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

Analysis of Potential Benefits and Costs of Updating the Recommended Commercial Building Energy Standard in North Dakota

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April 2004

Completed for the Building Standards and Guidelines Program,
U.S. Department of Energy under Contract DE-AC06-76RLO 1830

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Executive Summary

The state of North Dakota is considering updating its recommended commercial building energy standard. This report evaluates the potential costs and benefits to North Dakota residents from updating and requiring compliance with the most recent edition of the *ANSI/ASHRAE/IESNA 90.1-2001 Energy Standard for Buildings except Low-Rise Residential Buildings* (hereafter referred to as 90.1-2001 or ASHRAE 90.1-2001). 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 North Dakota's commercial building energy code are modeled by comparing the characteristics of assumed current building practices with the most recent edition of the ASHRAE Standard, 90.1-2001. Both qualitative and quantitative benefits and costs are assessed in this analysis. Energy and economic impacts are estimated using results from a detailed building simulation tool (Building Loads Analysis and System Thermodynamics [BLAST] model) combined with a Life-Cycle Cost (LCC) approach to assess corresponding economic costs and benefits.

Although the State of North Dakota has a recommended minimum commercial energy code, ASHRAE 90.1-1989, local jurisdictions must formally adopt this standard as a building code in order to make it mandatory for commercial builders. Because the state of North Dakota does not have a mandatory statewide energy code, this study develops two separate baseline building types to assess the impacts, generally described as: (1) Lower-efficiency Buildings and (2) Higher-efficiency Buildings. It is assumed that the "Lower-efficiency" buildings would tend to be smaller commercial buildings that do not employ professional architectural and engineering firms to design and construct the buildings. The "Higher-efficiency" buildings are considered "well-engineered" buildings that meet or exceed the current recommended standard and are assumed to be larger commercial buildings, which employ architectural and engineering firms as part of the design and construction process.

The energy simulation and economic results of the building prototypes selected for this study suggest that adopting a standard equivalent to ASHRAE 90.1-2001 as the commercial building energy code in North Dakota would have little impact on the manner in which High-Efficiency buildings are currently built, as these buildings appear to already be meeting or exceeding most of the minimum requirements of ASHRAE 90.1-2001. Adopting ASHRAE 90.1-2001 as the minimum standard would have an impact, however, for Lower-Efficiency buildings, which may tend to use lower levels of insulation, less efficient windows, and lighting fixtures with higher electricity consumption. For the Lower-Efficiency buildings, ASHRAE 90.1-2001 could potentially provide positive net benefits relative to the current building designs and characteristics. For a few of the Low-Efficiency building types, there are no significant net economic benefits to complying with the 90.1-2001 envelope requirements; however, the ASHRAE 90.1-2001 lighting requirements appear to provide significant net economic benefits and energy savings to the building owner. In all cases for Low-Efficiency buildings, the combined envelope and lighting LCC savings of adopting all the 90.1-2001 requirements is positive relative to the base cases.

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 North Dakota is considering adopting the most recent version of the ASHRAE Standard 90.1-2001, 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.

North Dakota currently applies ASHRAE Standard 90.1-1989 as the statewide recommended building energy code; however, the local jurisdictions must adopt this standard locally in order for it to become a mandatory building code. This report is written in response to a request for technical assistance from representatives of North Dakota's Department of Commerce, Division of Community Services. The request specified the need for an objective analysis that included the impacts of code adoption on predominant commercial building types in North Dakota.

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 60% of the total value of new commercial construction in North Dakota (Census 2000b). 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 90.1-2001. Hence, the savings from these equipment requirements will generally occur regardless of the adoption of a building standard in North Dakota. 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.*

North Dakota's current statewide recommended commercial energy standard is ASHRAE Standard 90.1-1989; however, although the State of North Dakota has a recommended minimum commercial energy code, it is up to the local jurisdictions to adopt this standard as a building code in order to make it mandatory for commercial builders. Because there are very few local jurisdictions who have reportedly adopted this standard, it is unclear what level of energy efficiency components are being employed in commercial buildings currently built in North Dakota. In order to develop an appropriate baseline of current building practice, data was gathered from the NC3[1] database, and information from this database was confirmed with a regional building engineering professional in North Dakota[2]. Based on the data gathered, this study develops two separate baseline building efficiency levels, generally described as: (1) Lower-Efficiency Buildings and (2) Higher-Efficiency Buildings. It is assumed that the Lower-Efficiency buildings would tend to be smaller commercial buildings and which professional architectural and engineering firms were *not* employed to design and construct the buildings. This is not meant to suggest that all small commercial buildings are built at a lower efficiency level than larger buildings and larger building prototypes are also included with Low-Efficiency characteristics in Appendix C. The Higher-Efficiency buildings are considered "well-engineered" buildings that meet or exceed the current recommended energy standard. These buildings are assumed to be larger and, as part of the design and construction process, architectural and engineering firms were engaged. An assortment of building types that meet the High-Efficiency criteria are found in Appendix D.

