1975. *ANSI/ASHRAE/IES Standard 90-75: Energy Conservation in New Building Design.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). 1980. *ASHRAE Standard 90A-1980: Energy Conservation in New Building Design.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)/ Illuminating Engineering Society of North America (IES). 1989. *ASHRAE/IES Standard 90.1-1989: Energy Conservation in New Buildings, Except Low-Rise Residential.*

Crawley, D. B., P. K. Riesen, and R. S. Briggs. 1989. *Users Guide for ENVSTD Program Version 2.1 and LTGSTD Program Version 2.1.* PNL-6839, Pacific Northwest Laboratory, Richland, Washington.

Hadley, D. L., and M. A. Halverson. 1993. *Energy Conservation Potential of the U.S. Department of Energy Interim Commercial Building Standards.* PNL-7967, Pacific Northwest Laboratory, Richland, Washington.

Illuminating Engineering Society of North America (IES). 1981. *Illuminating Engineering Society of North America Lighting Handbook.* Illuminating Engineering Society of North America, New York.

Lawrence Berkeley Laboratory (LBL). 1981. *DOE-2 Reference Manual (Version 2.1A), Part 1.* LBL-8706 Revision 2. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

R. S. Means Company, Inc. 1990a. *MEANS Building Construction Cost Data: 1991 14th Annual Edition.* R. S. Means Company, Inc., Kingston, Massachusetts.

R. S. Means Company, Inc. 1990b. *MEANS Electrical Cost Data: 1991 14th Annual Edition.* R. S. Means Company, Inc., Kingston, Massachusetts.

R. S. Means Company, Inc. 1990c. *MEANS Mechanical Cost Data: 1991 14th Annual Edition.* R. S. Means Company, Inc., Kingston, Massachusetts.

Pacific Northwest Laboratory (PNL). 1983a. *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings. Volumes I through IV.* DOE/NBB-0051 through DOE/NBB-0051/39. (Issued as 40 separate documents). National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

Pacific Northwest Laboratory (PNL). 1983b. *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings. Volume IV-A, Documentation of Test Results: Small Office Building (Bank), Part 1: Plans, Elevations, Photos, Compliance-Check Data Sheets, Cost Estimate Data Sheets.* DOE/NBB-0051/10. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

Pacific Northwest Laboratory (PNL). 1983c. *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings. Volume IV-A, Documentation of Test Results: Retail Store (Anchor Store), Part 1: Plans, Elevations, Photos, Compliance-Check Data Sheets, Cost Estimate Data Sheets.* DOE/NBB-0051/19. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

Pacific Northwest Laboratory (PNL). 1983d. *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings. Volume IV-A, Documentation of Test Results: Strip Store, Part 1: Plans, Elevations, Photos, Compliance-Check Data Sheets, Cost Estimate Data Sheets.* DOE/NBB-0051/22. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

Pacific Northwest Laboratory (PNL). 1983e. *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings. Volume IV-A, Documentation of Test Results: Apartment House, Part 1: Plans, Elevations, Photos, Compliance-Check Data Sheets, Cost Estimate Data Sheets.* DOE/NBB-0051/25. National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia.

U.S. Department of Energy (DOE). 1983. *Recommendations for Energy Conservation Standards and Guidelines for New Commercial Buildings.*

Distribution

No. of
Copies

OFFSITE

12 DOE/Office of Scientific and
Technical Information

J. J. Boulin
Office of Building Technologies
CE-43
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

S. J. Turchen
Office of Codes and Standards
CE-43
U.S. Department of Energy
1000 Independent Avenue SW
Washington, DC 20585

S. Walder
Office of Codes and Standards
CE-43
U.S. Department of Energy
1000 Independent Avenue SW
Washington, DC 20585

No. of
Copies

ONSITE

DOE Richland Operations Office

D. D. Green

25 Pacific Northwest Laboratory

L. M. Buel
J. L. Carlson, Program Files (10)
F. V. Di Massa (3)
J. A. Dirks
D. L. Hadley
M. A. Halverson
J. A. Johnson
D. L. Shankle
Publishing Coordination
Technical Report Files (5)

END

DATE
FILMED
2/11/94