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Pacific Northwest National Laboratory
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Analysis of Potential Benefits and Costs of Adopting ASHRAE Standard 90.1-1999 as a Building Energy Code in Illinois Jurisdictions

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May 2002

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Executive Summary

ANSI/ASHRAE/IESNA Standard 90.1-1999 Energy Standard for Buildings except Low-Rise Residential Buildings (hereafter referred to as ASHRAE 90.1-1999 or 90.1-1999) was developed in an effort to set minimum requirements for the energy efficient design and construction of new commercial buildings. A number of jurisdictions in the state of Illinois are considering adopting ASHRAE 90.1-1999 as their commercial building energy code. The potential benefits and costs of adopting this standard are considered in this report in an effort to evaluate whether or not this is an appropriate efficiency level for those jurisdictions and possibly the state.

Quantitative measures of impacts are estimated using the Building Loads Analysis and System Thermodynamics (BLAST) simulations combined with the measure of Life-Cycle Cost (LCC). Illinois does not currently have a statewide building energy code; thus, in the absence of a code, ASHRAE Standard 90.1-1989 was used as the baseline.

The energy simulation and economic results of the building prototypes selected for this study suggest that adopting ASHRAE 90.1-1999 as the commercial building energy code in Illinois jurisdictions would provide positive net benefits relative to the building and design requirements prescribed in ASHRAE 90.1-1989. For most requirements, the adoption of ASHRAE 90.1-1999 increases first costs, but decreases energy costs; however, some requirements of the standard decrease first costs while providing negligible energy cost savings. In either case, the LCC of 90.1-1999 requirements is lower than the LCC to meet the 90.1-1989 requirements.

A discussion is also provided to explain additional decreases in energy that result from ASHRAE 90.1-1999 requirements that were not included in the quantitative modeling analysis. In addition, if ASHRAE 90.1-1999 were adopted as code in its entirety, which includes the addition of commercial building renovation, it could further increase the energy efficiency of commercial buildings.

Finally, ASHRAE 90.1-1999 provides some qualitative improvements over the ASHRAE 90.1-1989 standard that makes adoption more desirable. For example, ASHRAE 90.1-1999 is written in mandatory, enforceable language, which makes it easier to enforce. It also improves the format of many of the reference tables so that it is easier to follow and, therefore, easier with which to comply.

Contents

Acronyms

ACP	–	Alternate Component Packages
AIRR	–	Adjusted internal rate of return
ASHRAE	–	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BLAST	–	Building Loads Analysis and System Thermodynamics
BLCC	–	Building Life-Cycle Cost
CBECS	–	Commercial Buildings Energy Consumption Survey
CDD	–	Cooling Degree-Days
DOE	–	U.S. Department of Energy
EIA	–	Energy Information Administration
EPCA	–	Energy Policy and Conservation Act
EUIs	–	Energy Use Intensities
FEMP	–	Federal Energy Management Program
HDD	–	Heating Degree-Days
HID	–	High Intensity Discharge
HVAC	–	Heating, Ventilation, and Air-Conditioning
IES	–	Illuminating Engineering Society
LCC	–	Life-Cycle Cost
LPD	–	Lighting Power Densities
NEMS	–	National Energy Modeling System
NIST	–	National Institute of Standards and Technology
OMB	–	Office of Management and Budget
PNNL	–	Pacific Northwest National Laboratory
SC	–	Shading Coefficient
SIR	–	Savings-to-Investment Ratio
SWH	–	Service Water Heating
TMY	–	Typical Metrological Year
TSD	–	Technical Support Document

(Glossary of selected terms found in Appendix A)

1.0 Introduction

1.1 Objective

A number of jurisdictions in the state of Illinois are considering adopting ASHRAE 90.1-1999 as their commercial building energy code. The potential benefits and costs of adopting this standard are considered in this report in an effort to evaluate whether or not this is an appropriate efficiency level for those jurisdictions and possibly the state.

The state of Illinois does not currently have a statewide building energy efficiency code, except for state-owned buildings. A number of jurisdictions in Illinois, however, have adopted *ANSI/ASHRAE/IESNA Standard 90.1-1999 Energy Standard for Buildings except Low-Rise Residential Buildings* and a number of other jurisdictions are interested in doing so. Rather than doing piecemeal studies to inform the decision process in individual jurisdictions, the U.S. Department of Energy (DOE) decided to do a statewide analysis of adopting ASHRAE 90.1-1999 in Illinois jurisdictions. Representatives from the State of Illinois specified the need for an objective analysis that included potential aggregate state energy cost savings resulting from code adoption as well as carbon reductions, SO_2 reduction, NO_x reduction, end-use electric savings, natural gas savings, consumer energy dollar savings, and building and material costs imposed by new energy codes.

1.2 Scope

This report provides a preliminary analysis with the scope limited to office, retail, and education buildings, as these building types made up over 60% of the total value of new commercial construction in Illinois in 1997 (Census 2000c). Within these building types, the impacts of the building envelope and lighting requirements are assessed, while mechanical requirements are excluded because of expected changes in efficiencies due to federal manufacturing standards as referenced under the Energy Policy and Conservation Act (EPCA) as amended by the 1992 Energy Policy Act (EPAct).

Under this legislation, the energy efficiency of most of the HVAC and SWH equipment regulated under ASHRAE 90.1-1999 is also regulated by federal manufacturing standards, which by law will soon be updated to levels at least as stringent as those in 90.1-1999. Hence, the savings from these equipment requirements will generally occur regardless of the adoption of a building standard in Illinois. Efficiency improvements in equipment that are not covered under EPCA are discussed in Section 5.4 of this report along with other requirements in the HVAC and SWH section of the standard. The potential quantitative impact of the equipment standards has been evaluated in detail in the report, *Screening Analysis for EPACT-Covered Commercial HVAC and Water heating Equipment.*

Illinois does not currently have a statewide building energy code that could be used as a baseline, so ASHRAE 90.1-1989 was chosen as it is the nationally recognized standard of professional practice in this area and is the current energy code for Illinois State-owned buildings. Although the design criteria for ASHRAE 90.1-1989 may not always accurately reflect all current building practices in Illinois, it is probable that many new buildings are at least at the level of the 90.1-1989 standard. In addition, a previous study has assessed the impact of adopting ASHRAE 90.1-1989 as code, using relatively current design and building practices as the baseline (Smith & Nadel 1994). Thus, this study uses 90.1-1989 as the baseline for evaluating the incremental impact of adopting the ASHRAE 90.1-1999 requirements.

This report includes a summary of background information regarding various building code requirements, state-specific information, and a description of the assumptions required to complete the quantitative analysis. The report includes sections that describe the building simulation process as well as the economic model and the assumptions used to calculate life-cycle cost savings for each building type. Detailed quantitative results are included in the appendix and discussed in Section 5. Finally, a discussion addressing benefits and costs associated with code adoption that are not specifically addressed in the quantitative study is included in the final sections of this report

2.0 Background

Energy codes set minimum standards for design and construction while ensuring occupant comfort. These codes eliminate building design practices that lead to unnecessarily high building energy use and associated costs. Energy cost savings resulting from energy code compliance directly benefit building owners and occupants over the life cycle of the building. An energy code, however, may impose higher initial costs on the building owner, as frequently the incentive is to use equipment and materials that have lower first costs and lower efficiencies. The energy savings also reduce the need for new generating and transmission capacity, and detrimental environmental effects associated with energy production, distribution, and use.

2.1 Summary of Differences between Standards

2.1.1 Building Envelope Standard Changes

Building envelope requirements apply to conditioned (i.e., heated and cooled) spaces that are separated from unconditioned spaces. The requirements, which vary by climate, apply to windows, doors, and insulation for roofs, walls, and floors. The portion of ASHRAE Standard 90.1 that addresses building envelope requirements includes prescriptive as well as mandatory and trade-off options in both the 1989 and 1999 editions. Window and door requirements specify U-factors and solar heat gain coefficients (the 1989 edition used shading coefficient). The 90.1-1999 standard has added air leakage requirements that apply to Illinois climates for the sealing of openings and joints in the building envelope (including windows and doors, loading docks, and vestibules). The prescriptive path of the 1999 edition also includes methods for calculating U-factors, C-factors, and F-factors for pre-assembled envelope sections. A performance trade-off option in both editions of the standard allows designers to use any combination of building envelope materials that meet both the mandatory requirements and a minimum envelope performance factor.

The general difference between ASHRAE 90.1-1989 and 90.1-1999 is the approach used to justify the minimum envelope requirements. ASHRAE 90.1-1989 set envelope requirements based on professional judgement regarding building type, characteristics, and climate. ASHRAE 90.1-1999 is based on an economic justification of energy efficiency that uses a life cycle cost approach to balance energy savings with the increased cost of materials and equipment.

One other significant difference between the 1989 and 1999 editions is that ASHRAE 90.1-1989 focused on setting a requirement for “all roofs” or “all walls” or “all floors” while ASHRAE 90.1-1999 looks at differences in roofs, walls, and floors. The outcome of this is that ASHRAE 90.1-1989 has a requirement for “all roofs” (or walls or floors) that is based on the performance of the best performing construction while ASHRAE 90.1-1999 has requirements specific to each type of construction (e.g., mass walls are treated differently than metal-framed walls). The end result is that ASHRAE 90.1-1989 has more stringent envelope requirements for buildings that are constructed of less insulating materials than ASHRAE 90.1-1999 (e.g., requirements for metal buildings tend to be more stringent in ASHRAE 90.1-1989 than in ASHRAE 90.1-1999). ASHRAE 90.1-1989 specified requirements for overall wall thermal performance while 90.1-1999 treats windows and opaque walls separately.

An additional distinction between ASHRAE 90.1-1989 and the 90.1-1999 standard is that the 1989 version is based on a series of continuous efficiency curves, leading to continuously changing requirements by climate. The 1999 version is based on a "step-function" approach. Thus, the1989 standard may have wall requirements of R-5.4, R-7.2, R-8.6, R-9, R-10, R-11.3 for various locations where the 1999 standard has either R-7 or R-11 or R-13. The resulting impact of the 90.1-1989 requirements is that one would typically need to exceed the prescriptive requirements in order find a commercially available product[1]. To meet the 90.1-1999 requirements, only commercially available R-value insulation is considered and the life cycle fuel cost savings achieved from going to the next level has to pay for the incremental cost of the material and/or equipment.

2.1.2 Lighting Standard Changes

The ASHRAE 90.1-1989 section on lighting includes both mandatory provisions and a prescriptive path to determine compliance. The 1989 mandatory requirements cover minimum lighting controls and their accessibility and include restrictions on single-lamp ballasts when more efficient multiple-lamp ballasts can be used. The 90.1-1989 standard includes efficiency requirements for ballasts, which have been absorbed into federal manufacturing standards under EPCA. Automatic controls are not required in the 1989 standard but credits allowing higher lighting power densities (LPDs) were allowed if occupancy, lumen maintenance, and/or daylight sensors are installed.

Whole building lighting power densities are considered the most reasonable and practical method of comparing lighting requirements. However, the 90.1-1989 standard provides direct lighting densities for only a few building categories and sizes. Therefore, LPDs for whole buildings used in this comparison were calculated on a space-by-space basis that are similarly represented in both the 1989 and 1999 editions of the standard. This provides the most directly comparable basis between the two standards. Space-by-space numbers in the 1989 standard are used as a base value and an adjustment factor is applied for each space to adjust for room size and ceiling height to make them comparable in application to the corresponding 1999 space-by-space power densities.

The mandatory provisions in 90.1-1999 focus on lighting controls and efficient use of lighting ballasts. The primary requirement is an automatic lighting control, which consists of a programmable whole building lighting shutoff control, occupancy sensors, or similar automatic lighting shutoff control system. Other control requirements define limits for area control of lighting, use of photosensor or timeclock controls for exterior lights, and additional control of specific lighting tasks. The use of less efficient single-lamp fluorescent ballasts is reduced through tandem wiring requirements. The mandatory section

[1] For example, 90.1-1989 could require an R-10.6 wall, where the only thing that would meet this requirement in the market would be an R-11 wall.

also defines calculation of fixture wattage and sets power limits for exit signs and exterior lighting.

The 90.1-1999 prescriptive path includes interior and exterior lighting power allowances, where the interior lighting power allowances may be determined by using either the total building area or the space-by-space (e.g., office, hallway) method. Interior lighting power requirements allow for design differences and special lighting needs by providing power allowances for decorative, display, accent lighting, merchandise highlighting, and computer screen glare reduction in specified spaces. Lighting excluded from the code is identified for specific tasks or applications such as safety lighting and lighting within living units. Exterior lighting, used at building entrances and exits and for building highlighting, has specified power limits while all other exterior grounds lighting is limited only by the efficiency of the light source itself.

Table 1 shows a comparison of the requirements in 1989 and 1999 editions for some selected lighting power density allowances using the whole building and space-by-space methods.