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.

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[1] NC3 is a database developed by Pacific Northwest National Laboratory based on building characteristics taken from McGraw Hill/F.W. Dodge commercial building plans submitted for bidding. All data is current (submitted in the past 5 years) and the database includes over 160 buildings.

[2] The primary source of information was provided in a phone interview (December 2003) with Lon Drevecky, P.E., President, from Prairie Engineering located in Minot, North Dakota.

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.

North Dakota's first commercial energy code was adopted in 1977, which was based on ASHRAE/IES Standard 90-1975. This code remained in effect for commercial buildings until 1995 when the ASHRAE 90.1-1989 was adopted as a statewide minimum standard for state-funded commercial buildings and a voluntary standard for jurisdictions that chose to adopt an energy code.

Since the publication of ASHRAE 90.1-1989, there have been two updates: ASHRAE Standard 90.1-1999 and ASHRAE Standard 90.1-2001. For North Dakota, these updates have very similar requirements. The approach of this analysis, for the most part, is to compare the impacts of moving from the characteristics that describe a Lower-Efficiency Building to requirements that would meet 90.1-2001. The analysis also looks at certain building types that are considered Higher-Efficiency Buildings and compares the energy use and life-cycle costs of such buildings under assumed sets of characteristics. By assumption, these Higher-Efficiency buildings are characterized as already meeting or exceeding the energy efficiency criteria in 90.1-1989. All baseline characteristics are described in Section 2.2. It is assumed that the incremental impact between these various building levels adequately captures the range of impacts likely to occur in North Dakota from adopting either ASHRAE 90.1-2001 or ASHRAE 90.1-1999.

2.1 Summary of Differences between Standards

Although the quantitative analysis does not directly compare the requirements of 90.1-1989 and 90.1-2001, 90.1-1989 appears to be the basis of many of the energy-related building components that make up the High-Efficiency building characterizations included in this study. In addition, because 90.1-1989 is the current mandatory standard for state-funded buildings (which includes most education buildings) as well as the voluntary standard for privately funded commercial buildings, it is useful to observe the differences and similarities between ASHRAE 90.1-1989 and 90.1-2001.

2.1.1 Building Envelope Standard Changes between 90.1-1989 and 90.1-2001

Building envelope requirements apply to those components (e.g., walls, windows, roofs, and floors) that are separate conditioned (i.e., heated and cooled) spaces from unconditioned spaces or the outdoors. The requirements vary by climate. The portion of ASHRAE 90.1-2001 that addresses building envelope requirements includes prescriptive as well as mandatory and trade-off options. Window and door requirements specify U-factors and fenestration solar heat gain coefficients (the 90.1-1989 edition actually specified shading coefficient requirements). ASHRAE 90.1-2001 has added air leakage requirements that apply to North Dakota climates for the sealing of openings and joints in the building envelope (including windows and doors, loading docks, and vestibules). The prescriptive path of 90.1-2001 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 90.1-2001 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 90.1-2001 requirements were put more emphasis on an economic justification of energy efficiency that considers life-cycle costs as a means of balancing energy savings with the increased first cost of materials and equipment.

One other significant difference between the ASHRAE 90.1-1989 and 90.1-2001 is that ASHRAE 90.1-1989 focused on setting a requirement for “all roofs” or “all walls” or “all floors” while 90.1-2001 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 90.1-2001 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 often requires higher insulation levels for buildings that are typically constructed with less insulation than 90.1-2001 (e.g., requirements for metal-frame buildings tend to be more stringent in ASHRAE 90.1-1989 than in 90.1-2001). In addition, ASHRAE 90.1-1989 requirements are characterized based on *overall* wall thermal performance (window plus opaque wall area) while 90.1-2001 treats windows and opaque walls separately.

An additional distinction between ASHRAE 90.1-1989 and 90.1-2001 is that ASHRAE 90.1-1989 is based on a series of continuous efficiency (e.g., wall U-value) curves, leading to continuously changing requirements by climate. ASHRAE 90.1-2001 envelope requirements were based on real building assemblies and hence have U-values that reflect real and typical assemblies and construction components. Thus, the1989 standard may have wall insulation requirements of R-5.4, R-7.2, R-8.6, R 9, R-10, and R-11.3 for different locations where 90.1-2001 would have fewer distinct requirements (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[3]. To meet the 90.1-2001 requirements, only commonly 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.

