PNNL-14016

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

# Analysis of Potential Benefits and Costs of Updating the Commercial Building Energy Code in Iowa

KA Cort
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DW Winiarski
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September 2002

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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**Completed for the Building Standards and Guidelines Program, U.S. Department of Energy**

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# Executive Summary

The state of Iowa is considering updating its commercial building energy code. This report evaluates the potential costs and benefits to Iowa resident from updating and requiring compliance with the most recent editions of the International Energy Conservation Code (IECC) or *ANSI/ASHRAE/IESNA 90.1-1999 Energy Standard for Buildings except Low-Rise Residential Buildings* (hereafter referred to 90.1-1999 or ASHRAE 90.1-1999). These standards were developed in an effort to set minimum requirements for the energy efficient design and construction of new commercial buildings. The quantitative benefits and costs of updating Iowa's commercial building energy code are modeled by comparing Iowa's existing code (ASHRAE Standard 90.1-1989) with the more recent edition, ASHRAE 90.1-1999. Both qualitative and quantitative benefits and costs are assessed in this analysis. Energy and economic impacts are estimated using the Building Loads Analysis and System Thermodynamics (BLAST) simulations combined with a Life-Cycle Cost (LCC) approach to assess corresponding economic costs and benefits.

The energy simulation and economic results of the building prototypes selected for this study suggest that adopting a standard equivalent to ASHRAE 90.1-1999 as the commercial building energy code in Iowa 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.

The results of the building prototype analysis are used to estimate potential statewide aggregate monetary savings from updating Iowa's commercial building energy code. Finally, the total primary energy savings potentially available to Iowa from updating the commercial energy code is estimated.

# Contents

# Acronyms and Abbreviations

| | |
|---|---|
| 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 |
| CFL | Compact Fluorescent Light |
| 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

The state of Iowa is considering adopting a recent version of the IECC (IECC 2000 or IECC 2001) or ASHRAE 90.1-1999 as its commercial building energy code. The potential benefits and costs of updating the code are considered in this report in an effort to evaluate whether or not these standards represent an appropriate efficiency level for the state.

Iowa currently applies Standard ASHRAE 90.1-1989 as the statewide building energy code. This report is written in response to a request for technical assistance from representatives of Iowa's Department of Natural Resources. The request specified the need for an objective analysis that included potential aggregate state energy savings and total net benefits to the state resulting from code adoption.

## 1.2 Scope

This study focuses on three commercial building types: office, retail, and education. These building types are the most common commercial buildings and make up over 50% of the total value of new commercial construction in Iowa (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 heating, ventilation, air-conditioning (HVAC) and service water heating (SWH) equipment regulated under IECC and ASHRAE also regulated by federal manufacturing standards, which by law will soon be updated to levels at least as stringent as those in ASHRAE 90.1-1999. Hence, the savings from these equipment requirements will generally occur regardless of the adoption of a building standard in Iowa. Efficiency improvements in equipment that are not covered under EPCA are discussed in Section 5.4 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.*

Iowa's current statewide commercial energy code is ASHRAE Standard 90.1-1989; therefore, this standard is used as a baseline for evaluating the incremental impact of updating the commercial code. The incremental impacts of updating the code will be modeled based on the differences in requirements between ASHRAE 90.1-1989 and 90.1-1999.

For this analysis, a study period of forty years was chosen to capture changes in building energy consumption from required energy-related designs and materials that occur over the life of the building. Specific simulation and Life Cycle Cost (LCC) assumptions are discussed in the respective sections of this report.

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 Sections 5 and 6.

# 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.

In 1972 the General Assembly of the state of Iowa passed House File 6, an Act to institute an Iowa building code to ensure the health, safety, and welfare of its citizens. House File 6 became known as Iowa Code Chapter 103A. The first energy code was established in 1978, based on the National Conference of States on Building Codes and Standards Model Code for Energy Conservation. Since that time, the Iowa commercial building code has been updated based on the ASHRAE Standard 90.1-1989.

The three most likely standard options for updating the Iowa commercial energy code include the IECC 2000, IECC 2001, and ASHRAE Standard 90.1-1999. The approach of this analysis is to compare the impacts of moving from ASHRAE 90.1-1989 to 90.1-1999, as the incremental impact between these two standards adequately captures the impact of adopting any one of these recent standard editions. The envelope components of the IECC are covered in Chapter 7 of the standard. Chapter 7 of IECC 2001 references 90.1-1999; therefore, a comparison of the envelope requirements of 90.1-1999 and 90.1-1989 adequately reflects the impacts that would result from the adoption of the IECC 2001 envelope requirements. Chapter 7 of IECC 2000 references 90.1-1989, which is the current code in Iowa; thus, there would be essentially no change in the commercial envelope requirements if Iowa were to adopt IECC 2000. Therefore, to evaluate the impact of adopting IECC 2000, only the lighting impacts and results included in this report need to be observed. The lighting requirements of IECC 2000 and IECC 2001 are very similar to the lighting requirements of 90.1-1999; thus, a comparison between 90.1-1989 and 90.1-1999 lighting requirements represents the incremental difference between 90.1-1989 and IECC 2000 as well as IECC 2001.

## 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 90.1-1999 that addresses building envelope requirements includes prescriptive as well as mandatory and trade-off options. Window and door requirements specify U-factors and solar heat gain coefficients (the 1989 edition used shading coefficient). ASHRAE 90.1-1999 has added air leakage requirements that apply to Iowa climates for the sealing of openings and joints in the building envelope (including windows and doors, loading docks, and vestibules). The prescriptive path of 90.1-1999 also includes methods for calculating U-factors, C-factors, and F-factors for pre-assembled envelope sections. A performance trade-off option in both standards 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 ASHRAE 90.1-1999 is the approach used to justify the minimum envelope requirements. ASHRAE 90.1-1989 set envelope requirements based on professional judgment 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 ASHRAE 90.1-1989 and 90.1-1999 is that ASHRAE 90.1-1989 focused on setting a requirement for “all roofs” or “all walls” or “all floors” while 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 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 90.1-1999 (e.g., requirements for metal buildings tend to be more stringent in ASHRAE 90.1-1989 than in 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 90.1-1999 is that ASHRAE 90.1-1989 is based on a series of continuous efficiency curves, leading to continuously changing requirements by climate. ASHRASE 90.1-1999 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, and R-11.3 for various locations where 90.1-1999 has either R-7 or R-11 or R-13. The resulting impact of the ASHRAE 90.1-1989 requirements is that one would typically need to exceed the prescriptive requirements in order to 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 ASHRAE 90.1-

[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.

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) are available 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 ASHRAE 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 ASHRAE 90.1-1989 and IECC 2000/IECC2001/ASHRAE 90.1-1999. 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.

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 could be met by 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 also defines calculation of fixture wattage and sets power and efficiency 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 Available 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 provide some of the key components considered in tailoring the study to the state.

### *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 Iowa range from 2653 cooling degree-days (CDD) and 7837 heating degree-days (HDD) in Mason City (northern Iowa) to 3601 CDD and 5943 HDD in Burlington (southern Iowa).

### *2.2.2 Demographic and Construction Data*

Iowa has a population of approximately 2.9 million. Although some of Iowa's population centers have experienced population declines in the past ten years (e.g., Des Moines County and Cerro Gordo County), the largest two cities, Des Moines and Cedar Rapids, and their surrounding suburbs have experienced significant growth well above the state average (Census 2000b). In 1997 the value of new commercial construction in Iowa was approximately $2 billion. Office, retail, and education buildings contributed to over half the total value of new construction in that year (Census 2000c).

[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.

### 2.2.3 *Energy Consumption and Sources*

Iowa consumes approximately 1.1 quadrillion Btu of energy each year and approximately 15% of this energy is consumed by the commercial sector (while residential consumes 20%, industrial consumes 40% and transportation consumes 25%). Gas is the primary energy source for building heating in Iowa. Coal power is the primary source of electricity generation in Iowa, making up over 60% of the total generating capacity and over 90% of actual electricity generation in 1999 (EIA 2001c).

## 2.3 Assumptions

Although Iowa's elevation and average temperatures do not vary dramatically throughout the state, the most distinct variations in climate characteristics are found between the northern and southern regions of the state. In order to capture this variation, two distinct simulations are run with weather data representative of the Iowa's northern and southern climates. The 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. Seven 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 buildings analyzed is shown in Table 2.

***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. 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 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 Iowa 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 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 fourteen different building types while the 90.1-1989 standard provides values for only eleven. However, the 90.1-1989 also provides different lighting power densities for six different building size categories within each of these eleven building types.

The whole building LPD values from the 90.1-1989 standard do not correspond directly to the representative building types required for the simulations. In order to develop comparable whole building lighting numbers, 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.

IECC 2000/90.1-1999 lighting requirements provide single value, whole building, LPD requirements for office, retail, and school 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[3].

[3] 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).

*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.

# 4.0 Economic Analysis

The economic benefit and cost analysis of adopting ASHRAE 90.1-1999 utilizes the LCC approach, which compares the monetary savings over a specified time horizon with 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 ASHRAE 90.1-1999 and ASHRAE 90.1-1989 requirements).

The primary ongoing monetary benefit of the code is the energy 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[4].

The current average gas and electricity prices for Iowa were obtained from the Energy Information Administration (EIA) and are listed in Table 4 (2001a). Based on the

[4] 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.