Table 1. Comparison of Lighting Power Densities – Standards 90.1-1989 and 90.1-1999

Whole Building Method Lighting Power Densities (W/ft^2)			**Space-by-Space Method Lighting Power Densities**		
Building Type	**90.1-1999**	**90.1-1989**	**Space Type**	**90.1-1999**	**90.1-1989**
Hospital	1.6	NA	Office Enclosed	1.5	1.8
Library	1.5	NA	Office Open	1.3	1.9
Manufacturing	2.2	NA	Conference	1.5	1.8
Museum	1.6	NA	Training	1.6	2.0
Office	1.3	1.5 to 1.9	Lobby	1.8	1.9
Parking Garage	0.3	0.2 to 0.3	Lounge/Dining	1.4	2.5
Retail	1.9	2.1 to 3.3	Food Prep	2.2	1.4
School	1.5	1.5 to 2.4	Corridor	0.7	0.8
			Restroom	1.0	0.8
			Active Storage	1.1	1.0

NA: Not Addressed in the 1989 Edition

2.2 State Characteristics

The building simulation and LCC inputs of this study are characterized to fit state-specific characteristics such as climate, building construction trends, and energy source characteristics. The following sections contain some of the key components considered in tailoring the study to Illinois.

2.2.1 Climate Zone

The climate zone is defined by long-term weather conditions, which affect heating and cooling loads in buildings. The zones are based on annual average number of degree-days, which are a measure of how cold/hot a building location is relative to the base temperature[2]. The climate zones in Illinois range from 2515 CDD and 7136 HDD in Waukegan (relatively cool climate zone) to 3934 CDD and 4865 HDD in Carbondale.

2.2.2 Demographic and Construction Data

In 2000 Illinois had a population of approximately 12.4 million, with the primary growth centers located in and around the counties surrounding Chicago. The five counties with the highest growth rate (Kendall, Will, Kane, McHenry, and Boone) are all located in the northeast corner of the state (Census 2000b).

In 1997 the value of new commercial construction in Illinois totaled $8.5 billion. Office, retail, and education buildings made up more than 60% of the total value of new construction in that year (Census 2000c).

2.2.3 Energy Consumption and Sources

Approximately 3.9 quadrillion Btu of energy is consumed in Illinois each year, of which about 20% of this energy is consumed in the commercial sector[3]. The primary energy sources for building heating, cooling, and lighting in Illinois are gas and electricity. Nuclear and coal power are the primary sources of electricity generation in Illinois, making up over 70% of the total generating capacity in 1999 (EIA 2001c).

2.3 Assumptions

Although Illinois has varying temperatures throughout the state, this preliminary analysis focuses on the northern region, where much of the population growth and building construction is occurring. The climate in northern Illinois is generally defined as having fewer than 3000 average annual CDD and 5500 to 7000 average annual HDD. Representative weather data is taken from the Typical Meteorological Year (TMY) weather data set.

This study focuses on three different commercial building types: office, retail, and education. Five building design prototypes are characterized and assessed. All buildings are characterized as rectangular buildings; however, they vary in size and window-to-wall ratios. A relatively small (1-story, 10,000 square foot) office building and a larger office building (3 floors, 60,000 square feet) are simulated and each size office is simulated with two separate window-to-wall ratios. Also a 24,000 square foot, single-story retail building and two education buildings are characterized in this evaluation. A general description of all seven building analyzed is shown in Table 2.

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[2] The daily heating degree days (HDD) is the numerical difference between a day's average temperature and 65 degrees Fahrenheit (HDD is zero if the day's average temperature is less than 65 ^{o}F and the annual HDD is the sum of the daily HDD for the year. The daily cooling degree days (CDD) is the numerical difference between a day's average temperature and 50 degrees Fahrenheit (CDD is zero if the day's average temperature greater than 50 ^{o}F) and annual CDD is the sum of the daily CDD for the year.

[3] The residential sector consumes 22% of the energy consumed in Illinois, while the industrial sector consumes 33%, and the transportation sector consumes 25%.

Table 2. Study Building Set

BUILDING TYPE	WINDOW-TO-WALL RATIO	SQUARE FOOTAGE	NUMBER OF FLOORS	ASPECT RATIO[1]
Small Office-1	18%	10,000	1	2.25
Small Office-2	38%	10,000	1	2.25
Large Office-3	18%	60,000	3	2.25
Large Office-4	38%	60,000	3	2.25
Retail	7%	24,000	1	2.5
Education-1 (Elementary)	18%	50,000	1	6
Education-2	18%	80,000	2	5

[1]The aspect ratio is the building length divided by the building width.

It is assumed that these representative buildings are heated with a gas furnace and cooled with an electric air conditioner, as that is most common in new commercial buildings in Illinois. The economic study period is set to be 40 years to adequately capture the changes in energy expenditures and replacement of key components over the (economic) life of the building. Costs and benefits are expressed in 2001 dollars, unless otherwise specified.

3.0 Energy Analysis

Annual building energy use simulations were made using the Building Loads Analysis and System Thermodynamics (BLAST) program, developed by the Building Systems Laboratory of the University of Illinois. BLAST performs hourly energy simulations of buildings, air-handling systems, and central plant equipment.

3.1 Simulation Process

The BLAST outputs used for this analysis were derived from previous work completed by PNNL in support of the Department of Energy's determination regarding whether ASHRAE 90.1-1999 would improve energy efficiency in new commercial buildings. The simulations were based on a 3-story prototype building with fifteen thermal zones. Each simulation has a given combination of 90.1-1989 and 90.1-1999 standard levels for lighting, equipment, and building envelope design. Each simulation provides annual Energy Use Intensity (Btu/ft^2) for gas and electricity in each of the thermal zones. The Energy Use Intensities (EUIs) for each of the representative building types presented in Section 2.3 and simulated in the Illinois climate were scaled to appropriately reflect variations in assumed building size and shapes.

3.2 Simulation Input Characterization

3.2.1 Building Envelope Inputs

The building envelope characteristics examined in the analysis were: U-factors for opaque walls, roofs, and fenestration (window and door); either the fenestration Shading Coefficient requirements (in ASHRAE 90.1-1989) or Solar Heat Gain Coefficient requirements (in ASHRAE 90.1-1999); and the effective slab U-factors for slab on grade construction. These characteristics were determined for each of the building types and requirement changes. The simulation of ASHRAE 90.1-1989's envelope requirements were based on ASHRAE 90.1-1989's Alternate Component Packages (ACP) tables that provide the prescriptive compliance path for the standard's envelope requirements.

ASHRAE 90.1-1989 is based on a series of continuous efficiency curves, leading to continuously changing requirements by climate. Thus, the1989 standard may have wall requirements of R-5.4, R-7.2, R-8.6, R-9, R-10, R-11.3 for various locations, where no actual product on the market precisely meets these specific requirements. Because ASHRAE 90.1-1989's requirements do not necessarily directly match with a typical building assembly, the actual U-factors used in the simulations were chosen to reflect the U-factors of real (e.g. R-11 rather than R-11.2) building assemblies that must reach new requirements without exceeding the U-factor requirements. This is expected to be more representative of the real envelope performance resulting from application of ASHRAE 90.1-1989. This procedure provides a lower estimate of the envelope energy savings compared to a more strict requirement-to-requirement characterization of the opaque wall

U-factors. The simulated U-factors are included for a each building type in the tables in Appendixes B and C.

3.2.2 Lighting Inputs

The lighting power density requirements were developed from the whole building lighting requirements for both ASHRAE 90.1-1989 and ASHRAE 90.1-1999 for comparable building types. The 90.1-1999 standard provides single value whole building lighting power density values for thirty-one different building types while the 90.1-1989 standard provides values for only eleven. ASHRAE 90.1-1989 also provides different lighting power densities for six different building size categories within each building type.

The whole building LPD values for 90.1-1989 do not correspond perfectly to the building types simulated. In order to develop whole building lighting numbers for each building type, a weighting process was employed based on the Commercial Buildings Energy Consumption Survey (CBECS) data (1995). In the case of education, for example, ASHRAE 90.1-1989 provides LPD values for subcategories (preschool/elementary, Jr. High/High School, and Technical/Vocational school) of this building type. With education buildings, the LPDs are first averaged for each building type category and then the resulting LPDs are weighted by building size. In the case of retail type buildings, ASHRAE 90.1-1989 has three basic retail building subcategories (retail, mall concourse, and service). A weighted average of the allowed LPDs was constructed, using ASHRAE 90.1-1989's LPD values and the CBECS 95 floor area data for each building type and size category.

ASHRAE 90.1-1999 provides single value, whole building, LPD requirements for office, retail, and education buildings, and these requirements were used in the simulations. Table 3 shows a comparison of the Whole Building lighting requirements under both editions.

Table 3. Lighting Power Density (Watts/sq. ft)

Building Type	**90.1-1989**	**90.1-1999**
Education	1.79	1.50
Offices	1.63	1.30
Retail	2.36	1.90

3.2.3 Mechanical Inputs

Although mechanical equipment is not included in the scope of this economic analysis, some energy simulation results for the average national impact of this requirement are available. DOEs overall comparison of the improvements in mechanical system efficiencies between ASHRAE 90.1-1989 and 90.1-1999 results in a 2.2% efficiency improvement in Site Electric EUI and 3% efficiency improvement in Gas EUI[4].

Heating
There is relatively little improvement in heating equipment efficiency requirements in ASHRAE 90.1-1999 for equipment used in single zones systems (typically furnaces). It was found that the impact of ASHRAE 90.1-1999 on heating energy use would principally be determined by changes in heating loads rather than equipment efficiency.

Cooling
In the case of cooling equipment, the average efficiency of cooling equipment, based on shipped capacity increased 7.5%.

Service Water Heating
Service water heating equipment efficiencies increased from 78% to 80% for most tank-type gas fired water heaters.

[4] The national simulation results for the Department of Energy's Determination regarding whether ASHRAE 90.1-1999 would improve energy efficiency in new commercial buildings are also found on the Building Standards and Guidelines website (http://www.energycodes.gov/implement/determinations_com.stm).

4.0 Economic Analysis

The economic benefit and cost analysis of adopting 90.1-1999 utilizes the life cycle cost (LCC) approach, which compares the monetary savings over a specified time horizon with comparison to the associated costs of complying with the code. For this study the LCC is a general measure of the cost of operating a building over its assumed 40-year lifetime and includes the initial incremental construction cost, replacement of key components, and annual energy expenditures. A key assumption in the valuation of future benefits and costs is the time value of money or discount rate that reflects the opportunity cost of capital.

Several factors influence the cost and savings from adopting an energy efficiency building code –first costs, replacement costs, maintenance costs, and energy savings. The primary costs associated with code adoption are the incremental costs of required materials and installation that will contribute to reduced annual energy consumption (e.g., higher levels of insulation, more efficient light fixtures) relative to the cost of building materials that would satisfy a less stringent set of requirements. These costs are often referred to as "first costs," as they are incurred when the building is first built. The collection and treatment of first costs for lighting and building envelope materials is discussed in the following sections. In addition to the first costs, many components will need to be replaced during the 40-year period assumed in this study. The sum of the first cost and the replacement cost is referred to as total investment cost. A comparison of ongoing maintenance costs (excluding replacement costs) for various types of equipment and materials is not included in this analysis (i.e. it can be interpreted that maintenance costs are assumed to be the same for 90.1-1999 and 90.1-1989 requirements).

The primary ongoing monetary benefit of the code is the energy that is saved over the life of a building by using relatively more energy efficient designs, materials and equipment. The incremental energy savings are valued using forecasted average commercial gas and electricity rates over a specified time horizon. These future values of replacement costs and energy savings are then discounted to a present value. This study uses a constant 7% (real) discount rate, which is consistent with the value used by U.S. Department of Energy in analyses of residential and commercial equipment efficiency standards[5].

The current average gas and electricity prices for Illinois were obtained from the Energy Information Administration (EIA) and are listed in Table 4 (2001a). Based on the Annual Energy Outlook 2002 forecasts (EIA 2001b) [6] the average fuel rates are escalated

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[5] This particular value is motivated by the recommendation of the Office of Management and Budget (OMB) in Circular A-94, (OMB1992). Circular A-94 indicates that this value corresponds to the approximate marginal pretax rate of return on the average investment in the private sector in recent years. All rates are reported as "real" rates, which refers to the discount rate above any nominal inflation rate.

[6] During 2001 gas prices spiked throughout the U.S. and over 20% in Illinois. In order to avoid this atypical spike in the analysis, the gas rates from the year 2000 are used in place of the elevated 2001 rates, and the bubble was removed from the escalation rates for 2002 through 2005.

throughout the first 20-years of the study period and are assumed to remain flat the remaining 20 years of the study period[7].

Table 4. Commercial Average Annual Fuel Rates in Illinois

Average Annual Price of Natural Gas (2000)	Average Annual Price of Electricity (2000)
$6.9/thousand cubic feet	$.0658/kWh

The economic impacts are calculated using a spreadsheet-based LCC model that compares alternative sets of building technologies corresponding to different building standards. The model borrows elements of the Building Life-Cycle Cost Program (BLCC) produced by the National Institute of Standards and Technology (NIST) and DOE Federal Energy Management Program (FEMP)[8].