[3] 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.

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 90.1-1989 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 to provide similar representation in ASHRAE 90.1-1989. This provides the most directly comparable basis between the two standards.

The mandatory provisions in 90.1-2001 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 90.1-2001 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 2001 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 90.1-2001*

Whole Building Method Lighting Power Densities (W/ft^2)			Space-by-Space Method Lighting Power Densities		
Building Type	90.1-2001	90.1-1989	Space Type	90.1-2001	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[4]. The climate zones in North Dakota range from around 2144 cooling degree-days (CDD) and 8657 heating degree-days (HDD) in Dickinson to 1973 CDD and 9950 HDD in Devils Lake.

2.2.2 Demographic

North Dakota has a population of approximately 640,000 people. Fargo is the largest city, with approximately 90,000 people and is one of few cities that has experienced positive growth in recent years. From 1990 to 2000, North Dakota's population grew by 0.5% (Census 2000a). In 1997 the value of new commercial construction in North Dakota was approximately $350 million. Office, retail, and education buildings contributed to over half the total value of new construction in that year (Census 2000b).

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

2.2.3 Commercial Construction Characteristics

Because there are very few local jurisdictions who have reportedly adopted the voluntary 90.1-1989 standard, it would not seem reasonable to assume that all commercial buildings are built to the specifications prescribed in 90.1-1989. In order to develop an appropriate baseline of current building practice, data was gathered from the NC3 database, and information from this database was confirmed with a regional building engineering professional in North Dakota.

The NC3 database contains very specific and detailed data on the various energy related components of new building construction. This includes details on space heating, cooling, water heating, lighting, insulation, controls, structure, and materials as they are currently applied in new commercial building construction. Data is compiled from building plans taken from buildings that are in the final bid process where plans and specifications are complete and construction is anticipated to start within a year or two. The specific source of these sets of building plans and specs is the F.W. DODGE Plans division of McGraw-Hill. Although limited in number (currently contains 162 buildings), this data provides at least a partial representation of current building practices. This database was queried for all commercial buildings in relatively cooler northern climates, similar to North Dakota that had not recently adopted mandatory commercial building energy codes.

Information regarding wall, floor, and roof insulation levels was extracted from the database, as well as average window u-values and solar heat gain coefficients. In addition, general construction characteristics were developed that provided information regarding common building practices such as types of roofs (e.g., built-up flat roofs versus metal roof decking), walls (e.g., masonry versus steel framing), and window-to-wall ratios. Information on lighting levels (watts/s.f.) was also extracted by building type. Although changes in HVAC equipment are not covered in this report, information was gathered on the type of HVAC equipment and systems that are commonly installed in northern climates.

In each category, the results of the database query indicated that most building types appeared to fall into one narrow range of insulation; however outliers were found in each category. For each building component, questions were asked of building engineering consultant from North Dakota (survey questions found in Appendix B). The consultant provided his expert opinion regarding the level of insulation and types of components that he believed represented current building practices in North Dakota.

The results of the database query and the consultant's expert opinion were combined to develop two separate base cases: (1) Lower-Efficiency Buildings and (2) Higher-Efficiency Buildings. Low-Efficiency buildings are assumed to include smaller office buildings and retail strip malls for which professional architectural and engineering firms were not used to design and construct the buildings. The Higher-Efficiency buildings are assumed to include larger office buildings, large retail buildings and school buildings, which meet or exceed the current 90.1-1989 voluntary standard. It is assumed that architectural and engineering firms were employed in the design and construction process of these buildings.

2.2.4 Energy Consumption and Sources

North Dakota consumes approximately 365 trillion Btu of energy each year and approximately 12% of this energy is consumed by the commercial buildings sector. Natural gas is the primary energy source for commercial building heating in North Dakota. Coal is the primary fuel used to generate electricity in North Dakota, making up over 90% of the total net generating capacity in 1999 (EIA 2003c).

2.3 Assumptions

North Dakota is one of the nation's coldest states, with heating degree days over 9,000 for many of the towns and cities. The climate of Fargo is used to simulate energy use in buildings, as Fargo is North Dakota's largest city and has a climate reasonably representative of many of the state's other jurisdictions. Fargo has an HDD of 9,254 and a CDD of 2,289. The weather data actually used in this simulation analysis is taken from the Typical Meteorological Year (TMY2) weather data set.