Annual Energy Outlook 2002 forecasts (EIA 2001b)[5] the average fuel rates are escalated throughout the first 20-years of the study period and are assumed to remain flat the remaining 20 years of the study period[6].

***Table 4**. Commercial Average Annual Fuel Rates in Iowa*

| Average Annual Price of Natural Gas (2000) | Average Annual Price of Electricity (2000) |
|---|---|
| $6.7/thousand cubic feet | $.0585/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)[7].

## 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 ASHRAE 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 appropriately 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 a 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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[5] During 2001 gas prices spiked throughout the U.S. 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.

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

[7] 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 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 based on the needs of the space, including task requirements, occupants, and overall desired atmosphere of the environment and is generally driven by 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 selected 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 (office, hallway, sales area, etc.) within each building type in the ASHRAE 90.1-1999 Whole Building Space Data Allocations is based on up to three different lighting types with each type representing a lighting technology and associated fixture[8]. 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 type allocations listed in the ASHRAE 90.1-1999 Space Type Models provide one method of meeting the lighting power limit 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.

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

The models also serve as the basis for comparison with other standards or current practice scenarios.

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 and 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.[9] The 90.1-1999 whole-building LPD will increase by different percentage amounts over 90.1-1989, depending

[9] 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.

upon the assumed fractions of floor space to be served by the technologies in each of the building types.

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. The less efficient technologies associated with the 90.1-1989 standard levels were then substituted into the same 90.1-1999 models (i.e., assuming the same illumination levels) to determine a corresponding increase in predicted LPD. 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 of 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 current published standard.[10]

[10] The use of the revised formula in the LPD spreadsheet (see previous footnote) causes the calculated 90.1-1999 LPDs for office, retail, and education 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.

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 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 resulting energy savings for particular building types included in this study are found in Appendixes B and C[11].

This section presents the estimated energy and economic impacts between the ASHRAE 90.1-1989 and ASHRAE 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 (which also represents the impact of adopting IECC 2000); and 3) Changing both envelope and lighting requirements (which also represents the impact of adopting IECC 2001). 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 interaction between the envelope and lights affect the overall impacts.

## 5.1 Buildings in Northern Iowa

As discussed in Section 2.3, the building simulations are run with two distinct weather data files in order to capture climate variation between the northern and southern region of Iowa. In each climate zone four different office building formats are characterized. The different office buildings are designed to capture the variation of the standard's impacts that stem from alternative window-to-wall ratios, building size, and number of floors. In addition, a retail building and two types of school buildings are characterized. All of the buildings are characterized as having metal frame walls.

### *5.1.1 Office Buildings*

Table 7 presents the engineering and cost summary for the small, 10,000 square foot, single-story office building in northern Iowa. The top panel of the table shows the key engineering and cost inputs for the building envelope. Based upon a 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 5,733 square feet. Given the assumed window-to-wall ratio of 0.18, this translates into 1,013 square feet of windows and 4,619 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 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.

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[11] The national simulation results for the U.S. 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 Energy Codes website (http://www.energycodes.gov/implement/determinations_com.stm).

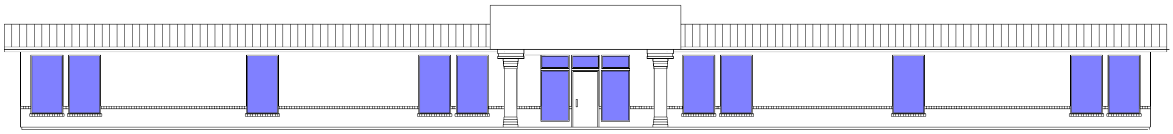

*Figure 1. Office Building – 10,000 s.f. with 18% window-to-wall ratio*

*Base Case*

The column under the heading "90.1-1989 Base" 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 essentially 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 averaged 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 $7.63.

Costs for the other envelope components are based upon the cost model developed as part of the ASHRAE Standard 90.1-1999. 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 $27,365. 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 total lighting cost for the building is $15,720.

*Table 7. Engineering and Cost Summary*

**Small Office (WWR=0.18)**

Climate: **Iowa (North)**

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) | 0.520 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.680 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.18) | | U-factor(cost) | 0.54 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.542 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $7.63 | $7.38 | | $7.38 |
| Opaque Walls | 4,619 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 10,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $27,365 | $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** | | | $43,085 | $37,749 | $44,919 | $39,584 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 321 | 321 | 281 | 281 |
| Electricity, HVAC | | MMBtu | 114 | 99 | 102 | 87 |
| Natural Gas | | MMBtu | 108 | 147 | 124 | 167 |
| **Total Annual Energy Cost** | | | $8,169 | $8,155 | $7,374 | $7,402 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$5,412** | **$7,087** | **$11,953** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.7 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 10.5% | Invest. < 0 |

**Notes:**

1 **No economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /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 are 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 $8,169 is based upon fuel prices for 2001[12]. 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 U-factor requirements are slightly relaxed in ASHRAE 90.1-1999, while the shading coefficient becomes more stringent. The net effect of these two changes is to slightly decrease the initial cost relative to the 1989 requirements by about $.25 per square foot of window area.

The ASHRAE 90.1-1999 standard also relaxes 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 $0.29 per square foot, the total cost reduction for this building is about $3,000. 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 $5,300 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 15 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 slightly since the cost per MMBtu of electricity is more than three times that of natural gas.

Life-cycle costs are about $5,400 lower as compared to the base ASHRAE 90.1-1989. The cost savings are the sum of the $5,300 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)[13] are undefined.

[12] As discussed in Section 4.0, 2000 fuel prices were used for 2001. Converted to dollars per MMBtu, the electricity price is $17.14 and the natural gas price is $6.47.

[13] 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

*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 52 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 requires more heat from 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 $800 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 over $7,000. The savings-to-investment ratio is over 3.7. In other words, for every dollar of initial and (discounted) replacement investment cost, nearly 4 dollars of (discounted) fuel expenditures are saved over the life of the building. The adjusted internal rate of return is 10.5%.[14]

*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 $770 lower than the base ASHRAE 90.1-1989 standard; life-cycle cost savings are about $12,000. 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.

#### 5.1.1.1 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 10,000 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 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 0.384 to 0.453 for the northern Iowa climate.

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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.

[14] The difference between the IRR and AIRR can be considerable. In this case the IRR is about 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 just over 2 years ($1,800/$800). 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.

*Table 8. Engineering and Cost Summary*

**Small Office (WWR=0.38)**

Climate: **Iowa (North)**

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) | 0.380 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.380 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.38) | | U-factor(cost) | 0.38 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.384 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $12.68 | $7.38 | | $7.38 |
| Opaque Walls | 3,493 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 10,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $45,649 | $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** | | | $61,369 | $45,278 | $63,203 | $47,112 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 321 | 321 | 281 | 281 |
| Electricity, HVAC | | MMBtu | 119 | 123 | 107 | 111 |
| Natural Gas | | MMBtu | 131 | 195 | 148 | 214 |
| **Total Annual Energy Cost** | | | $8,390 | $8,878 | $7,612 | $8,128 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$11,542** | **$6,873** | **$18,033** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.6 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 10.5% | Invest. < 0 |

**Notes:**

1 **No economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**

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

**Life-cycle cost savings includes replacement costs and residual values**

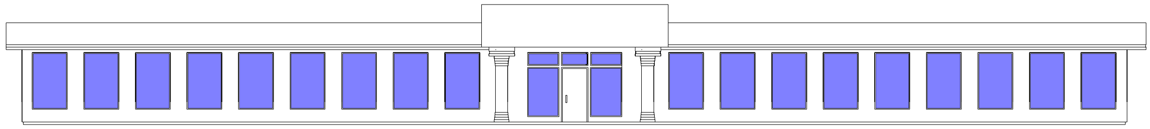

*Figure 2. Office – 10,000 s.f. with 38% window-to-wall ratio*

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 119 MMBtu to 123 MMBtu). During the heating season, the combined effect of relaxing wall, roof, and window insulation requirements leads to an increase in gas consumption by 64 MMBtu per year.

On a cost basis, the reduction in gas use does not offset the increase in electricity cost; annual energy expenditures for the building increase by nearly $500. 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 $10,000. Clearly, this case demonstrates that energy savings and cost-effectiveness need not go hand-in-hand.

#### 5.1.1.2 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.

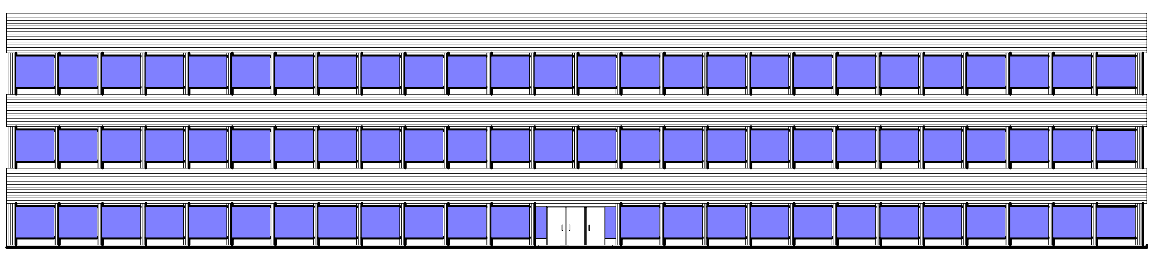

*Figure 3. Office – 60,000 s.f. with 3 stories and 38% window-to-wall ratio*

Tables similar to those presented for the small office 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 office 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 just discussed. Under the heading "Key Characteristics" are the physical characteristics of the building that have the most significant impact on its energy use.[15] On the right-hand side of the table, the key energy and cost results are normalized to a square-foot basis. This normalization helps to bring out differences that relate to the building geometry and may be used in future assessments of total benefits and costs of alternative standards (e.g., x million square feet times y savings per square feet in life-cycle cost).