4.1 Building Envelope Analysis

The costs for various building envelope materials are derived on a square footage basis. Costs for walls, roofs, and floors are dependent on the type of construction (e.g., masonry wall versus frame or flat built-up roof versus pitched roof with attic) and vary by U-factors. Discrete costs for various assembly types are based on cost estimates gathered during the development of the 90.1-1999 standard by the ASHRAE envelope subcommittee. Costs for windows and glazing materials were gathered and compiled by Charles Eley Associates. Although costs were collected from 1994-1997, all costs are inflated to 2001 by using price indexes from the Producer Price Index for specific building materials (BLS, 2002).

The building envelope costs are measured and reported as incremental costs to achieve a certain level of thermal integrity (U-factor). For the roof and opaque walls, the costs are estimated relative to a base wall and roof assembly containing no insulation. The window costs measure the incremental costs of glazing that has a specific U-factor and shading coefficient, as compared to a window with a single pane of clear glass.

For all envelope components, the spreadsheet model estimates the incremental costs per square foot for alternative levels of standards. The incremental costs per square foot are multiplied by the appropriate area (roof, walls, windows) to generate the total incremental building envelope cost. The envelope first costs, therefore, do *not* reflect the *total* cost of constructing roofs, walls, and windows.

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[7] The average annual escalation was -.2% for electricity rates and .2% for gas rates.

[8] Portions of a spreadsheet version of the BLCC, developed by M.S. Addison and Associates (Tempe, AZ) were adapted for use in the more extensive LCC model used for this study.

4.2 Lighting Analysis

There are numerous advantages to integrating flexibility into the ASHRAE 90.1 standards for the purpose of enabling consumers to choose lighting options appropriate for their situations. This flexibility, however, makes evaluating the economic impacts quite challenging because there are alternative ways to comply with the standard. Although a variety of alternatives may result in similar energy use outcomes, each alternative has its own distinct cost implication.

In order to assess the economic impacts of lighting code changes between ASHRAE 90.1-1989 and 90.1-1999, the factors impacting lighting design choices must be considered. Some of the primary lighting design choices affecting application of lighting technology in buildings include the following:

- Luminance Level – this varies by lighting technology, light distribution technology, and power input, and is subject to recommendations made by the Illuminating Engineering Society (IES).
- Lighting Technology Type (e.g, incandescent, fluorescent, high intensity discharge (HID), and ballast choices)
- Light Distribution Technology Type (e.g., lenses, louvers, reflective luminaries, and reflective materials).

It is likely that a lighting design change based on the stricter requirements of 90.1-1999 would primarily involve technology changes only. Other potential methods of complying with a new code would include simple lighting level reduction and/or total redesign of the space using advanced lighting techniques. Total redesign of the space, however, is considered to be uncommon in practice and will not be considered in this analysis.

Each space within each building type in the ASHRAE 90.1-1999 Whole Building Space Data Allocations is associated with up to three different lighting types with each type representing a lighting technology and associated fixture[9]. The amount of light specified for each space (determined by IES recommendations and ASHRAE sub-committee input) is further allocated to each of these (up to three) lighting types. Each of these types is also further defined by an efficacy of the technology (lumens per watt) and standard adjustment factors (lumen depreciation, room surface, etc.).

The set of space allocations listed in the ASHRAE 90.1-1999 Space Type Models provides a process for meeting the design requirements of the standard. These models, based on actual designer and experience input, are considered the most accurate and detailed of their kind available for providing efficient and effective lighting. The models also serve as the basis for comparison with other standards or current practice scenarios.

[9] For example, the three lighting types for an office conference room include linear fluorescent, wall wash fluorescent, and halogen down lights.

The approach used to evaluate lighting benefits utilizes lighting costs for systems of lighting, which include the lamp, fixture, and ballast combination. First, the ASHRAE Space Models are applied to the spaces in each building type to determine the lighting system that meets the standard at the lowest cost. The power densities and costs are then developed for each space and lighting system, and aggregated up to the whole building level for the analysis

The assignment of differences in power densities between the 1999 standard and the 1989 standard can be evaluated as either differences in light level or the efficacy of lighting technologies (or both). Some assumptions are made to permit a reasonable assessment of the actual difference in design to meet the two standards and allow a comparison of energy consumption and costs. Because of the vast variance in lighting design, it is impractical to assign too much detail to a scenario; however, many common space types within buildings exhibit some common lighting design attributes. Some examples are included in Table 5.

Table 5. Selected Examples of Building Spaces and Corresponding Common Lighting Designs

Space Type	**Lighting Design Characteristics**
Typical open office areas	Evenly spaced fluorescent troffers with little decorative lighting
Typical enclosed offices	Fluorescent troffers
Hallways/lobbies	Fluorescent troffers and incandescent downlights
Large Retail spaces	Overhead fluorescent troffers and incandescent display lights

Since the lighting requirements for the 90.1-1999 standard are well defined through the use of the space type models as described above, the development of capital costs for lighting meeting the 1989 standard is based upon a substitution of less efficient technologies than those used to comply with the 1999 standard. The substitution involves two types of lighting systems:

1) Magnetic ballast-T12 lamps for electronic ballast-T8 lamps
2) Incandescent lamps for compact fluorescent lamps in downlight applications.

These substitutions were made for all the space types used in the ASHRAE methodology underlying the development of the 1999 lighting standard.[10] The 90.1-1999 whole-building LPD will increase by different percentage amounts over 90.1-1989, depending upon the assumed fractions of floor space to be served by the technologies in each of the building types.

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[10] The methodology for the space type and LPD models is incorporated in a large spreadsheet that was developed by the lighting subcommittee of the SSPC 90.1 ASHRAE standards committee in support of the ASHRAE/IESNA 90.1-1999 energy standard. A working version of the spreadsheet tool with additional detailed descriptions of the various parts is available for review on the IESNA website (http://206.55.31.90/cgi-bin/lpd/lpdhome.pl). An offline version of the spreadsheet was modified in three ways: 1) technologies for magnetic ballasts and T-12 lamps were added, 2) a series of worksheets to estimate lighting system costs was added, and 3) a revised formula (consistent with the most recent ASHRAE/IES work) was used in the calculation of LPDs.

The first two columns of Table 6 show the building-level LPDs that were used in the economic analysis. Column 3 displays the efficiency improvement in the LPD between the 1999 and 1989 standard. Column 4 shows the increase from the 1999 standard brought about solely by the technology substitution discussed above. For office and education buildings, the technology substitution (as described in numbers (1) and (2) above) results in an increase in the LPD that is very close to the requirements of the 1989 standard.

Table 6. Comparison of 90.1-1999 and 90.1-1989 Lighting power Densities

	1999 LPD*	1989 LPD*	Percent Change	Technology Substitution (Percent Change)
Office	1.30 w/ft^2	1.63 w/ft^2	25.4%	24.0%
Retail	1.9 w/ft^2	2.36 w/ft^2	24.2%	16.0%
Education	1.5 w/ft^2	1.79 w/ft^2	19.3 %	20.8%

* As used in the building energy simulations and economic analysis.

As a first step, cost estimates were developed for the linear fluorescent and incandescent/CFL applications for both the 90.1-1999 standard based upon the ASHRAE Models and then after substituting the less efficient technologies into the same models (i.e., assuming the same illumination levels). A ratio was computed between the reduction in cost and the increase in the predicted LPD, going from the more efficient to the less efficient lighting technologies (the change in predicted LPD is equal to the percentage change in column 4 in Table 6 times the 1999 LPD in column 1). This ratio was then applied to the actual difference in the LPD between the two standards to make an estimate the change in cost.

For office and education buildings, this procedure yields essentially the same cost difference as that generated by the technology substitution without any adjustment. Since the predicted change in the LPD for retail buildings was lower than the actual difference (16% vs. 24% in Table 6), this procedure provides an upper bound to the cost difference (and, concomitantly, a conservative estimate of the life-cycle cost reduction) between the two standards for this building type. A further calibration was performed to account for a revision in the way in which the LPDs were calculated in the ASHRAE Models for this study as compared to how these models were employed when developing the published standard.[11]

Lighting costs are measured in terms of *total* lighting cost in dollars per square foot for linear fluorescent and incandescent/CFL systems. These costs include the cost of a fixture, ballast, and lamp plus the labor cost to install the assembly. The linear fluorescent lighting

[11] The use of the revised formula in the LPD spreadsheet (see previous footnote) causes the calculated 90.1-1999 LPDs to be higher than those published for the 1999 standard. The calculated LPDs were: 1) office, 1.40 $watts/ft^2$; 2) retail, 2.14 $watts/ft^2$, and 3) education 1.54 $watts/ft^2$. The revised formula ensures that the economic benefits from a technology substitution are consistent across building types. Unfortunately, it requires that the cost calibration must be performed on the basis of percentage changes rather than the absolute levels of the LPDs.

cost estimates are based on data from the Technical Support Document (TSD) for the DOE's rulemaking related to fluorescent lamp ballasts (DOE 1999). For compact fluorescent and incandescent systems, data were developed from the input data used in the commercial module of the National Energy Modeling System (NEMS) and from a PNNL analysis of contractor prices from Grainger Industrial Supply. Although the lighting cost may vary for any particular building due to the type of lighting technology used, the above derivations are representative of the cost differentials.

5.0 Quantitative Results

The changes in energy use between 90.1-1989 and 90.1-1999 are calculated in terms of EUI by fuel type developed from simulations based on each edition of the standard. The simulations produce EUIs by fuel type for each zone of the prototypical building. These results are then scaled to the building type of interest. The zone EUIs by fuel type can be converted to site energy, source energy, and energy cost intensities, by building type. Specific building simulation inputs and the resulting energy savings for each of the 7 building types included in this study are located in Appendix B[12].

This section presents the estimated energy and economic impacts between the 90.1-1989 and 90.1-1999 building standards for the selected set of buildings. Three separate variations of the 1999 standard are compared with the 1989 standard: 1) changing only requirements related to the building envelope; 2) changing only lighting requirements; and 3) changing both envelope and lighting requirements. This methodology helps to better understand how the energy and economic impacts are linked to various aspects of the standards. The combined lighting and envelope case shows the degree to which the interaction between the envelope and lights affect the overall impacts.

Seven buildings are characterized in this study. Four different types of office buildings are characterized to capture the variation of the standard's impacts that stem from alternative window-to-wall ratios, building size, and number of floors. All of the buildings described in Section 5 are characterized as having metal frame walls. Additional building energy simulation and economic results for buildings characterized with mass walls are found in Appendix C.

5.1 Office Buildings

Table 7 presents the engineering and cost summary for the small, 10,000 square foot, single-story office building. The top panel of the table shows the key engineering and cost inputs for the building envelope. The middle panel describes the engineering and cost inputs for lighting. The bottom panel shows total construction costs, annual energy use, LCC, and corresponding economic metrics.

The top panel of Table 7 describes the building height of 13 feet, and an aspect ratio of 2.25 (ratio of building length to width), the total wall area of the building is 5733 square feet. Given the assumed window-to-wall ratio of 0.18, this translates into 1013 square feet of windows and 4619 square feet of opaque wall. In a building with a single floor, the roof area is equal to the floor area. The insulation requirements for the slab are related to the

[12] The national simulation results for the Department of Energy's Determination regarding whether ASHRAE 90.1-1999 would improve energy efficiency in new commercial buildings are also found on the Building Standards and Guidelines website (http://www.energycodes.gov/implement/determinations_com.stm).

perimeter length. For this building, the perimeter of the building is 433 feet. Figure 1 provides an illustration of an office building that has these characteristics.

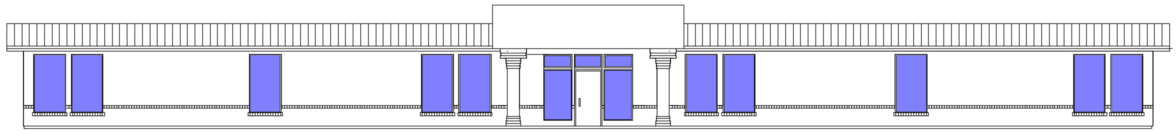

Figure 1. Office Building – 20,000 s.f. with 18% window-to-wall ratio

Base Case

The column under the heading “90.1-1989 Base” in Table 7 shows the thermal requirements and estimated costs for each of the major envelope components. Windows must satisfy requirements related to both thermal performance (U-factor) and shading coefficient (SC). The specific requirements under the 1989 standard are designated in the top two lines labeled (std). The current costing methodology for windows generally selects the window type that meets the performance requirements of the standard at the lowest cost. To avoid potential distortions in the incremental cost from one standard level to the next, an algorithm was developed that searches for the pair of glazing types in the cost database that are just below and just above the U-factor and SC criteria. The costs and performance measures are then averaged with a weighting procedure, the weights based upon how much each type deviates from the criteria. The weighted average U-factor and shading coefficient are labeled (cost) in the table. Using the weighting procedure, a representative cost per square foot of glazing was estimated to be $6.33.

Costs for the other envelope components are based upon the cost model developed as part of the ASHRAE 90.1-1999 Standard. The total cost for each component is simply the product of the area and the cost per square foot (or linear foot for slab insulation) to achieve the specified thermal performance. Total cost is shown in the last line of the first panel—in this case $24,131. As discussed in Section 4.1 above, this is *not* the *total* cost of the building envelope from an owner’s point of view. It is, rather, the incremental cost relative to an uninsulated building using single-pane clear glass windows.