This study focuses on three different commercial building types: office, retail, and education. Five building design prototypes are characterized and assessed. All buildings are characterized as rectangular buildings; however, they vary in size and window-to-wall ratios. A relatively small (1-story, 10,000 square foot) office building and a larger office building (3 floors, 60,000 square feet) are simulated and the larger-sized office is simulated with two separate window-to-wall ratios. Also, a 24,000 square foot, single-story ("big box") 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
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 (Elementary Style Design)	18%	50,000	1	6

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

It is assumed that the Low-Efficiency base building type is built with wall insulation of about R-10 and roof insulation about R-15. The windows for the Low-Efficiency buildings are assumed to be equivalent to a metal framed, double-paned window that does *not* have a low-e coating. For the High-Efficiency building types, the walls are assumed to be insulated to an R-16 level and the roofs are insulated at a minimum of R-20. The windows in the High-Efficiency building types are assumed to be equivalent to a metal-framed, double-paned, thermally broken window with some form of a low-e coating.

It is assumed that all 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 2003 dollars, unless otherwise specified.

3.0 Energy Analysis

Annual energy use simulations were made using the BLAST building engineering model, 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 simulations were based on a 3-story prototype building with fifteen thermal zones. Each simulation utilized a specific combination of either "Low-Efficiency," or "High-Efficiency" characteristics and then was compared against a simulation using 90.1-2001 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 Fargo 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 (windows); and Solar Heat Gain Coefficient requirements. Because slab insulation requirements are not included in ASHRAE 90.1-2001, changes in slab insulation are not examined in this study. These characteristics were determined for each of the building types and requirement changes. Table 3 presents the assumed baseline characteristics for Low-Efficiency and High-Efficiency commercial buildings, which were developed based on information gathered from the NC3 database and confirmed as reasonable by a building engineer consultant in North Dakota. The simulated U-factors are also included for each building type in the tables in Appendixes C and D.

Table 3. *Envelope Characteristics of Low-Efficiency and High-Efficiency Baselines*

	Low-Efficiency Base	**High-Efficiency Base**
Wall U-Factor	.10	.062
Roof U-Factor	.74	.048
Window U-Factor	.72	.65
Shading Coefficient	.84	.67

3.2.2 Lighting Inputs

The lighting power density requirements were developed from the whole building lighting requirements for both ASHRAE 90.1-1989, ASHRAE 90.1-2001 and based on current practice data gathered from the NC3 database for comparable building types. The 90.1-2001 standard provides single value whole building lighting power density values for fourteen different building types.

The 90.1-2001 lighting requirements provide single value, whole building, LPD requirements for office, retail, and school buildings, and these requirements were used in the simulations. Table 4 shows a comparison of the Whole Building lighting assumptions made for the Low-Efficiency base case and the High-Efficiency base case as well as for the requirements under both ASHRAE 90.1-1989 and 90.1-2001.

Table 4*. Lighting Power Density (Watts/sq. ft)*

Building Type	Low-Efficiency Base	High-Efficiency Base	90.1-1989	90.1-1999
Education	1.79	1.5	1.79	1.50
Offices	1.63	1.3	1.63	1.30
Retail	2.36	1.9	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. DOE's overall comparison of the improvements in mechanical system efficiencies between ASHRAE 90.1-1989 and 90.1-2001, nationwide, results in a 2.2% efficiency improvement in whole building Electric EUI and 3% efficiency improvement in Gas EUI[5].

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 90.1-2001 on heating energy use would principally be determined by changes in heating loads rather than equipment efficiency.

Cooling

[5] 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).

In the case of cooling equipment, the average efficiency of cooling equipment, based on shipped capacity of the different cooling equipment types used in commercial buildings, 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 90.1-2001 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 the base case and for ASHRAE 90.1-2001.)

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[6].

The current average gas and electricity prices for North Dakota were obtained from the Energy Information Administration (EIA) and are listed in Table 5 (2003). Based on the

[6] 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 2003 forecasts (EIA 2003b) 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.

***Table 5**. Commercial Average Annual Fuel Rates in North Dakota*

Average Annual Price of Natural Gas (2003)	Average Annual Price of Electricity (2003)
$7.24/thousand cubic feet	$.060/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 Cost 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 2003 dollars 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, and 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.

4.2 Lighting Cost Analysis

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[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.

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 characteristics between the baseline and 90.1-2001, 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 going from a Low-Efficiency base (the High-Efficiency base case is assumed to already meet the 90.1-2001 lighting requirements) to the more stringent requirements of 90.1-2001 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 90.1-2001 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 90.1-2001 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. The models also serve as the basis for comparison with other standards or current practice scenarios.