Looking first at the lighting-only case, Table 9 indicates that the cost effectiveness 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 an economizer in the large office. In the small office, the cooling equipment must meet all changes in the cooling loads.

In the envelope-only case, the LCC savings per square foot are significantly greater for offices with higher window-to-wall ratios. This outcome stems from the significant first cost reductions in windows moving from ASHRAE 90.1-1989 to ASHRAE 90.1-1999 for buildings with high window-to-wall ratios.

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[15] 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 9 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.

***Table 9. Summary of Office Results by Building Format (North)***

| Location: Iowa (North) | | | | 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/sqft/yr) | 43.5 | 1.6 | 5.2 | 6.7 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 10.8 | -3.9 | -1.5 | -5.8 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.82 | $0.00 | $0.08 | $0.08 |
| Core ratio | 0.44 | Life-cycle cost ($/sqft) | | $0.54 | $0.71 | $1.20 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.7 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.5% | Invest. < 0 |
| **Small Office (WWR=0.38)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 10,000 | Electricity (kBtu/sqft/yr) | 44.0 | -0.4 | 5.2 | 4.7 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 13.1 | -6.4 | -1.7 | -8.4 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.84 | -$0.05 | $0.08 | $0.03 |
| Core ratio | 0.44 | Life-cycle cost ($/sqft) | | $1.15 | $0.69 | $1.80 |
| Window-wall ratio | 0.38 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.6 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.5% | Invest. < 0 |
| **Large Office (WWR=0.18)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 60,000 | Electricity (kBtu/sqft/yr) | 42.0 | 1.0 | 4.7 | 5.7 |
| No. of floors | 3 | Nat. Gas (kBtu/sqft/yr) | 6.1 | -2.1 | -1.0 | -3.4 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.76 | $0.00 | $0.07 | $0.08 |
| Core ratio | 0.59 | Life-cycle cost ($/sqft) | | $0.26 | $0.65 | $0.88 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 3.5 | 30.5 |
| | | Adjusted IRR | | Invest. < 0 | 10.4% | 16.5% |
| **Large Office (WWR=0.38)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 60,000 | Electricity (kBtu/sqft/yr) | 42.5 | -0.6 | 4.7 | 4.1 |
| No. of floors | 3 | Nat. Gas (kBtu/sqft/yr) | 7.4 | -3.8 | -1.1 | -5.2 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.78 | -$0.03 | $0.07 | $0.04 |
| Core ratio | 0.59 | Life-cycle cost ($/sqft) | | $0.66 | $0.64 | $1.27 |
| Window-wall ratio | 0.38 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 3.4 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.3% | Invest. < 0 |

### *5.1.2 Retail*

Table 10 shows the normalized summary results for the retail and education buildings analyzed. The detailed engineering and cost tables (similar to Table 7 and Table 8 above) 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. Figure 4 provides an illustration of a retail building with these characteristics. The base electricity consumption per square foot is higher in the retail building as compared to any of the other buildings modeled (due, in large part, to higher lighting levels). The reduction in electricity use per square foot from the adoption of 90.1-1999 envelope requirements is higher for the retail building than the offices with WWR of 38% and lower than the offices with 18% WWR. Although the overall envelope requirements are somewhat relaxed moving from 90.1-1989 to 90.1-1999 for this building type, the life-cycle savings is positive due to reductions in first costs going to the more relaxed envelope requirements.

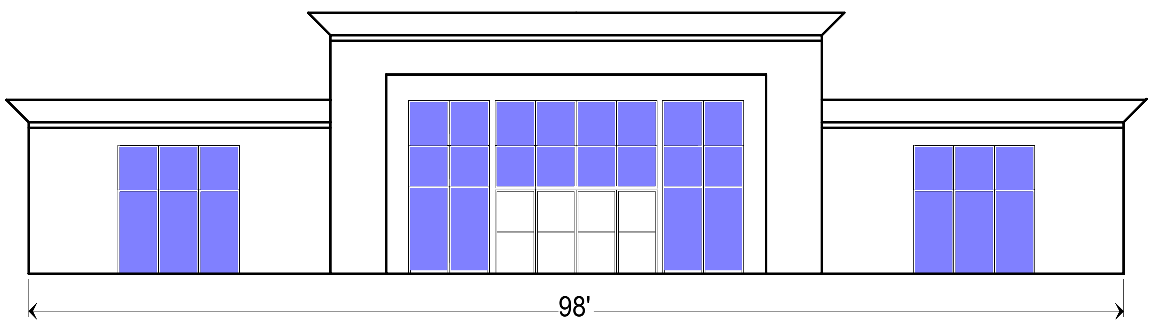


*Figure 4. Retail Building – 24,000 s.f. with 7% window-to-wall ratio*

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 10%.

### *5.1.3 Education*

Two education buildings were analyzed. 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.

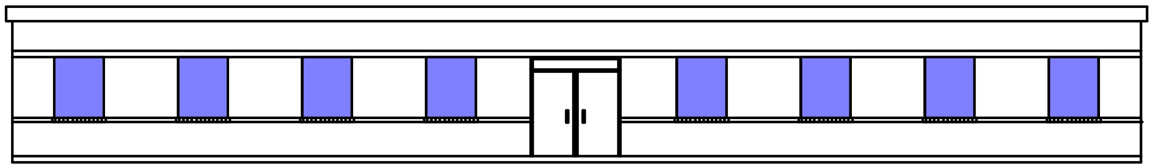

*Figure 5. Education Building (Elementary) – 50,000 s.f., 18% window-to-wall ratio*

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. 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 significantly greater than the decline in electricity, resulting in higher annual fuel costs. On a cost basis, however, the life-cycle savings increase under ASHRAE 90.1-1999 for both types of school buildings.

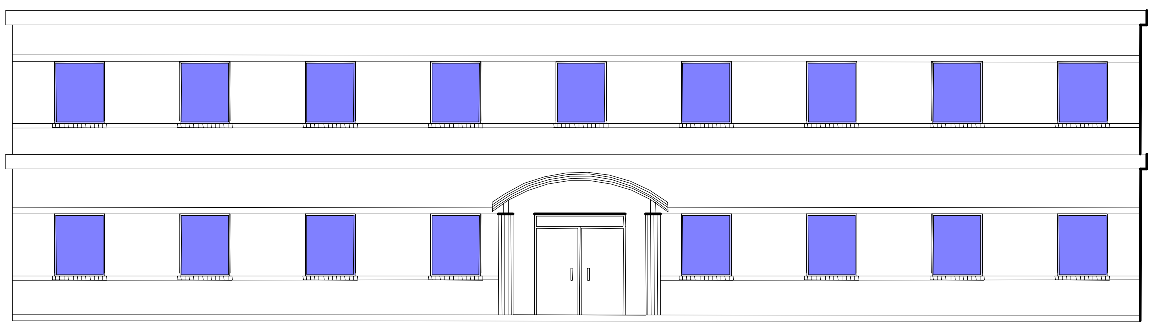

*Figure 6. Education Building – 80,000 s.f. with 18% window-to-wall ratio.*

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

| Location: Iowa (North) | | | 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/sqft/yr) | 49.3 | 0.5 | 8.1 | 8.5 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 4.2 | -1.5 | -1.2 | -3.1 |
| Aspect ratio | 2.50 | Energy cost ($/sqft/yr) | $0.87 | $0.00 | $0.13 | $0.13 |
| Core ratio | 0.61 | Life-cycle cost ($/sqft) | | $0.46 | $1.19 | $1.59 |
| Window-wall ratio | 0.07 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.8 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.6% | Invest. < 0 |
| **Education (elementary)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 50,000 | Electricity (kBtu/sqft/yr) | 28.7 | 0.6 | 3.3 | 3.9 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 25.7 | -3.5 | -1.6 | -5.1 |
| Aspect ratio | 6.00 | Energy cost ($/sqft/yr) | $0.66 | -$0.01 | $0.05 | $0.03 |
| Core ratio | 0.63 | Life-cycle cost ($/sqft) | | $0.27 | $0.33 | $0.60 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 9.3% | Invest. < 0 |
| **Education (two-story)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 80,000 | Electricity (kBtu/sqft/yr) | 29.7 | 0.8 | 3.3 | 4.1 |
| No. of floors | 2 | Nat. Gas (kBtu/sqft/yr) | 22.5 | -3.1 | -1.5 | -4.6 |
| Aspect ratio | 5.00 | Energy cost ($/sqft/yr) | $0.66 | -$0.01 | $0.05 | $0.04 |
| Core ratio | 0.62 | Life-cycle cost ($/sqft) | | $0.17 | $0.34 | $0.50 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 9.4% | Invest. < 0 |

The lighting-only case shows that the ASHRAE 90.1-1999 requirements for reduced LPDs in education buildings are highly cost effective. The SIR is 2.4 and the adjusted rate of return is more than 9%. The shorter operating hours for these buildings is reflected in the economic measures. The SIR and AIRR measures for the two education buildings are lower than the corresponding measures for office and retail buildings.