The second panel in Table 7 summarizes the key inputs related to lighting. As discussed in Section 4, the lighting power density for offices under the 1989 standard was assumed to be 1.63 watts per square foot. The first cost of the linear fluorescent and incandescent systems to meet this lighting density is estimated to be $1.57 per square foot. In the same manner as the envelope, this cost figure should not be construed as the total cost to install all the lighting in a typical office building. It includes only linear fluorescent and a segment of incandescent lighting that are assumed to change under the more stringent 1999 standard. Given this qualification, the lighting cost for the building is $15,720.

Table 7.   Engineering and Cost Summary

Small Office (WWR=0.18)
Wall Type: Metal Frame
Bldg. Size: 10,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	1,014	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	4,619	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	10,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	433	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$24,131	$22,029		$22,029
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$15,720		$17,554	$17,554
Construction Cost			$39,851	$37,749	$41,685	$39,584
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	116	100	103	88
Natural Gas		MMBtu	74	88	86	103
Total Annual Energy Cost			$8,954	$8,732	$8,013	$7,819
Economic Measures						
Life-Cycle Cost Savings				**$4,695**	**$8,924**	**$13,254**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.4	23.2
Adjusted IRR				Invest. < 0	11.0%	15.8%

Notes:
1 **No economizer used**
2 **2001 electricity price = 6.6 cents/kWh**   **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40**   **Discount Rate = 7.0%**
Life-cycle cost savings includes replacement costs and residual values

The bottom panel in the table shows the energy and cost implications for the entire building. The initial construction cost is the sum of the envelope and lighting costs, keeping in mind the incremental nature of this value. Annual energy consumption is shown in million Btu (MMBtu) for electricity and natural gas. Electricity consumption is shown for 1) lights and plugs, and 2) HVAC. In these simulations, all buildings were assumed to be heated with natural gas. Electricity consumed for HVAC equipment, therefore, consists of ventilation fan and cooling use only. Natural gas is used for space heating and water heating, but differences among standards are entirely related to space heating. Total annual energy cost of $8,954 is based upon fuel prices for 2001[13]. The fuel prices used in this calculation are shown in note (2) at the bottom of the table.

Envelope Only Case

The second column under the section labeled "Standard Level" shows the envelope requirements and the estimated costs for standard ASHRAE 90.1-1999. For windows, the significant change relates to the shading coefficient. The reduction of the shading coefficient to 0.453 is estimated to increase the initial cost relative to the 1989 requirements by about $1.05 per square foot of window area.

The ASHRAE 90.1-1999 Standard, however, relaxed requirements for all other envelope components (for a building in this particular climate). The largest cost reduction relates to the smaller amount of insulation for the roof. At an estimated differential of $0.19 per square foot, the total cost reduction for this building is $2,000. The ASHRAE 90.1-1999 Standard also dropped the requirement to insulate the slab foundation. This change contributed to an additional $900 reduction to the first costs. The bottom line of the envelope panel shows a net reduction of about $2,100 in first cost from the 1989 standard level.

The bottom panel shows the energy consumption and cost impacts associated with this case. Electricity consumption for lights and plugs is unchanged from the baseline case. Electricity consumption for cooling and ventilation falls by 16 MMBtu, a result achieved primarily from the reduced solar gain through the windows. Natural gas consumption, however, increases as a result of the reductions in the thermal performance of the other envelope components. Annual fuel costs decline by over $200 a year, since the cost per MMBtu of electricity is more than three times that of natural gas.

Life-cycle costs are about $4,700 lower as compared to the base ASHRAE 90.1-1989. The cost savings are the sum of the $2,100 initial construction cost reduction as well as the discounted energy cost savings over the 40-year study period. Since the change in the initial investment cost is negative, savings-to-investment (SIR) ratio and adjusted internal rate of return (AIRR)[14] are undefined.

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[13] As discussed in Section 4.0, 2000 fuel prices were used for 2001. See footnote 2 in Section 4.0. Converted to dollars per MMBtu, the electricity price is $19.34 and the natural gas price is $6.70.

[14] In this type of analysis, the internal rate of return (IRR) is the interest rate that makes the discounted (present) value of the initial and replacement investment equal to the discounted value of future fuel cost savings. The adjusted internal rate of return (AIRR) can be considered an improved measure of investment performance. The AIRR assumes that the annual cost savings are reinvested at a fixed discount rate, rather than at the internal rate. The AIRR is generated by the NIST Building Life-Cycle Cost model.

Lighting Only Case
In the lighting-only case, the approach described in Section 4.2 yields an incremental cost of $0.19 per square foot as shown in column three of the lighting panel. The total incremental cost for the building is about $1,800. Total electricity consumption falls by 53 MMBtu per year for the lighting-only case. Nearly one-fourth of this reduction stems from the lower cooling requirements because the efficient lights generate less heat. During the winter, less heat generated by the efficient lights means more heating by the furnace; thus, natural gas consumption increases. However, the reduction in cooling cost is larger than the increase in heating cost. Combined with reduced electricity use for the lighting, total fuel costs decline by nearly $1,000 per year.

All three economic measures show that the more stringent lighting requirements associated with the 1999 standards are highly cost effective. Life-cycle cost savings are nearly $9,000. The savings-to-investment ratio is over 4.8. In other words, for every dollar of initial and (discounted) replacement investment cost, over 4 dollars of (discounted) fuel expenditures are saved over the life of the building[15]. The adjusted internal rate of return is over 11%.[16]

Envelope and Lighting Case
The last column in the table shows the results of a simulation that combines both the envelope and lighting requirements of the ASHRAE 90.1-1999 Standard. Annual energy expenditures are about $1,100 lower than the base ASHRAE 90.1-1989 standard; life-cycle cost savings are about $13,000. The net effect of the envelope cost reduction and the lighting system cost increase is to yield an SIR of over 20 and adjusted IRR of over 16%. With the exception of natural gas consumption, the simulations suggest that the effects of the two sets of changes (envelope and lighting) are almost additive. The sum of the changes for the envelope-only and lighting-only are within 1.5% of the combined change for the electricity consumption, fuel cost, and life-cycle cost. Natural gas consumption in the combined case is about 8% higher than the sum of the first two cases.

5.1.1 Impact of Changing Window-to-Wall Ratios

Table 8 shows the results for a small office, but with a larger percentage (38% vs. 18%) of the wall area made up of windows. Figure 2 shows a 20,000 square foot office building with 38% of the walls made up of windows. As Section 2.1.2 explains, one key aspect of the 1999 standard as compared to the 1989 standard is that it sets the performance criteria of specific components independent of the way the whole building is constructed. The implication of this change is that the ASHRAE 90.1-1999 Standard will yield a reduction

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[15] Since discounted replacement cost is included in the denominator of the SIR calculation, one cannot derive this measure solely from the incremental first cost and energy cost savings shown in the table.
[16] The difference between the IRR and AIRR can be considerable. In this case the IRR is over 50%. The AIRR measure is more suitable for long-lived investments with its assumption that cost savings can be reinvested to achieve only a normal return over a long period of time. Another short-term measure is the payback period. In this case the payback is less than 2 years ($1,800/$1,000). The payback criterion is also not especially appropriate, however, for investments with a long life—those appropriate to the life-cycle of a building—as it ignores the benefits after the payback period.

in window performance for buildings that contain a large ratio of window area to the total wall area. As shown in Table 7, this translates into an allowable increase in the shading coefficient from 0.26 to 0.453 for the northern Illinois climate.

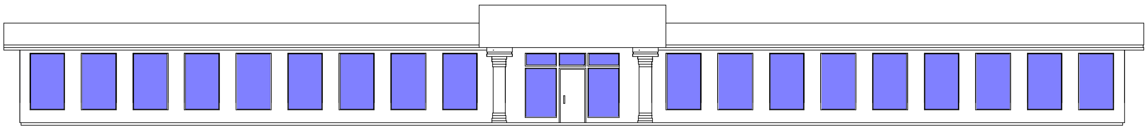

Figure 2. Office – 20,000 s.f. with 38% window-to-wall ratio

In this envelope-only case, the change for windows has a significant impact on the building's use of fuels. As expected, the lower shading coefficient leads to the greater solar gain through the windows and more electricity used for cooling (an increase from 97 MMBtu to 121 MMBtu). During the heating season, however, this solar gain leads to a reduction in the need for heat to be supplied by the furnace. Gas consumption falls by 17 MMBtu per year.

On a cost basis, the reduction in gas usage does not offset the increase in electricity cost; annual energy expenditures for the building increase by over $300. This change in energy savings, however, remains cost-justified from a life-cycle cost standpoint. The substantial drop in first cost (primarily from glazing with a higher shading coefficient) plus the reduction in heating cost more than compensates for the higher cooling costs. Life-cycle cost declines by more than $8,000. Clearly, this case demonstrates that energy savings and cost-effectiveness need not go hand-in-hand.

Table 8. Engineering and Cost Summary

Small Office (WWR=0.38)
Wall Type: Metal Frame
Bldg. Size: 10,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	2,141	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.250	0.453		0.453
(Window-Wall Ratio = 0.38)		U-factor(cost)	0.55	0.571		0.571
		sh. coef.(cost)	0.262	0.453		0.453
		cost ($/sqft)	$11.33	$7.38		$7.38
Opaque Walls	3,493	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	10,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	433	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$41,082	$29,558		$29,558
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$15,720		$17,554	$17,554
Construction Cost			$56,802	$45,278	$58,636	$47,112
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	97	121	86	109
Natural Gas		MMBtu	138	121	157	138
Total Annual Energy Cost			$9,018	$9,368	$8,151	$8,475
Economic Measures						
Life-Cycle Cost Savings				**$8,768**	**$7,955**	**$17,059**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.0	Invest. < 0
Adjusted IRR				Invest. < 0	10.8%	Invest. < 0

Notes:
1 **No economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**
Life-cycle cost savings includes replacement costs and residual values

5.1.2 Impact of Changing Building Size

The large office building analyzed has a larger footprint (20,000 square feet as compared to 10,000 square feet) and has three floors. Figure 3 illustrates an office building with these characteristics. Because it is assumed to use cooling equipment with a large capacity, it is modeled with an economizer. An economizer utilizes outside air for cooling once the temperature falls below a thermostat set point. Similar to the small office, two variations in the window-to-wall ratio (18% and 38%) were considered.

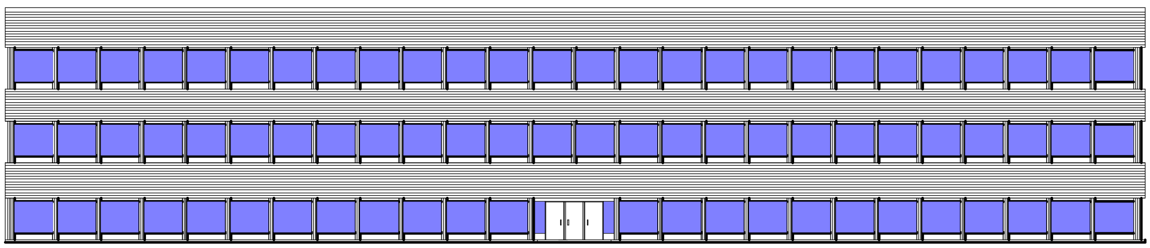

Figure 3. Office – 60,000 s.f. with 3 stories and 38% window-to-wall ratio

Tables similar to those presented for the small office were prepared and are shown in Appendix B. The envelope and lighting requirements for the various cases are identical to those for the small office. Differences in the small and large offices relate more to how the building geometry affects the envelope costs in total.

Table 9 shows a comparison of the key results for the four office building simulations. The top two panels show the results for the small office buildings for the .18 and .38 window-wall ratios, and the bottom two panels show the same for the large office building. The "Key Characteristics" column shows the physical characteristics of the building that have the most significant impact on its energy use with the only difference in the two cases (small and large office) being the window-wall ratio.[17] The three columns on the right hand side of the table provide the cost results of the savings relative to the 90.1-1989 base on a per square-foot basis for the envelope only, lighting only, and combined envelope and lighting improvements.

Life-cycle cost is the discounted energy savings minus the discounted incremental cost of 90.1-1999 over the 40 year lifetime of the building. Two metrics, the savings-to-investment ratio (SIR) and the internal-rate-of-return (IRR) are also shown to provide a measure of the financial attractiveness of the standard from an investment perspective. In the cases where the costs associated with 90.1-1999 decrease (investment is less than zero), these metrics have no economic interpretation, so no value is provided.

[17] The BLAST simulations used a 15-foot depth to represent the perimeter zones of the building. The interior floor space of the building is the core; the core ratio shown in Table 8 is the ratio of the core to the total floor area. It provides one means of assessing how much the wall and window components influence the overall energy use in the building.

In the envelope-only case, the most salient result is that life-cycle cost savings per square foot declines in the large office as compared to the small office with the same window-to-wall ratio. This outcome stems from the fact that the area of the building envelope does not increase as rapidly as total floor space. For example, the total window area in the large office is 4.25 times that of the small office, while floor space is 6 times larger. The initial construction costs, as well as the space conditioning energy consumption and costs are more closely tied to the area of the building envelope than the amount of floor space. Thus, as a result of basic building geometry, the normalized energy and cost changes are all lower (in absolute terms) in the large office relative to the small office. Contributing to this result is that the ratio of the roof area to floor space is lower in the large building as compared to the small building.