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

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

The assignment of differences in power densities between 90.1-2001 and the base case 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 6.

Table 6. *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 90.1-2001 standard are well defined through the use of the space type models as described above, the development of capital costs for lighting meeting the base case characteristics is based upon a substitution of less efficient technologies than those used to comply with the 2001 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.

As a first step, cost estimates were developed for the linear fluorescent and incandescent/CFL applications for both the 90.1-2001 standard based upon the ASHRAE Models. The less efficient technologies associated with the Low-Efficiency base case levels were then substituted into the same 90.1-2001 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. 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.

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 base cases and 90.1-2001 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 C and D[9].

This section presents the estimated energy and economic impacts between two separate base cases and ASHRAE 90.1-2001 building standards for the selected set of buildings. Three separate variations of the 2001 standard are compared with the base case characteristics: 1) Changing only requirements related to the building envelope; 2) Changing only lighting requirements; and 3) Changing both envelope and lighting requirements. This methodology helps to better understand how the energy and economic impacts are linked to various aspects of the standards. The combined lighting and envelope case shows the degree to which interaction between the envelope and lights affect the overall impacts.

5.1 The Low-Efficiency Buildings Base Case

As discussed in Section 2.3 and 3.2, two separate base cases are modeled to capture the range of impacts based on current construction practices in the commercial sector of North Dakota. The Low-Efficiency base case is characterized by a small office building, with a window-to-wall ratio of 18%. A retail building is also described and modeled under the Low-Efficiency base case. Although the smaller retail building and small office building appeared to be the most likely types of buildings to be built at the Low-Efficiency level, additional building types are modeled with Low-Efficiency characteristics and the results are all included in Appendix C. 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 North Dakota. 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,

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[9] 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).

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

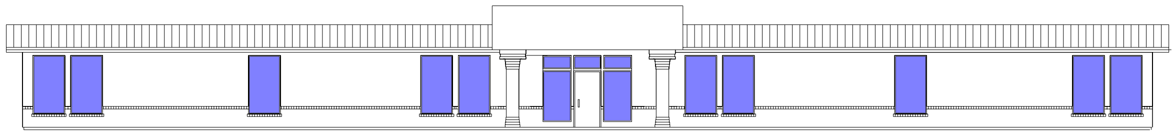

Figure 1. Office Building – 10,000 s.f. with 18% window-to-wall ratio

Base Case

The column under the heading "Low Base" shows the thermal building component characteristics and estimated costs for each of the major envelope components. Windows have both thermal performances (U-factor) and solar heat gain coefficients (SHGC). The specific characteristics under the Low Base 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 SHGC specified characteristics. 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 $4.94.

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 to achieve the specified thermal performance. Total cost is shown in the last line of the first panel—in this case $18,541. 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 and the Low-Efficiency base case 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 requirements of 90.1-2001. Given this qualification, the total lighting cost for the building is $15,670.

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

Small Office (WWR=0.18)

Bldg. Size	**10,000 sq. ft.**		Standard Level			
			Low Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	1,014	U-factor(std)	0.720	0.460		0.460
		sh. coef.(std)	0.840	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.72	0.461		0.461
		sh. coef.(cost)	0.836	0.423		0.423
		cost ($/sqft)	$4.94	$10.23		$10.23
Opaque Walls	4,619	U-factor	0.1	0.064		0.064
		cost ($/sqft)	$0.59	$0.99		$0.99
Roof	10,000	U-factor	0.074	0.063		0.063
		cost ($/sqft)	$1.08	$1.20		$1.20
	(feet)					
Envelope Cost (incremental)			$18,541	$26,936		$26,936
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.75	$1.75
Total Lighting Cost			$15,670		$17,504	$17,504
Construction Cost			$34,211	$42,606	$36,045	$44,440
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	102	83	93	74
Natural Gas		MMBtu	153	112	171	128
Total Annual Energy Cost			$8,464	$7,844	$7,742	$7,102
Economic Measures						
Life-Cycle Cost Savings				**($900)**	**$6,838**	**$6,225**
Savings-to-Investment Ratio (SIR)				0.9	3.6	1.5
Adjusted IRR				6.7%	10.5%	8.1%

Notes:

1 **No economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /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 $8,464 is based upon fuel prices for 2003. 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 90.1-2001. The U-factor requirements are all more stringent than the current practices that make up the Low-Efficiency base case. To achieve the higher efficiency, first costs for envelope increases from $18,541 to $26,936. Window costs make up $5,200 of this increase.