## 5.2 Buildings in Southern Iowa

Tables 11 and 12 summarize the findings for all building types included in the study, assuming they are located in southern Iowa. As with Tables 9 and 10, each panel summarizes the key characteristics and resulting LCC savings for a given building type. Tables describing the inputs and LCC results for each building type simulated in southern Iowa are found in Appendix C.

The buildings simulated with southern Iowa climate characteristics produce similar results to the buildings simulated with northern Iowa climate characteristics. The lighting results are virtually the same with only slight variations in the fan electricity savings, which is due to varied envelope characteristics in the base case between climates.

As with the buildings simulated in the north, all of the U-factor requirements roofs, walls, and floors are relaxed between ASHRAE 90.1-1989 and ASHRAE 90.1-1999 for buildings in southern Iowa. Under 90.1-1989, the envelope requirements in northern Iowa are slightly more stringent than the requirements for buildings in southern Iowa. Under 90.1-1999, however, the envelope requirements for both northern and southern Iowa climates are the same. This means that the incremental difference in U-factors between 90.1-1989 and 90.1-1999 is greater for buildings in the north. As a result, the increase in natural gas use is less in the south than the north, as the insulating requirements for buildings in the south are not as relaxed between 90.1-1989 and 90.1-1999.

There are also different impacts for northern and southern buildings with regards to the changes in window requirements. For buildings with larger window-to-wall ratios, both shading coefficients and U-factors are relaxed under 90.1-1999. For buildings in the south, these requirements are relaxed (under 90.1-1999) relatively more than buildings in the north. This leads to relatively less savings in energy required for cooling of offices with higher window-to-wall ratios in the south.

The most significant difference between the LCC results for buildings in the north and south stems from the differences in first costs. The first costs are reduced relatively more for buildings in the north than those in the south under ASHRAE 90.1-1999. This reduction in first costs leads to slightly higher LCC savings per square foot for all building types in the north.

***Table 11. Summary of Office Results by Building Format (South)***

| Location: Iowa (South) | | | 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/sqft/yr) | 43.7 | 1.6 | 5.3 | 6.9 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 7.4 | -1.4 | -1.2 | -2.8 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.80 | $0.02 | $0.08 | $0.10 |
| Core ratio | 0.44 | Life-cycle cost ($/sqft) | | $0.43 | $0.75 | $1.15 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.8 | 20.2 |
| | | Adjusted IRR | | Invest. < 0 | 10.7% | 15.4% |
| **Small Office (WWR=0.38)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 10,000 | Electricity (kBtu/sqft/yr) | 41.8 | -2.4 | 5.1 | 2.8 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 13.8 | 1.7 | -1.9 | 0.0 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.81 | -$0.03 | $0.08 | $0.05 |
| Core ratio | 0.44 | Life-cycle cost ($/sqft) | | $0.94 | $0.66 | $1.63 |
| Window-wall ratio | 0.38 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.5 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.4% | Invest. < 0 |
| **Large Office (WWR=0.18)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 60,000 | Electricity (kBtu/sqft/yr) | 41.7 | 1.1 | 4.7 | 5.8 |
| No. of floors | 3 | Nat. Gas (kBtu/sqft/yr) | 4.2 | -0.8 | -0.8 | -1.7 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.74 | $0.01 | $0.08 | $0.09 |
| Core ratio | 0.59 | Life-cycle cost ($/sqft) | | $0.19 | $0.67 | $0.84 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 3.5 | 4.5 |
| | | Adjusted IRR | | Invest. < 0 | 10.4% | 11.1% |
| **Large Office (WWR=0.38)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 60,000 | Electricity (kBtu/sqft/yr) | 40.7 | -1.8 | 4.7 | 2.9 |
| No. of floors | 3 | Nat. Gas (kBtu/sqft/yr) | 8.0 | 1.0 | -1.3 | -0.1 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.75 | -$0.02 | $0.07 | $0.05 |
| Core ratio | 0.59 | Life-cycle cost ($/sqft) | | $0.51 | $0.62 | $1.15 |
| Window-wall ratio | 0.38 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 3.4 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.3% | Invest. < 0 |

***Table 12. Summary of Retail and Education Results by Building (South)***

| Location: | Iowa (South) | | 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/sqft/yr) | 50.0 | 0.6 | 8.2 | 8.7 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 2.6 | -0.4 | -0.9 | -1.4 |
| Aspect ratio | 2.50 | Energy cost ($/sqft/yr) | $0.87 | $0.01 | $0.13 | $0.14 |
| Core ratio | 0.61 | Life-cycle cost ($/sqft) | | $0.35 | $1.23 | $1.56 |
| Window-wall ratio | 0.07 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.9 | 10.9 |
| | | Adjusted IRR | | Invest. < 0 | 10.7% | 13.6% |
| **Education (elementary)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 50,000 | Electricity (kBtu/sqft/yr) | 28.4 | 0.7 | 3.3 | 4.0 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 19.9 | -1.6 | -1.5 | -3.2 |
| Aspect ratio | 6.00 | Energy cost ($/sqft/yr) | $0.62 | $0.00 | $0.05 | $0.05 |
| Core ratio | 0.63 | Life-cycle cost ($/sqft) | | $0.21 | $0.33 | $0.53 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | 17.1 |
| | | Adjusted IRR | | Invest. < 0 | 9.3% | 14.9% |
| **Education (two-story)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 80,000 | Electricity (kBtu/sqft/yr) | 29.3 | 0.9 | 3.3 | 4.2 |
| No. of floors | 2 | Nat. Gas (kBtu/sqft/yr) | 17.5 | -1.4 | -1.4 | -2.9 |
| Aspect ratio | 5.00 | Energy cost ($/sqft/yr) | $0.62 | $0.01 | $0.05 | $0.05 |
| Core ratio | 0.62 | Life-cycle cost ($/sqft) | | $0.13 | $0.34 | $0.47 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | 3.9 |
| | | Adjusted IRR | | Invest. < 0 | 9.4% | 10.7% |

## 5.3 Other Factors Impacting Benefits and Costs

There are numerous areas of ASHRAE 90.1-1999 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 quantitative economic and energy impacts. The following section briefly describes some probable energy benefits and costs of selected components of 90.1-1999 that are not captured in the previous analysis.

### 5.3.1 *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 Iowa. The impact of air leakage requirement differences between ASHRAE 90.1-1989 and 90.1-1999 are difficult to evaluate. However, 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 these subjects. 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 and R-8 slab-on-grade insulation, while ASHRAE 90.1-1999 has no such requirements. 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.

### 5.3.2 *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.

### 5.3.3 *Mechanical and SWH*

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 can be reviewed online at http://www.energycodes.gov/implement/determinations_com.stm.

### 5.3.4 *Scope of Standard*

One dominating factor influencing 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, alternations, or reconstruction in Iowa was about $650 million in 1997, as compared to new building construction valued at $2 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 over 30% more savings than if it were applied exclusively to new buildings.

# 6.0 Statewide Impacts

Using the LCC savings estimates per square foot derived in this study, total savings from updating the statewide energy code to a stringency level equivalent to ASHRAE 90.1-1999 are estimated based on several key assumptions. It is assumed that all commercial buildings are currently built at a level that just satisfy the minimum requirements of ASHRAE 90.1-1989, and under the new code all commercial buildings would be built at a level that would satisfy the minimum requirements of ASHRAE 90.1-1999. It is also assumed that the LCC savings estimated from the prototype buildings included in this study are representative of the commercial buildings built in Iowa. Based on these assumptions, the prototypical building LCC savings are weighted by building type and region.

Approximately 11 million square feet of new commercial building space is constructed in Iowa each year[16]. It is estimated that office, retail, and education buildings make up more than 50% of the total square feet of new commercial space. Table 13 categorizes the types of new commercial floor space built in Iowa, based on a recent Census survey (Census 2000c).

***Table 13.*** *Building Weights*

| BUIDING TYPE | ESTIMATED SQUARE FOOTAGE (In Millions) |
|---|---|
| Office | **2.0** |
| • *"Small" Office (1-2 floors)* | *0.8* |
| • *"Large" Office (3 or more floors)* | *1.2* |
| Retail | **2.4** |
| Education | **1.5** |
| • *Single-story (Elementary)* | *0.6* |
| • *More than one floor* | *0.9* |
| Other | **5.1** |
| TOTAL | **11.0** |

The LCC savings per square foot for each prototypical building included in the study are listed in Table 14. Using the overall commercial floor space weights listed in Table 14, along with wall construction and window-to-wall ratio splits from CBECS, the total annual LCC savings for Iowa is estimated and presented in the bottom row of Table 14, assuming that the energy and cost savings estimated for the building prototypes modeled

[16] This estimate is based on 1997 Census study (Census 2000), which estimates total expenditures on new commercial construction by building type in Iowa. New commercial square footage estimates are derived by dividing the total dollars spent on new commercial construction by the average cost/s.f. (MEANS) by building category. These numbers are then adjusted to total U.S. square footage estimates listed in the Statistical Abstract of the United States (2000).

are representative of new building construction in Iowa. The total annual LCC savings is estimated to be approximately $12 million.