The lighting-only case in Table 9 indicates that the cost of the 1999 standard is relatively constant across all of the offices considered. The SIR and AIRR values are slightly lower for the large office than the small office. This difference is likely due to the presence of the economizer as the cooling equipment must meet all changes in the entire cooling load in the small office, whereas the economizer helps meet the cooling loads in the large offices by introducing outside air.

Table 9. Summary of Results by Building (Office Buildings)

Wall Type: Metal Frame			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Small Office (WWR=0.18)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	10,000	Electricity (kBtu/sf/yr)	43.7	1.6	5.3	6.9
No. of floors	1	Nat. Gas (kBtu/sf/yr)	7.4	-1.4	-1.2	-2.8
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.90	$0.02	$0.09	$0.11
Core ratio	0.44	Life-cycle cost ($/sf)		$0.47	$0.89	$1.33
Window-wall ratio	0.18					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	4.4	23.2
		Adjusted IRR		Invest. < 0	11.0%	15.8%
Small Office (WWR=0.38)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	10,000	Electricity (kBtu/sf/yr)	41.8	-2.4	5.1	2.8
No. of floors	1	Nat. Gas (kBtu/sf/yr)	13.8	1.7	-1.9	0.0
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.90	-$0.03	$0.09	$0.05
Core ratio	0.44	Life-cycle cost ($/sf)		$0.88	$0.80	$1.71
Window-wall ratio	0.38					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	4.0	Invest. < 0
		Adjusted IRR		Invest. < 0	10.8%	Invest. < 0
Large Office (WWR=0.18)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	60,000	Electricity (kBtu/sf/yr)	41.7	1.1	4.7	5.8
No. of floors	3	Nat. Gas (kBtu/sf/yr)	4.2	-0.8	-0.8	-1.7
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.84	$0.02	$0.09	$0.10
Core ratio	0.59	Life-cycle cost ($/sf)		$0.21	$0.79	$0.99
Window-wall ratio	0.18					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	4.0	5.2
		Adjusted IRR		Invest. < 0	10.8%	11.5%
Large Office (WWR=0.38)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	60,000	Electricity (kBtu/sf/yr)	40.7	-1.8	4.7	2.9
No. of floors	3	Nat. Gas (kBtu/sf/yr)	8.0	1.0	-1.3	-0.1
Aspect ratio	2.25	Energy cost ($/sf)	$0.84	-$0.03	$0.08	$0.06
Core ratio	0.59	Life-cycle cost ($/sf)		$0.47	$0.75	$1.23
Window-wall ratio	0.38					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	3.8	Invest. < 0
		Adjusted IRR		Invest. < 0	10.7%	Invest. < 0

5.2 Retail

Table 10 shows the summary results for the retail building. The detailed engineering and cost tables for these buildings are shown in Appendix B.

The top panel of Table 10 shows the summary results for a single-story, 24,000 square foot, retail building with a window-to-wall ratio of 7%. Figure 4 provides an illustration of a retail building with these characteristics. While the base electricity consumption per square foot is higher in the retail building as compared to any of the office buildings (due, in large part, to higher lighting levels), the reduction in electricity intensity (MMBtu/ft^2) from the 1999 envelope requirements is only about half that of offices. Although the requirements for the window shading coefficient increases in the 1999 standard, the smaller window area in most retail buildings diminishes the influence of this requirement on total energy use. The building footprint is also similar to the large office analyzed. Again, the smaller ratio of the envelope area to total floor space reduces the energy and cost savings per square foot (as compared to the small office).

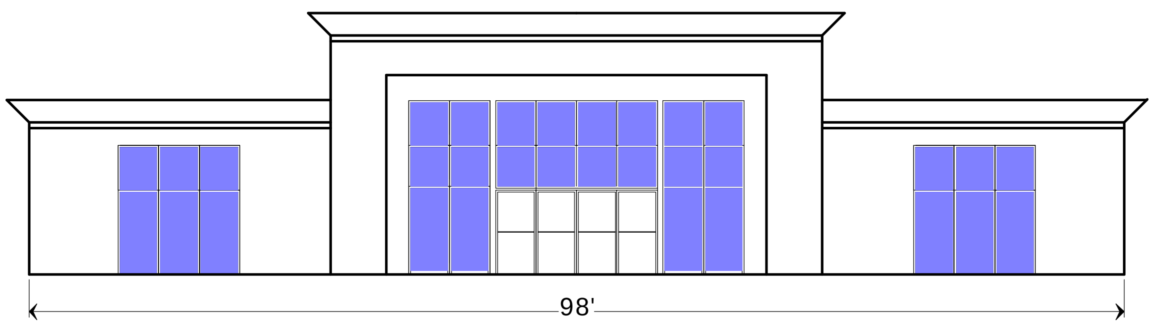

Figure 4. Retail Building – 24,000 s.f. with 7% window-to-wall ratio

The lighting-only case for retail shows larger absolute reductions in total energy consumption, stemming largely from the relatively large difference in the LPD between the ASHRAE 90.1-1989 and 1999 standards. Even under the assumption that the reduction in LPD between the 1989 level of 2.36 watts/ft^2 and the 1999 level of 1.9 watts/ft^2 is accomplished entirely by changes to more efficient (and more expensive) technologies, the change is still cost effective. The savings-to-investment ratio is 8 and the adjusted IRR is over 12%.

5.3 Education

The two education buildings analyzed are shown in Table 10 and the detailed engineering cost tables are provided in Appendix B. The first is intended to represent a typical elementary school—a single story building with classrooms on either side of a hallway (See Figure 5). The second building is more likely to be found at a secondary school or college campus—two floors with a slightly smaller footprint than the elementary school

(See Figure 6). Both buildings were simulated with a window-to-wall ratio of 0.18 and both use economizers.

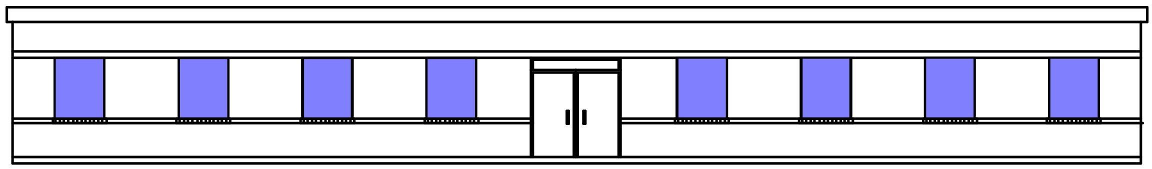

Figure 5. Education Building (Elementary) – 50,000 s.f., 18% window-to-wall ratio

With the relatively low window-to-wall ratio (0.18) the ASHRAE 90.1-1999 Standard calls for a significant improvement in the shading coefficient, the same as analyzed for two of the office buildings with window-to-wall ratios of 18%. Compared to offices, schools have significantly lower internal loads as a result of lower plug loads and shorter operating hours. As a result, in the envelope-only case, electricity savings are somewhat lower on a per square foot basis for the education buildings than for offices. The increase in annual natural gas consumption is greater than the decline in electricity, measured in MMBtu consumed by the building. Since the price per MMBtu is significantly higher for electricity, however, total annual fuel costs decline.

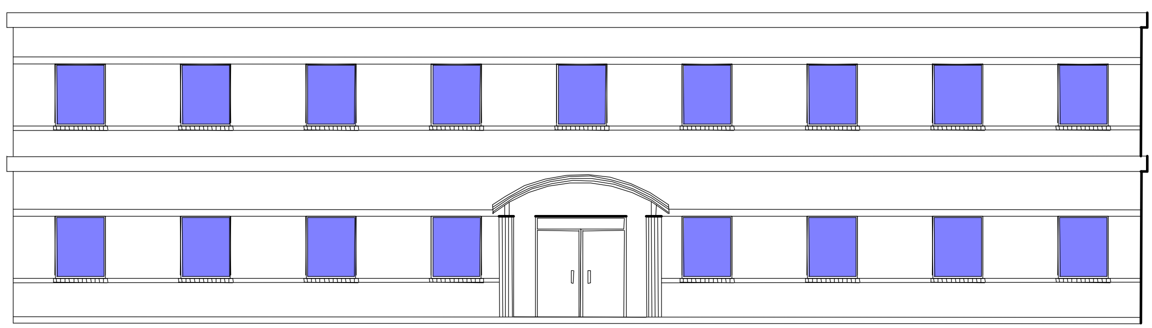

Figure 6. Education Building – 80,000 s.f. with 18% window-to-wall ratio.

The lower annual fuel costs combined with lower first costs lead to life-cycle cost savings for both education buildings. On a per square foot basis, the life-cycle cost savings are higher for the elementary school. One factor contributing to this result is that the cost savings from the reduced insulation requirements for the roof are divided by a smaller amount of floor space. The lighting-only case shows that the ASHRAE 90.1-1999 requirement for reduced LPDs in education buildings is highly cost effective. The SIR is about 3 and the adjusted rate of return is about 10%. The shorter operating hours for these buildings is reflected in the economic measures in that the SIR and AIRR measures than the corresponding measures for office and retail buildings.

Table 10. Summary of Results by Building (Retail and Education Buildings)

				Standard Level			
Wall Type:	Metal Frame			*90.1-1989 Base*	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Retail		Normalized Results		Base	Savings Relative to Base		
Key Characteristics		Energy Use:					
Floor space	24,000	Electricity	(kBtu/sf/yr)	50.0	0.6	8.2	8.7
No. of floors	1	Nat. Gas	(kBtu/sf/yr)	2.6	-0.4	-0.9	-1.4
Aspect ratio	2.50	Energy cost	($/sf/yr)	$0.98	$0.01	$0.15	$0.16
Core ratio	0.61	Life-cycle cost	($/sf)		$0.36	$1.63	$1.97
Window-wall ratio	0.07						
Economizer (?)	no	Savings-to-invest. Ratio			Invest. < 0	7.7	Invest. < 0
		Adjusted IRR			Invest. < 0	12.6%	Invest. < 0
Education (elementary)		Normalized Results		Base	Savings Relative to Base		
Key Characteristics		Energy Use:					
Floor space	50,000	Electricity	(kBtu/sf/yr)	28.4	0.7	3.3	4.0
No. of floors	1	Nat. Gas	(kBtu/sf/yr)	19.9	-1.6	-1.5	-3.2
Aspect ratio	6.00	Energy cost	($/sf/yr)	$0.68	$0.00	$0.05	$0.06
Core ratio	0.63	Life-cycle cost	($/sf)		$0.22	$0.42	$0.63
Window-wall ratio	0.18						
Economizer (?)	yes	Savings-to-invest. Ratio			Invest. < 0	2.7	20.1
		Adjusted IRR			Invest. < 0	9.7%	15.3%
Education (two-story)		Normalized Results		Base	Savings Relative to Base		
Key Characteristics		Energy Use:					
Floor space	80,000	Electricity	(kBtu/sf/yr)	29.3	0.9	3.3	4.2
No. of floors	2	Nat. Gas	(kBtu/sf/yr)	17.5	-1.4	-1.4	-2.9
Aspect ratio	5.00	Energy cost	($/sf/yr)	$0.68	$0.01	$0.05	$0.06
Core ratio	0.62	Life-cycle cost	($/sf)		$0.15	$0.43	$0.57
Window-wall ratio	0.18						
Economizer (?)	yes	Savings-to-invest. Ratio			Invest. < 0	2.8	4.5
		Adjusted IRR			Invest. < 0	9.8%	11.1%

5.4 Other Factors Impacting Benefits and Costs

There are numerous areas of the ASHRAE 90.1-1999 Standard that are not easily valued and modeled with the quantitative approach taken in this study. Many of these other elements of the standard, however, do have measurable economic and energy impacts. The following section briefly describes some potential energy benefits and costs of selected components of the ASHRAE 90.1-1999 Standard that are not captured in the previous analysis.

5.4.1 Building Envelope

The impact of air leakage requirement differences between ASHRAE 90.1-1989 and ASHRAE 90.1-1999 are difficult to evaluate. Air leakage requirements for windows are more stringent in the 1999 edition for four window types and less stringent in one other window type. In addition, some door types are more stringent in the 1999 edition, while others are not. ASHRAE 90.1-1999, however, also includes requirements for loading dock weather seals and vestibules, which would be applicable in Illinois. The net effect of these requirements is expected to improve energy efficiency with the ASHRAE 90.1-1999 relative to the 1989 edition.

ASHRAE 90.1-1999 requires that insulation be installed in substantial contact with the inside surface of cavities. It also requires that lighting fixtures, heating, ventilating, and air-conditioning, and other equipment not be recessed in such a manner as to affect the insulation performance. Finally, the 1999 edition bans installation of insulation on suspended ceilings with removable ceiling panels. The 1989 edition does not address this subject. The ASHRAE 90.1-1999 insulation installation requirements are expected to save energy in commercial buildings relative to the ASHRAE 90.1-1989 baseline.