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 19 MMBtu, a result achieved from improvements in wall and roof insulation and the reduced solar gain through the windows. Natural gas consumption also falls as a result of the improved thermal performance of envelope components. Annual fuel costs decline by $620 per year.

Calculated life-cycle costs are about $900 higher as compared to the base case. The life-cycle costs include the increase in first costs of $8,428 less the ongoing energy cost savings discounted over the 40-year study period. This analysis does not provide for any additional reduction in total installed HVAC installation costs that might occur in the more insulated building. Although the calculated LCC savings are negative, this result is dependent on the presumed 7% discount rate. The Adjusted Internal Rate of Return (AIRR)[10] is 6.7%, which, depending on a business' investment strategy, may be high enough to justify the first cost investments. Considering that a slight change in the assumptions regarding such things as thermostat settings, internal gains (e.g., electronic equipment in building), and infiltration rates could result in a positive LCC, this results is relatively uncertain with regards to whether or not the envelope measures provide net economic benefits.

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

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

49 MMBtu per year for the lighting-only case. About 20% 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. In combination with the reduced electricity use for the lighting, total fuel costs decline by about $700 per year.

All three economic measures show that the more stringent lighting requirements associated with 90.1-2001 standards are highly cost effective. Life-cycle cost savings are nearly $7,000. The savings-to-investment ratio is over 3.6. 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%.[11]

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 90.1-2001 standard. Annual energy expenditures are about $1400 lower than the base case; life-cycle cost savings are about $6,000. Note that the sum of the savings (from envelope and lighting changes) is greater than the LCC savings measured separately. This is because the reduction in lighting loads raises the balance point of the building and makes the envelope measures more cost-effective.

[11] 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.

5.1.2 Retail

Table 8 shows the 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 office buildings due, in large part, to higher lighting levels. 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 base case and 2001 standard. Even under the assumption that the reduction in LPD between the base case 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 3.7 and the adjusted IRR is over 10%.

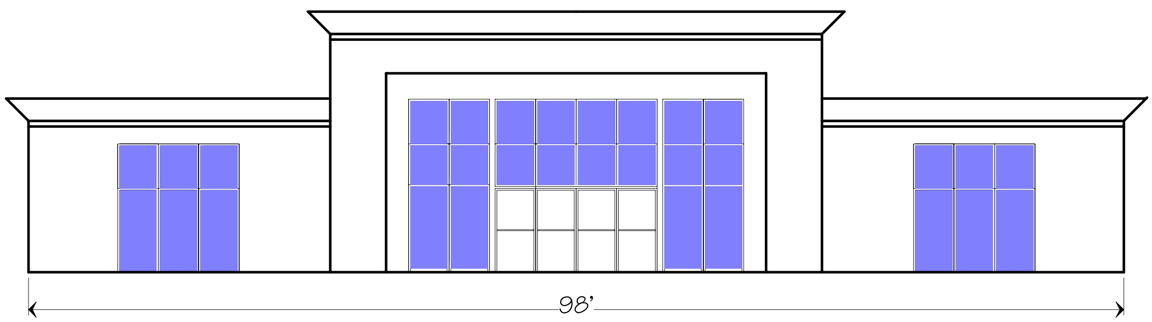

Figure 4. Retail Building – 24,000 s.f. with 7% window-to-wall ratio

For the envelope-only case, although the requirements for the window U-factor and solar heat gain coefficient are more stringent under the 90.1-2001 standard as compared with the current Low-Efficiency practices, the smaller window area in most retail buildings (simulated here with a window-to-wall ratio of 0.07) diminishes the influence of this requirement on total energy use. The net effect is an increase in life-cycle cost of $3,787. The combined effect of lighting and envelope, however, is a net decrease in life-cycle cost of just over $25,000 relative to the base case.

***Table 8**. Engineering and Cost Summary*

Retail

Bldg. Size	24,000 sq. ft.		Standard Level			
			Low Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	624	U-factor(std)	0.720	0.460		0.460
		sh. coef.(std)	0.840	0.570		0.570
(Window-Wall Ratio = 0.07)		U-factor(cost)	0.72	0.517		0.517
		sh. coef.(cost)	0.836	0.490		0.490
		cost ($/sqft)	$4.94	$9.49		$9.49
Opaque Walls	8,292	U-factor	0.1	0.064		0.064
		cost ($/sqft)	$0.59	$0.99		$0.99
Roof	24,000	U-factor	0.074	0.063		0.063
		cost ($/sqft)	$1.08	$1.20		$1.20
Envelope Cost (incremental)			$33,907	$42,916		$42,916
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			$71,629	$80,637	$77,066	$86,075
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	900	900	754	754
Electricity, HVAC		MMBtu	220	217	184	180
Natural Gas		MMBtu	151	98	193	129
Total Annual Energy Cost			$20,616	$20,196	$17,735	$17,213
Economic Measures						
Life-Cycle Cost Savings				**($3,787)**	**$27,718**	**$25,325**
Savings-to-Investment Ratio (SIR)				0.6	3.7	2.3
Adjusted IRR				5.7%	10.6%	9.2%