***Table 14.*** *LCC Savings by Building Type and State Totals*

| BUIDING TYPE | 90.1-1989 Baseline | |
|---|---|---|
| | North | South |
| | **LCC Savings ($/ S.F.)** | **LCC Savings ($/ S.F.)** |
| **Office** | | |
| *"Small" Office (1-2 floors)* | | |
| • *With less than 38% window-to-wall ratio* | 1.2 | 1.15 |
| • *With more than 38% window-to-wall ratio* | 1.8 | 1.63 |
| *"Large" Office (3 or more floors)* | | |
| • *With less than 38% window-to-wall ratio* | 0.88 | 0.84 |
| • *With more than 38% window-to-wall ratio* | 1.27 | 1.15 |
| **Retail** | 1.59 | 1.56 |
| **Education** | | |
| • *Single-story (Elementary)* | 0.6 | 0.53 |
| • *More than one floor* | 0.5 | 0.47 |
| **Other (Average)** | 1.12 | 1.05 |
| **Total Annual LCC Savings in Iowa** (Derived from per square foot savings) | **$12 Million** | |

The annual LCC savings is equivalent to the net present value of the changes in capital (first) and energy costs associated with code adoption for all new buildings built in a given year. Assuming approximately 11 million square feet of building space is added to the commercial building stock each year; the net present value for construction over a 20-year period would be approximately $143 million. The net present value is calculated by discounting the LCC savings for each future year's construction (i.e., $12 million) back to 2002, using a discount rate of 7%.[17] This number only represents savings from new building construction. This estimate does not include the savings available if the code is applied also to building renovations and additions.

Primary energy savings are reported in trillion Btu (TBtu) per year. These results are derived from the site electricity savings[18] per square foot (from fan systems, cooling, and lighting savings), added together with the natural gas savings (or losses) for each building

[17] Assuming a constant rate of annual LCC savings.
[18] Site electricity is converted to primary electricity to derive primary energy.

type, multiplied by the total number of square feet in each building category. The energy savings from the updated building requirements are listed in Table 15.

***Table 15.*** *Primary Energy Savings from 90.1-1999 adoption (in TBtu/Year)**

| YEAR | 2002 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|
| **TBtu Savings** | **0.2** | **0.7** | **1.5** | **2.3** | **3.2** |

*Using Average Electricity Conversion Factors

The energy savings resulting from energy code adoption persist for the life of the building. Although the total amount saved in the first year of adoption may be relatively modest compared with the total amount of energy consumed by the entire commercial sector, these savings from new buildings adopting codes in any given year continue into the future as more new buildings are added to the existing building stock. The savings from code adoption relative to total energy consumption become more significant in future years. Figure 7 illustrates the potential impact through 2020 of code adoption (applied only to new construction) on total commercial energy consumption in Iowa. This does not include potential savings if the code is applied to commercial building renovations[19].

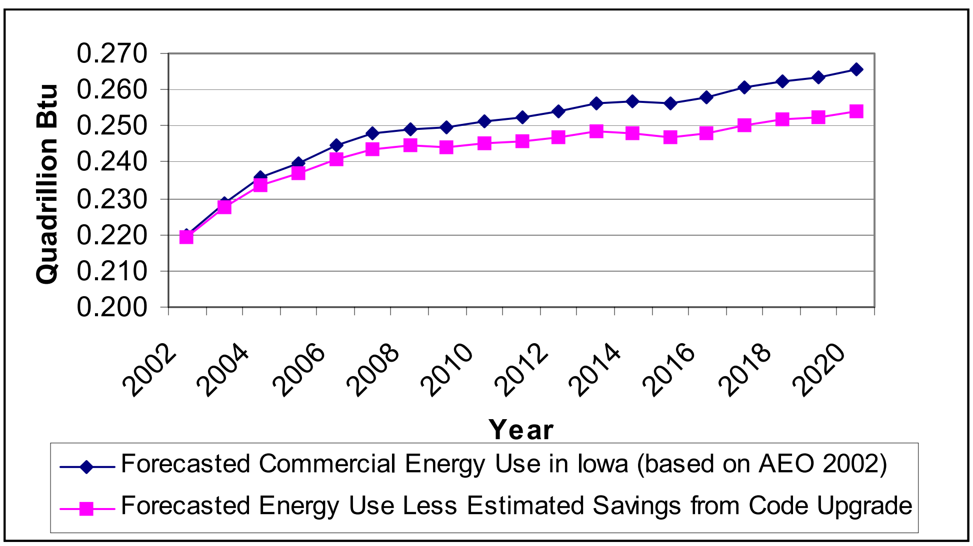


*Figure 7. Forecasted Primary Energy Savings from Code Adoption*

[19] The value of annual investment in commercial alterations and renovations is approximately 30% of the value of new construction in a given year. Expanding the application of the code to commercial building alterations and renovations would potentially significantly increase the statewide energy savings.

# 7.0 Conclusions

One of the primary differences between the development of ASHRAE 90.1-1999 and ASHRAE 90.1-1989 is that ASHRAE 90.1-1999 is based more heavily on economic justification for envelope requirements. 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 ASHRAE 90.1-1999 has succeeded, for the most part, in developing cost-justified energy savings for these building types. Despite the fact that 90.1-1999 relaxes some of the building envelope requirements, relative to the 1989 standard, while increasing others, the adoption of 90.1-1999 (or IECC 2001) envelope requirements result in a reduction of building life-cycle costs as well as first costs for building envelope. Figure 8 provides a comparison of the LCC savings per square foot by building type for envelope and lighting requirements, individually and together for building prototypes in northern Iowa, while Figure 9 illustrates LCC savings for buildings simulated in a southern Iowa climate.

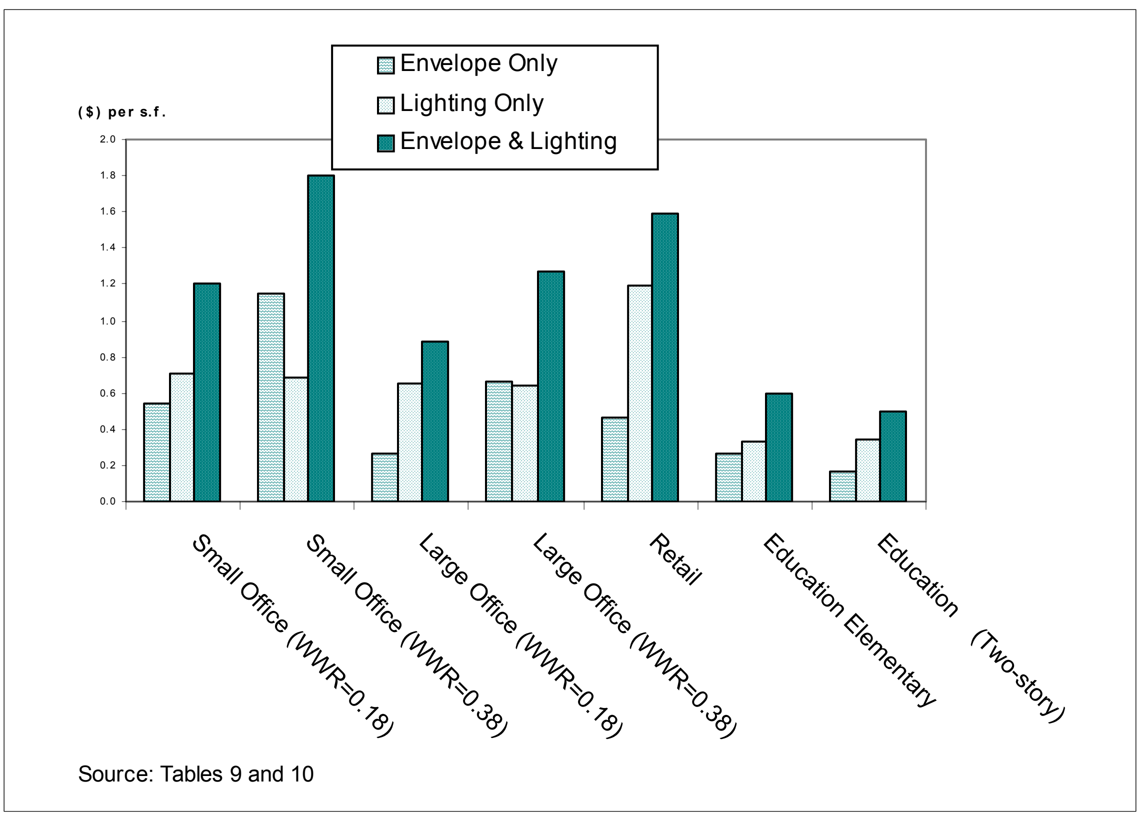


*Figure 8. A Comparison of Life Cycle Cost Saving Per Square Foot Between Different Types of Buildings (North Iowa Climate)*

The simulation results suggest the importance of the different glazing requirements between the two standards. In the buildings with modest window-to-wall ratios, 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.