For cooler climates, ASHRAE 90.1-1989 requires between R-7 to R-8 slab-on-grade insulation, while ASHRAE 90.1-1999 has no such requirement. This is expected to result in higher heating loads in cold climates with ASHRAE 90.1-1999 and thus result in a net reduction in energy savings relative to the 1989 edition.

The net efficiency improvement resulting from these three envelope upgrades to meet 90.1-1999 standard are expected to be positive, but insufficient information prevents further quantification.

5.4.2 Lighting

One of the more significant lighting requirement elements of ASHRAE 90.1-1999 not included in the quantitative results is lighting control requirement. Lighting controls, such as occupancy sensors, have the potential to significantly reduce energy use by switching off electrical lighting loads when a space is vacated. Manufacturers claim savings of 15% to 85%, although there is little published research to support the magnitude or timing of reductions. Energy savings and performance are directly related to the total wattage of the load being controlled, effectiveness of the previous control method, occupancy patterns within the space, and proper sensor commissioning. Case studies of energy savings have had varied results due largely to differences in human factors, previous control strategies and proper sensor commissioning (Floyd 1997).

In the area of lighting controls, ASHRAE 90.1-1999 specifies that a building utilize a "whole-building controller," at a minimum. Although a whole building controller is a relatively low-cost lighting control solution, it is not very practical for many applications and therefore it is unlikely that this would be the alternative of choice for most building designs. More likely, a building design would incorporate something like occupancy sensors; however, this is above and beyond the minimal ASHRAE requirement, which makes the evaluation of the code impacts with regard to lighting controls difficult to assess. It is expected, however, that including a lighting control requirement should save energy.

There are a number of lighting exemptions in ASHRAE 90.1-1989 that are not included in the 1999 edition, such as commercial greenhouses and process facilities. These changes would be expected to result in some reduction in lighting power use with the adoption of ASHRAE 90.1-1999. On the other hand, there are also a number of narrowly-targeted exemptions in the 1999 edition that are not in the ASHRAE 90.1-1989.

The net effect of these differences, however, is expected to be an increase in lighting efficiency with ASHRAE 90.1-1999 relative to the 1989 edition.

5.4.3 Mechanical

There are significant changes to HVAC and SWH equipment efficiencies between 90.1-1989 and 90.1-1999; however, most of this equipment is covered by federal manufacturing standards whose adoption by federal statute will set their efficiencies at least as high as those in ASHRAE 90.1-1999 within a relatively short time frame. Chillers, however, which are not covered under manufacturing standards have significantly higher efficiencies under 90.1-1999. In addition, 90.1-1999 sets requirements for heat rejection equipment (fluid coolers and cooling towers) as well as for absorption chillers that were not addressed in 90.1-1989. Two other significant additions to 90.1-1999 include more stringent performance requirements for variable speed fan systems as well as the addition of requirements for heat recovery. The 90.1-1999 standard has dropped much of the non-enforceable language as well as difficult to enforce requirements (like system sizing) that were in the 90.1-1989 standard. These and other differences between the mechanical systems, the bulk of which can be reviewed online at http://www.energycodes.gov/implement/determinations_com.stm.

5.4.4 Scope of Standard

One dominating factor impacting potential impacts of costs and benefits of adopting ASHRAE 90.1-1999 is the inclusion of alterations and renovations to the scope of the standard. This greatly expands the scope of the standard beyond ASHRAE 90.1-1989, which only applied to new buildings or new portions of existing buildings (additions).

While it is difficult to quantify the energy efficiency impact of alterations and renovations, the U.S. Census Bureau 1997 Construction Geographic Area Series reports that the dollar value of commercial construction devoted to additional, alterations, or reconstruction in Illinois was $4.4 billion in 1997, as compared to new buildings construction valued at $8.5 billion (2000c). If the value of annual investment in building alterations and renovations is a good indicator of its impact on energy use, then the expansion of this code to existing buildings could produce approximately 50% more savings than if it were applied exclusively to new buildings.

6.0 Qualitative Considerations

In comparing ASHRAE 90.1-1999 to ASHRAE 90.1-1989, various revisions have been made in an effort to make the standard clearer and easier to enforce. For example, the inclusion of specific direction on how to calculate luminaire power in Standard 90.1-1999 is expected to eliminate some under-calculation of lighting power, which may lead to lower energy usage for lighting. In addition, various language and formatting changes have been made to make the standard easier to apply.

While the ASHRAE 90.1-1989 Standard provided climate-specific guidance by using example cities, the ASHRAE 90.1-1999 Standard provides requirements in terms of "climate bins" that cover a larger area. This allows builders to more easily find an appropriate climate for the area in which they are building. The ASHRAE 90.1-1999 Standard also simplifies the code compliance for smaller-scale construction by providing a "Simplified Approach Option for HVAC Systems." This section condenses the mechanical system requirements for a large class of simple systems.

ASHRAE Standard 90.1-1999 is written in mandatory, enforceable language. ASHRAE Standard 90.1-1989 contains guidance written as suggestive statements, which may complicate enforcement and compliance if not properly defined and revised. ASHRAE 90.1-1999 also provides specific guidance for applying the code to existing building alternations and additions. From an energy savings standpoint, any changes that make ASHRAE Standard 90.1-1999 easier to understand and enforce may have a small positive impact on energy savings.

7.0 Conclusions

One of the primary differences between the development of the ASHRAE 90.1-1999 and 1989 is that ASHRAE 90.1-1999 is based more heavily on economic justification for envelope requirements. The ASHRAE 90.1-1999 envelope requirements were developed under a minimum life-cycle cost process that balances the energy savings achieved by setting the requirement at a particular level against the cost of equipment associated with that level of efficiency. The results of this limited study appear to confirm that the ASHRAE 90.1-1999 Standard has succeeded, for the most part, in developing cost-justified energy savings for these building types. Despite the fact that ASHRAE 90.1-1999 relaxes some of the building envelope requirements, relative to the 1989 standard, while increasing others, the adoption of ASHRAE 90.1-1999 envelope requirements result in a reduction of building life-cycle costs as well as first costs for building envelope. Figure 7 provides a comparison of the LCC savings per square foot by building type for envelope and lighting requirements, individually and together.

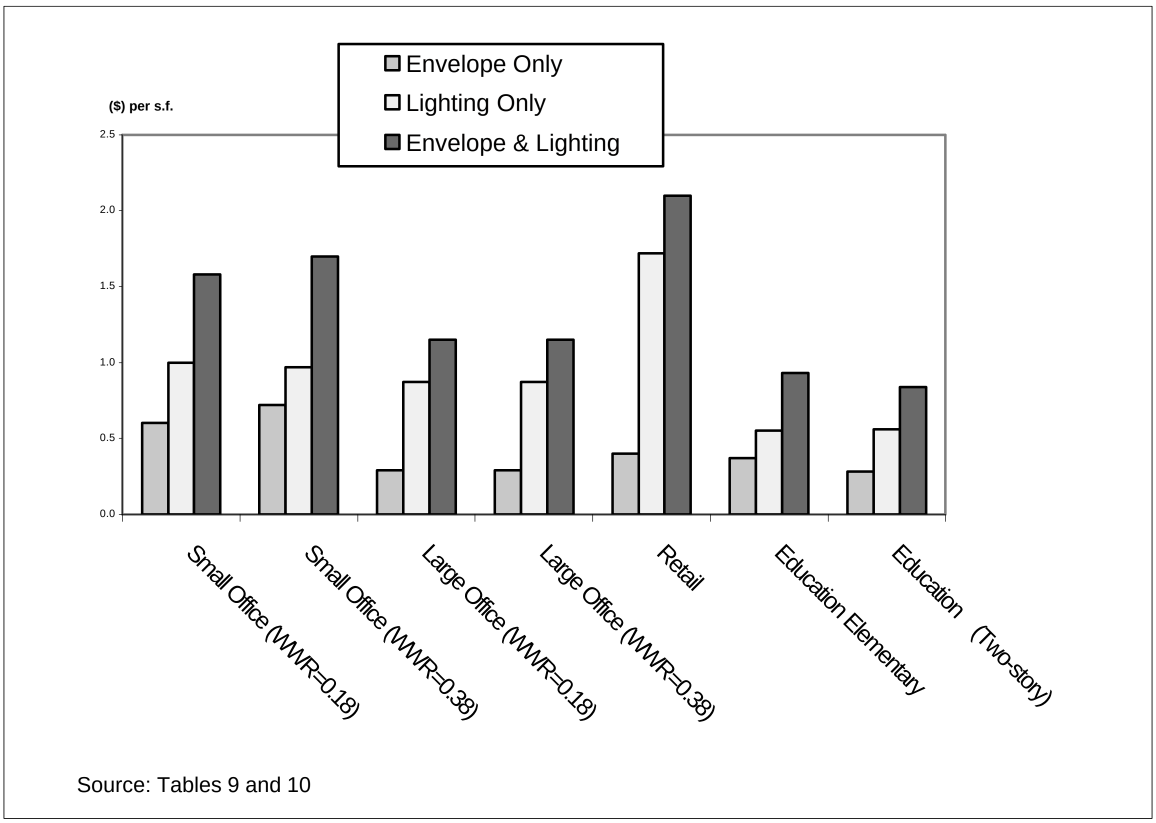

Figure 7. Comparison of LCC Savings Per Square Foot Between Different Types of Buildings

The simulation results suggest the importance of the different glazing requirements between the two standards. In the buildings with modest window-to-wall ratios, ASHRAE 90.1-1999 calls for better performance windows and both life-cycle costs and energy consumption decline. In buildings with window-to-wall ratios roughly exceeding 30%, the window shading coefficient/solar heat gain coefficient requirements are less stringent in the 1999 standard. The analysis here suggests this still leads to lower-life cycle cost, but higher energy consumption and energy cost for these high window-to-wall ratio buildings.[18]

The ASHRAE 90.1-1999 lighting requirements appear to be highly cost-effective for these building types in terms of life-cycle cost savings relative to the 90.1-1989 baseline. These results are obtained assuming the light levels in the space are maintained at the IES recommended light levels used in development of the 90.1-1999 lighting power densities, but that the 90.1-1999 levels require the use of more efficient lamp and ballast technologies. When lighting and envelope requirements are combined, all of the buildings simulated display savings in energy use, annual fuel cost, and life-cycle costs. Based on these limited quantitative results, it appears that adopting the ASHRAE 90.1-1999 Standard in Illinois, either in specific jurisdictions or statewide, would provide positive net economic benefits to the state relative to the building and design requirements prescribed in ASHRAE 90.1-1989.

In addition to quantitative benefits, it appears that ASHRAE 90.1-1999 may also provide other advantages over ASHRAE 90.1-1989 in achieving compliance. ASHRAE 90.1-1999 has significantly modified the structure and language of the standard in an effort to make it easier to understand, use, and enforce.

[18] The latest national data related to the percentage of window glass on exterior walls in commercial buildings is from the 1992 CBECS. That data suggest that more than three-quarters of the floor space constructed in the U.S. between 1987 and 1992 had window-to-wall ratios less than 30%.

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APPENDIX A
Glossary of Selected Terms

Glossary

Ballast: a device used in conjunction with an electric-discharge lamp to cause the lamp to start and operate under the proper circuit conditions of voltage, current, wave form, electrode heat, etc

Building Envelope: the exterior plus the semi-exterior portions of a building. For the purposes of determining building envelope requirements, the classifications are defined as follows:

(a) ***building envelope, exterior***: the elements of a building that separate conditioned space from the exterior
(b) ***building envelope, semi-exterior***: the elements of a building that separate conditioned space from unconditioned space or that enclose semi-heated spaces through which thermal energy may be transferred to or from the exterior, or to or from unconditioned spaces, or to or from conditioned spaces.

CDD50 Cooling Degree-Day base 50° F: for any one day, when the mean temperature is more than 50°F, there are as many degree-days as degree Fahrenheit temperature difference between the mean temperature for the day and 50° F. Annual cooling degree-days (CDDs) are the sum of the degree-days over a calendar years.

C-*factor (thermal conductance):* time rate of steady state heat flow through unit area of a material or construction, induced by a unit temperature difference between the body surfaces. Units of C are Btu/h· ft^{2}· °F. Note that the C-factor does not include soil or air films.

Envelope performance factor: the trade-off value for the building envelope performance compliance option calculated using the procedure in Section 5. of the ASHRAE/IESNA Standards 90.1-1999.
F-*factor:* the perimeter heat loss factor for slab-on-grade floors, expressed in Btu/h· ft^{2}°F

HDD65 Heating Degree-Day base 65° F: for any one day, when the mean temperature is less than 65°F, there are as many degree-days as degree Fahrenheit temperature difference between the mean temperature for the day and 65° F. Annual heating degree-days (HDDs) are the sum of the degree-days over a calendar years.

HVAC system: the equipment, distribution systems, and terminals that provide, either collectively or individually, the processes of heating, ventilating, or air conditioning to a building or portion of a building.

Life Cycle Cost (LCC): analysis is a method of analyzing the cost of a system or a product over its entire lifespan. LCC enables you to define the elements included in the lifespan of a system or product, and assign equations to each element. These equations represent the calculation of the cost of that particular element.