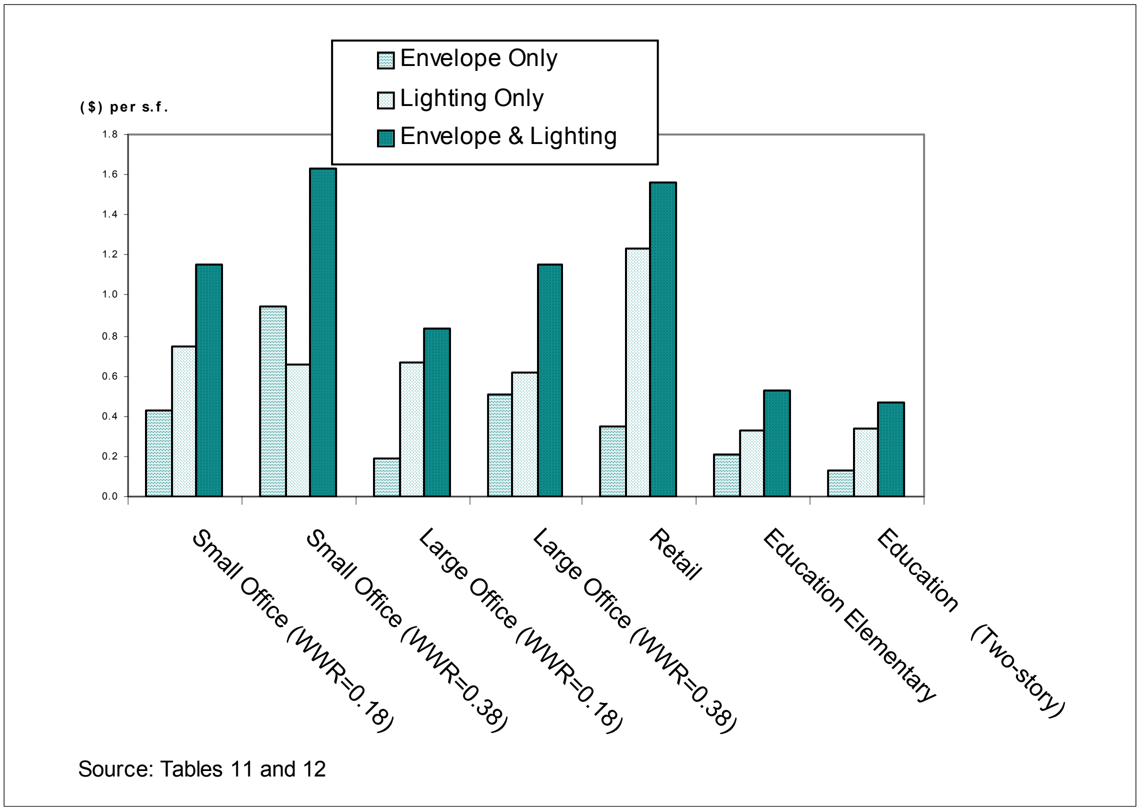


***Figure 9.*** *A Comparison of Life Cycle Cost Saving Per Square Foot Between Different Types of Buildings (South Iowa Climate)*

The lighting requirements of 90.1-1999 (or IECC 2000 or IECC 2001) appear to be highly cost-effective for these building types in terms of life-cycle cost savings relative to the ASHRAE 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. The "lighting only" results represent the net benefits to Iowa of adopting IECC 2000, as IECC 2000 has lighting requirements equivalent to 90.1-1999, but has envelope requirements equivalent to 90.1-1989 (Iowa's current standard).

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 90.1-1999 or IECC 2001 in Iowa would provide positive net economic benefits to the state relative to the building and design requirements prescribed in ASHRAE 90.1-1989.

Assuming that the new building code impacts approximately 11 million square feet of new commercial building space each year and that the building prototypes modeled in this study are representative of new building stock in Iowa, the monetary impact of adopting a state-wide building energy code in Iowa could produce approximately $12 million dollars of LCC savings for each year of construction. When evaluating the benefits of the code over a series of future years, the net present value represents an aggregate measure of the discounted total dollar savings to the state. Including future construction over the next 20 years, the estimated net present value is on the order of $140 million.

# 8.0 References

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and Illuminating Engineering Society of North America (IESNA). 1999. *ASHRAE Standard Energy Standard for Buildings Except Low-Rise Residential Buildings.* .

Energy Information Administration (EIA). 2001a. "Annual Electric Utility Report," and EIA-826, "Monthly Electric Utility Sales and Revenue Report with State Distributions." EIA-861, U.S. Department of Energy. Summer, 2001. Washington D.C.

Energy Information Administration (EIA). 2001b. *Annual Energy Outlook 2002 with Projections to 2020.* U.S. Department of Energy. December 2001. Washington D.C.

Energy Information Administration (EIA). 1992. *Commercial Building Energy Consumption and Expenditures Survey 1992* (CBECS 92), Public Use Data, Micro-data files on EIA website: ftp://ftp.eia.doe.gov/pub/consumption/commercial/micro.data/ U.S. Department of Energy. Washington D.C.

Energy Information Administration (EIA). 1995. *Commercial Building Energy Consumption and Expenditures Survey 1995* (CBECS 95), Public Use Data, Micro-data files on EIA website. [Online].
Available: ftp://ftp.eia.doe.gov/pub/consumption/commercial/micro.data/
U.S. Department of Energy. Washington D.C.

Energy Information Administration (EIA). 2000. *National Energy Modeling System (NEMS)* U.S. Department of Energy. 2000. Washington D.C.

Energy Information Administration (EIA). 2001c. "State Energy Profiles,"
U.S. Department of Energy. August 2001. Washington D.C.

Floyd, D. et. al. "Measured Field Performance and Energy Savings of Occupancy Sensors: Three Case Studies." FSEC-PF309, 1997. [Online].
Available: http://www.fsec.ucf.edu/~bdac/pubs/PF309/PF309.htm, accessed 02/01.

National Institute of Standards and Technology (NIST). April 2001. "Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis." NISTIR 85-3273-16, U.S. Department of Commerce,. Washington D.C.

Office of Management and Budget (OMB). 1992. *Guidelines and Discount Rates for Benefit-Cost Analyses of Federal Programs.* OMB Circular A-94. [Online]. Available: http://www.whitehouse.gov/OMB/circulars/a094/a094.html

Somasundaram, S. et. al. 2000. *Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment.* Pacific Northwest National Laboratory, PNNL-13232. April 2000.

Smith, LA and Nadel, S (1994). *Energy Efficiency Codes and Standards for Iowa.* American Council for an Energy-Efficiency Economy (ACEEE), May, 1994. Washington D.C.

U.S. Bureau of Labor Statistics (BLS). 2002. *Producer Price Index Industry Series.* Public Use Data available on BLS website. [Online]. Available: http://data.bls.gov/labjava/outside/jsp?survey=pc.

U.S. Census Bureau (Census). 2000a. *Construction Reports, Series C-40,* "Housing Units Authorized by Building Permits." U.S. Department of Commerce, Spring, 2000. Washington D.C.

U.S. Census Bureau (Census). 2000b. *United States Census 2000*. U.S. Department of Commerce, April 2000, Washington D.C.

U.S. Census Bureau (Census). 2000c. "1997 Economic Census Construction Geographic Area Series." U.S. Department of Commerce, March 2000. Washington D.C.Energy

U.S. Department of Energy (DOE). 2000. January 2000. "Fluorescent Lamp Ballast Technical Support Document." DOE website. [Online]. Available: http://www.eren.doe.gov/buildings/codes_standards/reports/ballasts/index.htm

W. W. Grainger Industrial Supply - Lighting Catalog 2000-01. 2000. W. W. Grainger, Incorporated. Lake Forest, IL.

# 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 year.

**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 $Btu/h \cdot ft^2 \cdot °F$. 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 $Btu/h \cdot ft^2 °F$.

**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 year.

**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:** 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 transmittance)**: 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
# Iowa – North Results

***Table 6. Engineering and Cost Summary***

**Small Office (WWR=0.18)**

Climate: **Iowa (North)**

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) | 0.520 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.680 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.18) | | U-factor(cost) | 0.54 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.542 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $7.63 | $7.38 | | $7.38 |
| Opaque Walls | 4,619 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 10,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $27,365 | $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** | | | $43,085 | $37,749 | $44,919 | $39,584 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 321 | 321 | 281 | 281 |
| Electricity, HVAC | | MMBtu | 114 | 99 | 102 | 87 |
| Natural Gas | | MMBtu | 108 | 147 | 124 | 167 |
| **Total Annual Energy Cost** | | | $8,169 | $8,155 | $7,374 | $7,402 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$5,412** | **$7,087** | **$11,953** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.7 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 10.5% | Invest. < 0 |

**Notes:**

1 **No economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**

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

**Life-cycle cost savings includes replacement costs and residual values**

***Table 7. Engineering and Cost Summary***

**Small Office (WWR=0.38)**

Climate: **Iowa (North)**

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) | 0.380 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.380 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.38) | | U-factor(cost) | 0.38 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.384 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $12.68 | $7.38 | | $7.38 |
| Opaque Walls | 3,493 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 10,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $45,649 | $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** | | | $61,369 | $45,278 | $63,203 | $47,112 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 321 | 321 | 281 | 281 |
| Electricity, HVAC | | MMBtu | 119 | 123 | 107 | 111 |
| Natural Gas | | MMBtu | 131 | 195 | 148 | 214 |
| **Total Annual Energy Cost** | | | $8,390 | $8,878 | $7,612 | $8,128 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$11,542** | **$6,873** | **$18,033** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.6 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 10.5% | Invest. < 0 |

**Notes:**

1 **No economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /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)

Climate: **Iowa (North)**
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) | 0.520 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.680 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.18) | | U-factor(cost) | 0.54 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.542 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $7.63 | $7.38 | | $7.38 |
| Opaque Walls | 19,598 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 20,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $81,790 | $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** | | | $176,108 | $162,430 | $187,116 | $173,438 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 1,926 | 1,926 | 1,686 | 1,686 |
| Electricity, HVAC | | MMBtu | 597 | 537 | 552 | 493 |
| Natural Gas | | MMBtu | 366 | 495 | 428 | 572 |
| **Total Annual Energy Cost** | | | $45,643 | $45,464 | $41,167 | $41,098 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$15,331** | **$39,123** | **$52,983** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.5 | 30.5 |
| Adjusted IRR | | | | Invest. < 0 | 10.4% | 16.5% |

**Notes:**
1 **Economizer used**
2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /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)

Climate: **Iowa (North)**
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) | 0.380 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.380 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.38) | | U-factor(cost) | 0.38 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.384 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $12.68 | $7.38 | | $7.38 |
| Opaque Walls | 14,818 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 20,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $159,361 | $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** | | | $253,680 | $194,372 | $264,688 | $205,380 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 1,926 | 1,926 | 1,686 | 1,686 |
| Electricity, HVAC | | MMBtu | 623 | 657 | 579 | 614 |
| Natural Gas | | MMBtu | 447 | 676 | 515 | 760 |
| **Total Annual Energy Cost** | | | $46,615 | $48,691 | $42,198 | $44,396 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$39,750** | **$38,342** | **$76,463** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.4 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 10.3% | Invest. < 0 |

**Notes:**

1 **Economizer used**
2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**

**Life-cycle cost savings includes replacement costs and residual values**

## Retail

Climate: **Iowa (North)**

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) | | 0.520 | 0.570 | | 0.570 |
| | | sh. coef.(std) | | 0.680 | 0.570 | | 0.570 |
| (Window-Wall Ratio = 0.07) | | U-factor(cost) | | 0.54 | 0.570 | | 0.570 |
| | | sh. coef.(cost) | | 0.542 | 0.570 | | 0.570 |
| | | cost ($/sqft) | | $7.63 | $6.81 | | $6.81 |
| Opaque Walls | 8,292 | U-factor | | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | | $0.99 | $0.70 | | $0.70 |
| Roof | 24,000 | U-factor | | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | | $1.42 | $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) | | | | $48,366 | $37,190 | | $37,190 |
| **Lighting** | | | | | | | |
| Lighting Power Density | | watts/sqft | | 2.36 | | 1.90 | 1.90 |
| Lighting Cost | | $/sqft | | $1.57 | | $1.80 | $1.80 |
| Total Lighting Cost | | | | $37,722 | | $43,159 | $43,159 |
| **Construction Cost** | | | | $86,088 | $74,911 | $91,525 | $80,349 |
| **Annual Energy Consumption** | | | | | | | |
| Electricity, lights and plugs | | MMBtu | | 899 | 899 | 754 | 754 |
| Electricity, HVAC | | MMBtu | | 283 | 271 | 234 | 225 |
| Natural Gas | | MMBtu | | 101 | 137 | 131 | 177 |
| **Total Annual Energy Cost** | | | | $20,942 | $20,968 | $17,790 | $17,930 |
| **Economic Measures** | | | | | | | |
| Life-Cycle Cost Savings | | | | | **$11,117** | **$28,575** | **$38,200** |
| Savings-to-Investment Ratio (SIR) | | | | | Invest. < 0 | 3.8 | Invest. < 0 |
| Adjusted IRR | | | | | Invest. < 0 | 10.6% | Invest. < 0 |

**Notes:**

1 **No economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**

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

**Life-cycle cost savings includes replacement costs and residual values**

## Education (elementary)

Climate: **Iowa (North)**

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) | 0.520 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.680 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.18) | | U-factor(cost) | 0.54 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.542 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $7.63 | $7.38 | | $7.38 |
| Opaque Walls | 13,624 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 50,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $109,751 | $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** | | | $199,525 | $177,925 | $207,556 | $185,956 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 1,056 | 1,056 | 915 | 915 |
| Electricity, HVAC | | MMBtu | 377 | 347 | 351 | 322 |
| Natural Gas | | MMBtu | 1,287 | 1,460 | 1,366 | 1,541 |
| **Total Annual Energy Cost** | | | $32,962 | $33,581 | $30,625 | $31,257 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$13,747** | **$16,437** | **$30,023** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 2.4 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 9.3% | Invest. < 0 |

**Notes:**

1 **Economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**

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

**Life-cycle cost savings includes replacement costs and residual values**

## Education (two-story)

Climate: **Iowa (North)**
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) | 0.520 | 0.570 | | 0.570 |
| | | sh. coef.(std) | 0.680 | 0.453 | | 0.453 |
| (Window-Wall Ratio = 0.18) | | U-factor(cost) | 0.54 | 0.571 | | 0.571 |
| | | sh. coef.(cost) | 0.542 | 0.453 | | 0.453 |
| | | cost ($/sqft) | $7.63 | $7.38 | | $7.38 |
| Opaque Walls | 22,883 | U-factor | 0.062 | 0.084 | | 0.084 |
| | | cost ($/sqft) | $0.99 | $0.70 | | $0.70 |
| Roof | 40,000 | U-factor | 0.048 | 0.063 | | 0.063 |
| | | cost ($/sqft) | $1.42 | $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) | | | $119,820 | $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** | | | $263,458 | $241,984 | $276,308 | $254,833 |
| **Annual Energy Consumption** | | | | | | |
| Electricity, lights and plugs | | MMBtu | 1,690 | 1,690 | 1,464 | 1,464 |
| Electricity, HVAC | | MMBtu | 690 | 630 | 648 | 588 |
| Natural Gas | | MMBtu | 1,802 | 2,048 | 1,923 | 2,174 |
| **Total Annual Energy Cost** | | | $52,557 | $53,131 | $48,761 | $49,366 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$13,395** | **$27,050** | **$40,015** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 2.4 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 9.4% | Invest. < 0 |

**Notes:**
1 **Economizer used**
2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**
**Life-cycle cost savings includes replacement costs and residual values**

***Table 9. Summary of Office Results by Building Format (North)***

| Location: | Iowa (North) | | | 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/sqft/yr) | 43.5 | 1.6 | 5.2 | 6.7 |
| No. of floors | 1 | Nat. Gas | (kBtu/sqft/yr) | 10.8 | -3.9 | -1.5 | -5.8 |
| Aspect ratio | 2.25 | Energy cost | ($/sqft/yr) | $0.82 | $0.00 | $0.08 | $0.08 |
| Core ratio | 0.44 | Life-cycle cost | ($/sqft) | | $0.54 | $0.71 | $1.20 |
| Window-wall ratio | 0.18 | | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | | Invest. < 0 | 3.7 | Invest. < 0 |
| | | | Adjusted IRR | | Invest. < 0 | 10.5% | Invest. < 0 |
| **Small Office (WWR=0.38)** | | Normalized Results | | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | | |
| Floor space | 10,000 | Electricity | (kBtu/sqft/yr) | 44.0 | -0.4 | 5.2 | 4.7 |
| No. of floors | 1 | Nat. Gas | (kBtu/sqft/yr) | 13.1 | -6.4 | -1.7 | -8.4 |
| Aspect ratio | 2.25 | Energy cost | ($/sqft/yr) | $0.84 | -$0.05 | $0.08 | $0.03 |
| Core ratio | 0.44 | Life-cycle cost | ($/sqft) | | $1.15 | $0.69 | $1.80 |
| Window-wall ratio | 0.38 | | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | | Invest. < 0 | 3.6 | Invest. < 0 |
| | | | Adjusted IRR | | Invest. < 0 | 10.5% | Invest. < 0 |
| **Large Office (WWR=0.18)** | | Normalized Results | | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | | |
| Floor space | 60,000 | Electricity | (kBtu/sqft/yr) | 42.0 | 1.0 | 4.7 | 5.7 |
| No. of floors | 3 | Nat. Gas | (kBtu/sqft/yr) | 6.1 | -2.1 | -1.0 | -3.4 |
| Aspect ratio | 2.25 | Energy cost | ($/sqft/yr) | $0.76 | $0.00 | $0.07 | $0.08 |
| Core ratio | 0.59 | Life-cycle cost | ($/sqft) | | $0.26 | $0.65 | $0.88 |
| Window-wall ratio | 0.18 | | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | | Invest. < 0 | 3.5 | 30.5 |
| | | | Adjusted IRR | | Invest. < 0 | 10.4% | 16.5% |
| **Large Office (WWR=0.38)** | | Normalized Results | | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | | |
| Floor space | 60,000 | Electricity | (kBtu/sqft/yr) | 42.5 | -0.6 | 4.7 | 4.1 |
| No. of floors | 3 | Nat. Gas | (kBtu/sqft/yr) | 7.4 | -3.8 | -1.1 | -5.2 |
| Aspect ratio | 2.25 | Energy cost | ($/sqft/yr) | $0.78 | -$0.03 | $0.07 | $0.04 |
| Core ratio | 0.59 | Life-cycle cost | ($/sqft) | | $0.66 | $0.64 | $1.27 |
| Window-wall ratio | 0.38 | | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | | Invest. < 0 | 3.4 | Invest. < 0 |
| | | | Adjusted IRR | | Invest. < 0 | 10.3% | Invest. < 0 |