Shading Coefficient (SC): the ratio of solar heat gain at normal incidence through glazing to that occurring through 1/8 in.thick clear, double-strength glass. Shading coefficient, as used herein, does not include interior, exterior, or integral shading devices.

U-*factor (thermal transimittance):* heat transmission in unit time through unit area of material or construction and boundary air films, induced by unit temperature difference between the environment and each side. Units of U are Btu/h· °F.

Source: For details refer to ASHRAE STANDARD, Energy Standard for Buildings Except Low-Rise Residential Buildings. I-P edition. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1999.

APPENDIX B
Metal Frame Results

Table 7. Engineering and Cost Summary

Small Office (WWR=0.18)
Wall Type: Metal Frame
Bldg. Size: 10,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	1,014	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	4,619	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	10,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	433	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$24,131	$22,029		$22,029
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$15,720		$17,554	$17,554
Construction Cost			$39,851	$37,749	$41,685	$39,584
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	116	100	103	88
Natural Gas		MMBtu	74	88	86	103
Total Annual Energy Cost			$8,954	$8,732	$8,013	$7,819
Economic Measures						
Life-Cycle Cost Savings				**$4,695**	**$8,924**	**$13,254**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.4	23.2
Adjusted IRR				Invest. < 0	11.0%	15.8%

Notes:

1 **No economizer used**

2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**

3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Table 8. Engineering and Cost Summary

Small Office (WWR=0.38)
Wall Type: Metal Frame
Bldg. Size: 10,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	2,141	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.250	0.453		0.453
(Window-Wall Ratio = 0.38)		U-factor(cost)	0.55	0.571		0.571
		sh. coef.(cost)	0.262	0.453		0.453
		cost ($/sqft)	$11.33	$7.38		$7.38
Opaque Walls	3,493	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	10,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	433	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$41,082	$29,558		$29,558
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$15,720		$17,554	$17,554
Construction Cost			$56,802	$45,278	$58,636	$47,112
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	97	121	86	109
Natural Gas		MMBtu	138	121	157	138
Total Annual Energy Cost			$9,018	$9,368	$8,151	$8,475
Economic Measures						
Life-Cycle Cost Savings				**$8,768**	**$7,955**	**$17,059**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.0	Invest. < 0
Adjusted IRR				Invest. < 0	10.8%	Invest. < 0

Notes:
1 **No economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**
Life-cycle cost savings includes replacement costs and residual values

Large Office (WWR=0.18)

Wall Type: Metal Frame
Bldg. Size: 60,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	4,302	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	19,598	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	20,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	613	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$70,219	$68,112		$68,112
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$94,319		$105,326	$105,326
Construction Cost			$164,538	$162,430	$175,546	$173,438
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,926	1,926	1,686	1,686
Electricity, HVAC		MMBtu	579	514	535	470
Natural Gas		MMBtu	250	299	299	355
Total Annual Energy Cost			$50,138	$49,202	$44,978	$44,106
Economic Measures						
Life-Cycle Cost Savings				**$12,829**	**$47,683**	**$59,669**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.0	5.2
Adjusted IRR				Invest. < 0	10.8%	11.5%

Notes:

1 **Economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Large Office (WWR=0.38)
Wall Type: Metal Frame
Bldg. Size: 60,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	9,082	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.250	0.453		0.453
(Window-Wall Ratio = 0.38)		U-factor(cost)	0.55	0.571		0.571
		sh. coef.(cost)	0.262	0.453		0.453
		cost ($/sqft)	$11.33	$7.38		$7.38
Opaque Walls	14,818	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	20,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	613	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$142,137	$100,053		$100,053
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$94,319		$105,326	$105,326
Construction Cost			$236,455	$194,372	$247,463	$205,380
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,926	1,926	1,686	1,686
Electricity, HVAC		MMBtu	517	624	475	582
Natural Gas		MMBtu	479	416	554	483
Total Annual Energy Cost			$50,478	$52,127	$45,524	$47,122
Economic Measures						
Life-Cycle Cost Savings				**$28,013**	**$44,924**	**$73,630**
Savings-to-Investment Ratio (SIR)				Invest. < 0	3.8	Invest. < 0
Adjusted IRR				Invest. < 0	10.7%	Invest. < 0

Notes:
1 **Economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**
Life-cycle cost savings includes replacement costs and residual values

Retail
Wall Type: Metal Frame
Bldg. Size: 24,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	624	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.770	0.570		0.570
(Window-Wall Ratio = 0.07)		U-factor(cost)	0.60	0.570		0.570
		sh. coef.(cost)	0.763	0.570		0.570
		cost ($/sqft)	$6.15	$6.81		$6.81
Opaque Walls	8,292	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	24,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	686	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$43,424	$37,190		$37,190
Lighting						
Lighting Power Density		watts/sqft	2.36		1.90	1.90
Lighting Cost		$/sqft	$0.70		$0.84	$0.84
Total Lighting Cost			$16,848		$20,215	$20,215
Construction Cost			$60,272	$54,038	$63,639	$57,405
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	899	899	754	754
Electricity, HVAC		MMBtu	300	287	249	237
Natural Gas		MMBtu	63	74	85	98
Total Annual Energy Cost			$23,621	$23,434	$19,965	$19,823
Economic Measures						
Life-Cycle Cost Savings				**$8,716**	**$39,238**	**$47,385**
Savings-to-Investment Ratio (SIR)				Invest. < 0	7.7	Invest. < 0
Adjusted IRR				Invest. < 0	12.6%	Invest. < 0

Notes:
1 **No economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Education (elementary)

Wall Type: Metal Frame
Bldg. Size: 50,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	2,991	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	13,624	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	50,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	1,278	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$98,245	$88,151		$88,151
Lighting						
Lighting Power Density		watts/sqft	1.79		1.50	1.50
Lighting Cost		$/sqft	$1.80		$1.96	$1.96
Total Lighting Cost			$89,774		$97,805	$97,805
Construction Cost			$188,019	$177,925	$196,050	$185,956
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,056	1,056	915	915
Electricity, HVAC		MMBtu	362	328	338	303
Natural Gas		MMBtu	996	1,077	1,073	1,158
Total Annual Energy Cost			$34,131	$34,006	$31,445	$31,345
Economic Measures						
Life-Cycle Cost Savings				**$11,204**	**$20,758**	**$31,626**
Savings-to-Investment Ratio (SIR)				Invest. < 0	2.7	20.1
Adjusted IRR				Invest. < 0	9.7%	15.3%

Notes:

1 **Economizer used**

2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**

3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Education (two-story)
Wall Type: Metal Frame
Bldg. Size: 80,000 sq. ft.

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	5,023	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	22,883	U-factor	0.077	0.084		0.084
		cost ($/sqft)	$0.78	$0.70		$0.70
Roof	40,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	1,073	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$104,714	$98,346		$98,346
Lighting						
Lighting Power Density		watts/sqft	1.79		1.50	1.50
Lighting Cost		$/sqft	$1.80		$1.96	$1.96
Total Lighting Cost			$143,638		$156,487	$156,487
Construction Cost			$248,351	$241,984	$261,201	$254,833
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,690	1,690	1,464	1,464
Electricity, HVAC		MMBtu	657	588	617	548
Natural Gas		MMBtu	1,398	1,514	1,512	1,634
Total Annual Energy Cost			$54,794	$54,231	$50,415	$49,888
Economic Measures						
Life-Cycle Cost Savings				**$12,121**	**$34,294**	**$45,924**
Savings-to-Investment Ratio (SIR)				Invest. < 0	2.8	4.5
Adjusted IRR				Invest. < 0	9.8%	11.1%

Notes:

1 **Economizer used**

2 **2001 electricity price = 6.6 cents/kWh** — **2001 gas price = $6.71 /MMBtu**

3 **Years for Analysis = 40** — **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Table 9. Summary of Results by Building (Office Buildings)

Wall Type: Metal Frame			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Small Office (WWR=0.18)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	10,000	Electricity (kBtu/sf/yr)	43.7	1.6	5.3	6.9
No. of floors	1	Nat. Gas (kBtu/sf/yr)	7.4	-1.4	-1.2	-2.8
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.90	$0.02	$0.09	$0.11
Core ratio	0.44	Life-cycle cost ($/sf)		$0.47	$0.89	$1.33
Window-wall ratio	0.18					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	4.4	23.2
		Adjusted IRR		Invest. < 0	11.0%	15.8%
Small Office (WWR=0.38)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	10,000	Electricity (kBtu/sf/yr)	41.8	-2.4	5.1	2.8
No. of floors	1	Nat. Gas (kBtu/sf/yr)	13.8	1.7	-1.9	0.0
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.90	-$0.03	$0.09	$0.05
Core ratio	0.44	Life-cycle cost ($/sf)		$0.88	$0.80	$1.71
Window-wall ratio	0.38					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	4.0	Invest. < 0
		Adjusted IRR		Invest. < 0	10.8%	Invest. < 0
Large Office (WWR=0.18)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	60,000	Electricity (kBtu/sf/yr)	41.7	1.1	4.7	5.8
No. of floors	3	Nat. Gas (kBtu/sf/yr)	4.2	-0.8	-0.8	-1.7
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.84	$0.02	$0.09	$0.10
Core ratio	0.59	Life-cycle cost ($/sf)		$0.21	$0.79	$0.99
Window-wall ratio	0.18					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	4.0	5.2
		Adjusted IRR		Invest. < 0	10.8%	11.5%
Large Office (WWR=0.38)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	60,000	Electricity (kBtu/sf/yr)	40.7	-1.8	4.7	2.9
No. of floors	3	Nat. Gas (kBtu/sf/yr)	8.0	1.0	-1.3	-0.1
Aspect ratio	2.25	Energy cost ($/sf)	$0.84	-$0.03	$0.08	$0.06
Core ratio	0.59	Life-cycle cost ($/sf)		$0.47	$0.75	$1.23
Window-wall ratio	0.38					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	3.8	Invest. < 0
		Adjusted IRR		Invest. < 0	10.7%	Invest. < 0

Table 10. Summary of Results by Building (Retail and Education Buildings)

			Standard Level			
Wall Type: Metal Frame			*90.1-1989 Base*	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Retail		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	24,000	Electricity (kBtu/sf/yr)	50.0	0.6	8.2	8.7
No. of floors	1	Nat. Gas (kBtu/sf/yr)	2.6	-0.4	-0.9	-1.4
Aspect ratio	2.50	Energy cost ($/sf/yr)	$0.98	$0.01	$0.15	$0.16
Core ratio	0.61	Life-cycle cost ($/sf)		$0.36	$1.63	$1.97
Window-wall ratio	0.07					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	7.7	Invest. < 0
		Adjusted IRR		Invest. < 0	12.6%	Invest. < 0
Education (elementary)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	50,000	Electricity (kBtu/sf/yr)	28.4	0.7	3.3	4.0
No. of floors	1	Nat. Gas (kBtu/sf/yr)	19.9	-1.6	-1.5	-3.2
Aspect ratio	6.00	Energy cost ($/sf/yr)	$0.68	$0.00	$0.05	$0.06
Core ratio	0.63	Life-cycle cost ($/sf)		$0.22	$0.42	$0.63
Window-wall ratio	0.18					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	2.7	20.1
		Adjusted IRR		Invest. < 0	9.7%	15.3%
Education (two-story)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	80,000	Electricity (kBtu/sf/yr)	29.3	0.9	3.3	4.2
No. of floors	2	Nat. Gas (kBtu/sf/yr)	17.5	-1.4	-1.4	-2.9
Aspect ratio	5.00	Energy cost ($/sf/yr)	$0.68	$0.01	$0.05	$0.06
Core ratio	0.62	Life-cycle cost ($/sf)		$0.15	$0.43	$0.57
Window-wall ratio	0.18					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	2.8	4.5
		Adjusted IRR		Invest. < 0	9.8%	11.1%

APPENDIX C
Mass Wall Results

Small Office (WWR=0.18)
Wall Type: **Mass**
Bldg. Size **10,000 sq. ft.**

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	1,014	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	4,619	U-factor	0.097	0.123		0.123
		cost ($/sqft)	$2.54	$2.08		$2.08
Roof	10,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	433	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$32,241	$28,380		$28,380
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$15,720		$17,554	$17,554
Construction Cost			$47,961	$44,099	$49,796	$45,934
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	114	96	101	85
Natural Gas		MMBtu	83	108	97	126
Total Annual Energy Cost			$8,963	$8,802	$8,041	$7,917
Economic Measures						
Life-Cycle Cost Savings				**$5,537**	**$8,668**	**$13,721**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.3	Invest. < 0
Adjusted IRR				Invest. < 0	11.0%	Invest. < 0

Notes:
1 **No economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**
Life-cycle cost savings includes replacement costs and residual values

Small Office (WWR=0.38)