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

| Location: Iowa (North) | | | 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/sqft/yr) | 49.3 | 0.5 | 8.1 | 8.5 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 4.2 | -1.5 | -1.2 | -3.1 |
| Aspect ratio | 2.50 | Energy cost ($/sqft/yr) | $0.87 | $0.00 | $0.13 | $0.13 |
| Core ratio | 0.61 | Life-cycle cost ($/sqft) | | $0.46 | $1.19 | $1.59 |
| Window-wall ratio | 0.07 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.8 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.6% | Invest. < 0 |
| **Education (elementary)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 50,000 | Electricity (kBtu/sqft/yr) | 28.7 | 0.6 | 3.3 | 3.9 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 25.7 | -3.5 | -1.6 | -5.1 |
| Aspect ratio | 6.00 | Energy cost ($/sqft/yr) | $0.66 | -$0.01 | $0.05 | $0.03 |
| Core ratio | 0.63 | Life-cycle cost ($/sqft) | | $0.27 | $0.33 | $0.60 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 9.3% | Invest. < 0 |
| **Education (two-story)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 80,000 | Electricity (kBtu/sqft/yr) | 29.7 | 0.8 | 3.3 | 4.1 |
| No. of floors | 2 | Nat. Gas (kBtu/sqft/yr) | 22.5 | -3.1 | -1.5 | -4.6 |
| Aspect ratio | 5.00 | Energy cost ($/sqft/yr) | $0.66 | -$0.01 | $0.05 | $0.04 |
| Core ratio | 0.62 | Life-cycle cost ($/sqft) | | $0.17 | $0.34 | $0.50 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 9.4% | Invest. < 0 |

# APPENDIX B
# Iowa – South Results

## Small Office (WWR=0.18)

Climate: **Iowa (South)**

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** | | | $7,979 | $7,790 | $7,152 | $6,989 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$4,284** | **$7,516** | **$11,461** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.8 | 20.2 |
| Adjusted IRR | | | | Invest. < 0 | 10.7% | 15.4% |

**Notes:**

1 **No economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /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)

Climate: **Iowa (South)**

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** | | | $8,072 | $8,372 | $7,314 | $7,590 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$9,375** | **$6,605** | **$16,295** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.5 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 10.4% | Invest. < 0 |

**Notes:**

1 **No economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /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)

Climate: **Iowa (South)**
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** | | | | $44,583 | $43,781 | $40,037 | $39,296 |
| **Economic Measures** | | | | | | | |
| Life-Cycle Cost Savings | | | | | **$11,180** | **$40,088** | **$50,461** |
| Savings-to-Investment Ratio (SIR) | | | | | Invest. < 0 | 3.5 | 4.5 |
| Adjusted IRR | | | | | Invest. < 0 | 10.4% | 11.1% |

**Notes:**

1 **Economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /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)

Climate: **Iowa (South)**

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** | | | $45,014 | $46,440 | $40,666 | $42,042 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$30,762** | **$37,437** | **$68,880** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.4 | Invest. < 0 |
| Adjusted IRR | | | | Invest. < 0 | 10.3% | Invest. < 0 |

**Notes:**

1 **Economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**

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

**Life-cycle cost savings includes replacement costs and residual values**

## Retail

Climate: **Iowa (South)**
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 | $1.57 | | $1.80 | $1.80 |
| Total Lighting Cost | | | $37,722 | | $43,159 | $43,159 |
| **Construction Cost** | | | $81,146 | $74,911 | $86,583 | $80,349 |
| **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** | | | $20,973 | $20,813 | $17,745 | $17,626 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$8,382** | **$29,573** | **$37,430** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 3.9 | 10.9 |
| Adjusted IRR | | | | Invest. < 0 | 10.7% | 13.6% |

## Education (elementary)

Climate: **Iowa (South)**
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** | | | $30,819 | $30,754 | $28,482 | $28,442 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$10,474** | **$16,452** | **$26,600** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 2.4 | 17.1 |
| Adjusted IRR | | | | Invest. < 0 | 9.3% | 14.9% |

**Notes:**

1 **Economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**

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

**Life-cycle cost savings includes replacement costs and residual values**

## Education (two-story)

Climate: **Iowa (South)**

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** | | | $49,362 | $48,929 | $45,546 | $45,148 |
| **Economic Measures** | | | | | | |
| Life-Cycle Cost Savings | | | | **$10,540** | **$27,352** | **$37,411** |
| Savings-to-Investment Ratio (SIR) | | | | Invest. < 0 | 2.4 | 3.9 |
| Adjusted IRR | | | | Invest. < 0 | 9.4% | 10.7% |

**Notes:**

1 **Economizer used**

2 **2001 electricity price = 5.9 cents/kWh** **2001 gas price = $6.52 /MMBtu**

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

**Life-cycle cost savings includes replacement costs and residual values**

*Table 11. Summary of Office Results by Building Format (South)*

| Location: | Iowa (South) | | | 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/sqft/yr) | 43.7 | 1.6 | 5.3 | 6.9 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 7.4 | -1.4 | -1.2 | -2.8 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.80 | $0.02 | $0.08 | $0.10 |
| Core ratio | 0.44 | Life-cycle cost ($/sqft) | | $0.43 | $0.75 | $1.15 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.8 | 20.2 |
| | | Adjusted IRR | | Invest. < 0 | 10.7% | 15.4% |
| **Small Office (WWR=0.38)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 10,000 | Electricity (kBtu/sqft/yr) | 41.8 | -2.4 | 5.1 | 2.8 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 13.8 | 1.7 | -1.9 | 0.0 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.81 | -$0.03 | $0.08 | $0.05 |
| Core ratio | 0.44 | Life-cycle cost ($/sqft) | | $0.94 | $0.66 | $1.63 |
| Window-wall ratio | 0.38 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.5 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.4% | Invest. < 0 |
| **Large Office (WWR=0.18)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 60,000 | Electricity (kBtu/sqft/yr) | 41.7 | 1.1 | 4.7 | 5.8 |
| No. of floors | 3 | Nat. Gas (kBtu/sqft/yr) | 4.2 | -0.8 | -0.8 | -1.7 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.74 | $0.01 | $0.08 | $0.09 |
| Core ratio | 0.59 | Life-cycle cost ($/sqft) | | $0.19 | $0.67 | $0.84 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 3.5 | 4.5 |
| | | Adjusted IRR | | Invest. < 0 | 10.4% | 11.1% |
| **Large Office (WWR=0.38)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 60,000 | Electricity (kBtu/sqft/yr) | 40.7 | -1.8 | 4.7 | 2.9 |
| No. of floors | 3 | Nat. Gas (kBtu/sqft/yr) | 8.0 | 1.0 | -1.3 | -0.1 |
| Aspect ratio | 2.25 | Energy cost ($/sqft/yr) | $0.75 | -$0.02 | $0.07 | $0.05 |
| Core ratio | 0.59 | Life-cycle cost ($/sqft) | | $0.51 | $0.62 | $1.15 |
| Window-wall ratio | 0.38 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 3.4 | Invest. < 0 |
| | | Adjusted IRR | | Invest. < 0 | 10.3% | Invest. < 0 |

*Table 12. Summary of Retail and Education Results by Building (South)*

| Location: Iowa (South) | | | 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/sqft/yr) | 50.0 | 0.6 | 8.2 | 8.7 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 2.6 | -0.4 | -0.9 | -1.4 |
| Aspect ratio | 2.50 | Energy cost ($/sqft/yr) | $0.87 | $0.01 | $0.13 | $0.14 |
| Core ratio | 0.61 | Life-cycle cost ($/sqft) | | $0.35 | $1.23 | $1.56 |
| Window-wall ratio | 0.07 | | | | | |
| Economizer (?) | no | Savings-to-invest. Ratio | | Invest. < 0 | 3.9 | 10.9 |
| | | Adjusted IRR | | Invest. < 0 | 10.7% | 13.6% |
| **Education (elementary)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 50,000 | Electricity (kBtu/sqft/yr) | 28.4 | 0.7 | 3.3 | 4.0 |
| No. of floors | 1 | Nat. Gas (kBtu/sqft/yr) | 19.9 | -1.6 | -1.5 | -3.2 |
| Aspect ratio | 6.00 | Energy cost ($/sqft/yr) | $0.62 | $0.00 | $0.05 | $0.05 |
| Core ratio | 0.63 | Life-cycle cost ($/sqft) | | $0.21 | $0.33 | $0.53 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | 17.1 |
| | | Adjusted IRR | | Invest. < 0 | 9.3% | 14.9% |
| **Education (two-story)** | | Normalized Results | Base | Savings Relative to Base | | |
| Key Characteristics | | Energy Use: | | | | |
| Floor space | 80,000 | Electricity (kBtu/sqft/yr) | 29.3 | 0.9 | 3.3 | 4.2 |
| No. of floors | 2 | Nat. Gas (kBtu/sqft/yr) | 17.5 | -1.4 | -1.4 | -2.9 |
| Aspect ratio | 5.00 | Energy cost ($/sqft/yr) | $0.62 | $0.01 | $0.05 | $0.05 |
| Core ratio | 0.62 | Life-cycle cost ($/sqft) | | $0.13 | $0.34 | $0.47 |
| Window-wall ratio | 0.18 | | | | | |
| Economizer (?) | yes | Savings-to-invest. Ratio | | Invest. < 0 | 2.4 | 3.9 |
| | | Adjusted IRR | | Invest. < 0 | 9.4% | 10.7% |