Wall Type: **Mass**

Bldg. Size: **10,000 sq. ft.**

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	2,141	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.250	0.453		0.453
(Window-Wall Ratio = 0.38)		U-factor(cost)	0.55	0.571		0.571
		sh. coef.(cost)	0.262	0.453		0.453
		cost ($/sqft)	$11.33	$7.38		$7.38
Opaque Walls	3,493	U-factor	0.097	0.123		0.123
		cost ($/sqft)	$2.54	$2.08		$2.08
Roof	10,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	433	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$47,214	$34,360		$34,360
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$15,720		$17,554	$17,554
Construction Cost			$62,934	$50,079	$64,769	$51,914
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	96	120	85	108
Natural Gas		MMBtu	148	136	168	153
Total Annual Energy Cost			$9,070	$9,440	$8,211	$8,558
Economic Measures						
Life-Cycle Cost Savings				**$9,754**	**$7,847**	**$17,911**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.0	Invest. < 0
Adjusted IRR				Invest. < 0	10.8%	Invest. < 0

Notes:

1 **No economizer used**

2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**

3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Large Office (WWR=0.18)

Wall Type: **Mass**

Bldg. Size: **60,000 sq. ft.**

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	4,302	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	19,598	U-factor	0.097	0.123		0.123
		cost ($/sqft)	$2.54	$2.08		$2.08
Roof	20,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	613	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$104,629	$95,055		$95,055
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.76	$1.76
Total Lighting Cost			$94,319		$105,326	$105,326
Construction Cost			$198,947	$189,373	$209,955	$200,381
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,926	1,926	1,686	1,686
Electricity, HVAC		MMBtu	559	494	515	450
Natural Gas		MMBtu	280	366	334	433
Total Annual Energy Cost			$49,946	$49,264	$44,820	$44,232
Economic Measures						
Life-Cycle Cost Savings				**$16,572**	**$47,225**	**$62,532**
Savings-to-Investment Ratio (SIR)				Invest. < 0	4.0	9.8
Adjusted IRR				Invest. < 0	10.8%	13.3%

Notes:

1 **Economizer used**

2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**

3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Large Office (WWR=0.38)
Wall Type: **Mass**
Bldg. Size: **60,000 sq. ft.**

				Standard Level			
				90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope		**Area (sq. ft.)**					
	Windows	9,082	U-factor(std)	0.580	0.570		0.570
			sh. coef.(std)	0.250	0.453		0.453
	(Window-Wall Ratio = 0.38)		U-factor(cost)	0.55	0.571		0.571
			sh. coef.(cost)	0.262	0.453		0.453
			cost ($/sqft)	$11.33	$7.38		$7.38
	Opaque Walls	14,818	U-factor	0.097	0.123		0.123
			cost ($/sqft)	$2.54	$2.08		$2.08
	Roof	20,000	U-factor	0.053	0.063		0.063
			cost ($/sqft)	$1.32	$1.13		$1.13
		(feet)					
	Slab perimeter	613	U-factor	0.125	not req'd		not req'd
			cost ($/ft)*	$2.08	$2.08		$2.08
			*24-inch depth				
	Envelope Cost (incremental)			$168,153	$120,425		$120,425
Lighting							
	Lighting Power Density		watts/sqft	1.63		1.30	1.30
	Lighting Cost		$/sqft	$1.57		$1.76	$1.76
	Total Lighting Cost			$94,319		$105,326	$105,326
Construction Cost				$262,472	$214,744	$273,480	$225,751
Annual Energy Consumption							
	Electricity, lights and plugs		MMBtu	1,926	1,926	1,686	1,686
	Electricity, HVAC		MMBtu	501	602	459	559
	Natural Gas		MMBtu	517	469	597	541
Total Annual Energy Cost				$50,424	$52,044	$45,500	$47,079
Economic Measures							
	Life-Cycle Cost Savings				**$33,685**	**$44,528**	**$78,765**
	Savings-to-Investment Ratio (SIR)				Invest. < 0	3.8	Invest. < 0
	Adjusted IRR				Invest. < 0	10.6%	Invest. < 0

Notes:

1 **Economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Retail
Wall Type: **Mass**
Bldg. Size: **24,000 sq. ft.**

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	624	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.770	0.570		0.570
(Window-Wall Ratio = 0.07)		U-factor(cost)	0.60	0.570		0.570
		sh. coef.(cost)	0.763	0.570		0.570
		cost ($/sqft)	$6.15	$6.81		$6.81
Opaque Walls	8,292	U-factor	0.097	0.123		0.123
		cost ($/sqft)	$2.54	$2.08		$2.08
Roof	24,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	686	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$57,983	$48,589		$48,589
Lighting						
Lighting Power Density		watts/sqft	2.36		1.90	1.90
Lighting Cost		$/sqft	$0.70		$0.84	$0.84
Total Lighting Cost			$16,848		$20,215	$20,215
Construction Cost			$74,830	$65,437	$78,198	$68,804
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	899	899	754	754
Electricity, HVAC		MMBtu	294	279	243	230
Natural Gas		MMBtu	73	100	101	136
Total Annual Energy Cost			$23,569	$23,459	$19,968	$19,944
Economic Measures						
Life-Cycle Cost Savings				**$10,668**	**$38,512**	**$48,063**
Savings-to-Investment Ratio (SIR)				Invest. < 0	7.5	Invest. < 0
Adjusted IRR				Invest. < 0	12.5%	Invest. < 0

Notes:
1 **No economizer used**
2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**
Life-cycle cost savings includes replacement costs and residual values

Education (elementary)
Wall Type: **Mass**
Bldg. Size: **50,000 sq. ft.**

				Standard Level			
				90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**						
Windows	2,991		U-factor(std)	0.580	0.570		0.570
			sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)			U-factor(cost)	0.59	0.571		0.571
			sh. coef.(cost)	0.709	0.453		0.453
			cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	13,624		U-factor	0.097	0.123		0.123
			cost ($/sqft)	$2.54	$2.08		$2.08
Roof	50,000		U-factor	0.053	0.063		0.063
			cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)						
Slab perimeter	1,278		U-factor	0.125	not req'd		not req'd
			cost ($/ft)*	$2.08	$2.08		$2.08
			*24-inch depth				
Envelope Cost (incremental)				$122,165	$106,881		$106,881
Lighting							
Lighting Power Density			watts/sqft	1.79		1.50	1.50
Lighting Cost			$/sqft	$1.80		$1.96	$1.96
Total Lighting Cost				$89,774		$97,805	$97,805
Construction Cost				$211,938	$196,654	$219,969	$204,685
Annual Energy Consumption							
Electricity, lights and plugs			MMBtu	1,056	1,056	915	915
Electricity, HVAC			MMBtu	354	318	330	294
Natural Gas			MMBtu	1,025	1,144	1,106	1,230
Total Annual Energy Cost				$34,157	$34,275	$31,507	$31,656
Economic Measures							
Life-Cycle Cost Savings					**$12,873**	**$20,280**	**$32,746**
Savings-to-Investment Ratio (SIR)					Invest. < 0	2.7	Invest. < 0
Adjusted IRR					Invest. < 0	9.7%	Invest. < 0

Notes:

1 **Economizer used**

2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**

3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Education (two-story)

Wall Type: **Mass**

Bldg. Size: **80,000 sq. ft.**

			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	5,023	U-factor(std)	0.580	0.570		0.570
		sh. coef.(std)	0.710	0.453		0.453
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.59	0.571		0.571
		sh. coef.(cost)	0.709	0.453		0.453
		cost ($/sqft)	$6.33	$7.38		$7.38
Opaque Walls	22,883	U-factor	0.097	0.123		0.123
		cost ($/sqft)	$2.54	$2.08		$2.08
Roof	40,000	U-factor	0.053	0.063		0.063
		cost ($/sqft)	$1.32	$1.13		$1.13
	(feet)					
Slab perimeter	1,073	U-factor	0.125	not req'd		not req'd
		cost ($/ft)*	$2.08	$2.08		$2.08
		*24-inch depth				
Envelope Cost (incremental)			$144,890	$129,805		$129,805
Lighting						
Lighting Power Density		watts/sqft	1.79		1.50	1.50
Lighting Cost		$/sqft	$1.80		$1.96	$1.96
Total Lighting Cost			$143,638		$156,487	$156,487
Construction Cost			$288,528	$273,443	$301,378	$286,292
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,690	1,690	1,464	1,464
Electricity, HVAC		MMBtu	633	564	592	525
Natural Gas		MMBtu	1,452	1,624	1,570	1,751
Total Annual Energy Cost			$54,675	$54,514	$50,325	$50,228
Economic Measures						
Life-Cycle Cost Savings				**$15,078**	**$33,905**	**$48,134**
Savings-to-Investment Ratio (SIR)				Invest. < 0	2.8	11.3
Adjusted IRR				Invest. < 0	9.8%	13.7%

Notes:

1 **Economizer used**

2 **2001 electricity price = 6.6 cents/kWh** **2001 gas price = $6.71 /MMBtu**

3 **Years for Analysis = 40** **Discount Rate = 7.0%**

Life-cycle cost savings includes replacement costs and residual values

Summary of Results by Building

Wall Type: Mass			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Small Office (WWR=0.18)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	10,000	Electricity (kBtu/sf/yr)	43.5	1.7	5.3	6.9
No. of floors	1	Nat. Gas (kBtu/sf/yr)	8.3	-2.5	-1.4	-4.3
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.90	$0.02	$0.09	$0.10
Core ratio	0.44	Life-cycle cost ($/sf)		$0.55	$0.87	$1.37
Window-wall ratio	0.18					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	4.3	Invest. < 0
		Adjusted IRR		Invest. < 0	11.0%	Invest. < 0
Small Office (WWR=0.38)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	10,000	Electricity (kBtu/sf/yr)	41.7	-2.4	5.1	2.8
No. of floors	1	Nat. Gas (kBtu/sf/yr)	14.8	1.3	-1.9	-0.5
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.91	-$0.04	$0.09	$0.05
Core ratio	0.44	Life-cycle cost ($/sf)		$0.98	$0.78	$1.79
Window-wall ratio	0.38					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	4.0	Invest. < 0
		Adjusted IRR		Invest. < 0	10.8%	Invest. < 0
Large Office (WWR=0.18)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	60,000	Electricity (kBtu/sf/yr)	41.4	1.1	4.7	5.8
No. of floors	3	Nat. Gas (kBtu/sf/yr)	4.7	-1.4	-0.9	-2.5
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.83	$0.01	$0.09	$0.10
Core ratio	0.59	Life-cycle cost ($/sf)		$0.28	$0.79	$1.04
Window-wall ratio	0.18					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	4.0	9.8
		Adjusted IRR		Invest. < 0	10.8%	13.3%
Large Office (WWR=0.38)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	60,000	Electricity (kBtu/sf/yr)	40.5	-1.7	4.7	3.0
No. of floors	3	Nat. Gas (kBtu/sf/yr)	8.6	0.8	-1.3	-0.4
Aspect ratio	2.25	Energy cost ($/sf/yr)	$0.84	-$0.03	$0.08	$0.06
Core ratio	0.59	Life-cycle cost ($/sf)		$0.56	$0.74	$1.31
Window-wall ratio	0.38					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	3.8	Invest. < 0
		Adjusted IRR		Invest. < 0	10.6%	Invest. < 0

Summary of Results by Building (continued)

Wall Type: Mass			Standard Level			
			90.1-1989 Base	*90.1-1999 Envelope Only*	*90.1-1999 Lighting Only*	*90.1-1999 Envelope & Lighting*
Retail		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	24,000	Electricity (kBtu/sf/yr)	49.7	0.6	8.1	8.7
No. of floors	1	Nat. Gas (kBtu/sf/yr)	3.1	-1.1	-1.1	-2.6
Aspect ratio	2.50	Energy cost ($/sf/yr)	$0.98	$0.00	$0.15	$0.15
Core ratio	0.61	Life-cycle cost ($/sf)		$0.44	$1.60	$2.00
Window-wall ratio	0.07					
Economizer (?)	no	Savings-to-invest. Ratio		Invest. < 0	7.5	Invest. < 0
		Adjusted IRR		Invest. < 0	12.5%	Invest. < 0
Education (elementary)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	50,000	Electricity (kBtu/sf/yr)	28.2	0.7	3.3	4.0
No. of floors	1	Nat. Gas (kBtu/sf/yr)	20.5	-2.4	-1.6	-4.1
Aspect ratio	6.00	Energy cost ($/sf/yr)	$0.68	$0.00	$0.05	$0.05
Core ratio	0.63	Life-cycle cost ($/sf)		$0.26	$0.41	$0.65
Window-wall ratio	0.18					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	2.7	Invest. < 0
		Adjusted IRR		Invest. < 0	9.7%	Invest. < 0
Education (two-story)		Normalized Results	Base	Savings Relative to Base		
Key Characteristics		Energy Use:				
Floor space	80,000	Electricity (kBtu/sf/yr)	29.0	0.9	3.3	4.2
No. of floors	2	Nat. Gas (kBtu/sf/yr)	18.2	-2.2	-1.5	-3.7
Aspect ratio	5.00	Energy cost ($/sf/yr)	$0.68	$0.00	$0.05	$0.06
Core ratio	0.62	Life-cycle cost ($/sf)		$0.19	$0.42	$0.60
Window-wall ratio	0.18					
Economizer (?)	yes	Savings-to-invest. Ratio		Invest. < 0	2.8	11.3
		Adjusted IRR		Invest. < 0	9.8%	13.7%