Notes:

1 **No economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**

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

Life-cycle cost savings includes replacement costs and residual values

5.2 The High-Efficiency Buildings Base Case

The High-Efficiency base case is primarily characterized by larger office buildings and government buildings, such as school buildings; however, it also could include some well-engineered smaller office buildings and retail buildings. Detailed results for all of these building prototypes are included in Appendix D.

5.2.1 Large Office Building

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. Two variations in the window-to-wall ratio (18% and 38%) were considered.

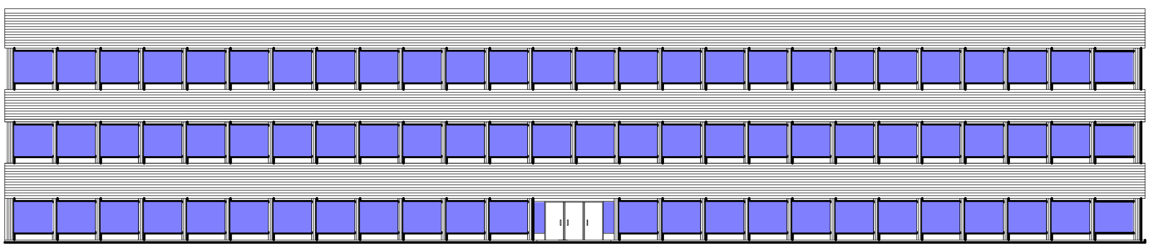

Figure 3. Office – 60,000 s.f. with 3 stories and 38% window-to-wall ratio

Base Case

It Table 9, the column under the heading "High Base" shows the thermal building component characteristics and estimated costs for each of the major envelope components under the High-Efficiency base case. The specific characteristics under the High Base are designated in the top two lines labeled (std). The current costing methodology for windows generally selects the window type that meets the performance characteristics of the High-Efficiency baseline and the standard at the lowest cost. Using the weighting procedure described in 5.1.1, a representative cost per square foot of glazing was estimated to be $6.13.

Total cost is shown in the last line of the first panel—in this case $76,940. 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 9 summarizes the key inputs related to lighting. As discussed in Section 4, the lighting power density for large offices under the High-Efficiency base case was assumed to meet the 90.1-2001 standard requirements of 1.30 watts per square foot; thus, the base case lighting costs, $1.75 per square foot, are the same under both the base case and the standard.

Table 9. Engineering and Cost Summary

Large Office (WWR=0.18)

Bldg. Size	**60,000 sq. ft.**		Standard Level			
			High Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	4,302	U-factor(std)	0.650	0.460		0.460
		sh. coef.(std)	0.670	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.67	0.461		0.461
		sh. coef.(cost)	0.564	0.423		0.423
		cost ($/sqft)	$6.13	$10.23		$10.23
Opaque Walls	19,598	U-factor	0.062	0.064		0.064
		cost ($/sqft)	$1.05	$0.99		$0.99
Roof	20,000	U-factor	0.048	0.063		0.063
		cost ($/sqft)	$1.50	$1.20		$1.20
Envelope Cost (incremental)			$76,940	$87,386		$87,386
Lighting						
Lighting Power Density		watts/sqft	1.30		1.30	1.30
Lighting Cost		$/sqft	$1.75		$1.75	$1.75
Total Lighting Cost			$105,026		$105,026	$105,026
Construction Cost			$181,966	$192,412	$181,966	$192,412
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,687	1,687	1,687	1,687
Electricity, HVAC		MMBtu	407	356	407	356
Natural Gas		MMBtu	500	492	500	492
Total Annual Energy Cost			$40,091	$39,140	$40,091	$39,140
Economic Measures						
Life-Cycle Cost Savings				**($126)**	**$0**	**($126)**
Savings-to-Investment Ratio (SIR)				1.0	Invest. < 0	1.0
Adjusted IRR				7.0%	Invest. < 0	7.0%

Notes:

1 **Economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**

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

Life-cycle cost savings includes replacement costs and residual values

The bottom panel in Table 9 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 $40,091 is based upon fuel prices for 2003. 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 90.1-2001. Although some well-engineered buildings are most likely already meeting the U-factor requirements of the 90.1-2001 standard, it is possible that a number are not considering that that U-factor and SHGC requirements were significantly modified between the 1989 and 2001 versions of the ASHRAE standard. It is therefore assumed that the ASHRAE 90.1-2001 standard would require slightly lower U-factors and SHGC than is current practice. As for the wall and roof insulation requirements, it is assumed that the High-Efficiency base case practices exceed the insulation requirements of 90.1-2001, thus no additional first costs would be required to meet the insulation requirements. To achieve the higher efficiency of the window, however, first costs for envelope increases from $76,940 to $87,386.

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 51 MMBtu, a result achieved primarily from the reduced solar gain through the windows. Natural gas consumption also falls as a result of the improved thermal performance of the windows. Annual fuel costs decline by $951 per year.

Life-cycle costs are essentially the same as compared to the base case (only $126 higher). The life-cycle costs include the increase in first costs of $10,446 less the ongoing energy cost savings discounted over the 40-year study period.

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 90.1-2001 standard. As there are no lighting impacts due the assumption that the High-Efficiency buildings are already meeting 2001 requirements, the total LCC savings is equal to the envelope-only case.

5.2.2 Education

An education building, which resembles the style of many of the new elementary school buildings currently built, was analyzed. With the relatively low window-to-wall ratio (0.18) the ASHRAE 90.1-2001 standard may call for slight improvements in the shading coefficient over the High-Efficiency base case, which is meant to depict current practices.

This impact would be similar to those described for the office building. 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. On a cost basis, the life-cycle savings increase under ASHRAE 90.1-2001 for the school building.

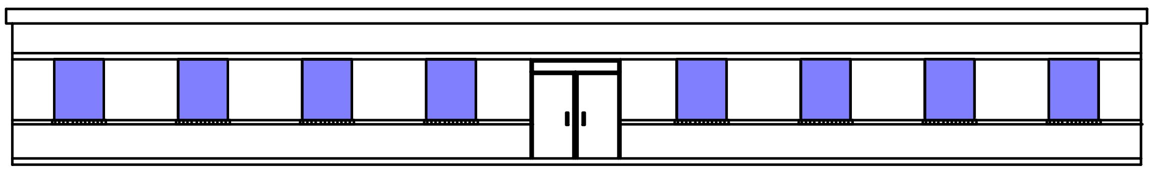

Figure 5. Education Building (Elementary) – 50,000 s.f., 18% window-to-wall ratio

Figure 4 illustrates a 50,000 square foot, single-story school building with the characteristics of those used to model energy-use in school buildings. Table 10 describes the energy and economic results of the same building.

***Table 10**. Engineering and Cost Summary*

Education (elementary)

Bldg. Size	**50,000 sq. ft.**		Standard Level			
			High Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	2,991	U-factor(std)	0.650	0.460		0.460
		sh. coef.(std)	0.670	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.67	0.461		0.461
		sh. coef.(cost)	0.564	0.423		0.423
		cost ($/sqft)	$6.13	$10.23		$10.23
Opaque Walls	13,624	U-factor	0.062	0.064		0.064
		cost ($/sqft)	$1.05	$0.99		$0.99
Roof	50,000	U-factor	0.048	0.063		0.063
		cost ($/sqft)	$1.50	$1.20		$1.20
Envelope Cost (incremental)			$107,722	$104,035		$104,035
Lighting						
Lighting Power Density		watts/sqft	1.50		1.50	1.50
Lighting Cost		$/sqft	$1.95		$1.95	$1.95
Total Lighting Cost			$97,629		$97,629	$97,629
Construction Cost			$205,351	$201,664	$205,351	$201,664
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	915	915	915	915
Electricity, HVAC		MMBtu	301	273	301	273
Natural Gas		MMBtu	1,443	1,481	1,443	1,481
Total Annual Energy Cost			$31,406	$31,194	$31,406	$31,194
Economic Measures						
Life-Cycle Cost Savings				**$5,682**	**$0**	**$5,682**
Savings-to-Investment Ratio (SIR)				Invest. < 0	Invest. < 0	Invest. < 0
Adjusted IRR				Invest. < 0	Invest. < 0	Invest. < 0

Notes:
1 **No economizer used**
2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**
3 **Years for Analysis = 40** **Discount Rate = 7.0%**
Life-cycle cost savings includes replacement costs and residual values

5.3 Other Factors Impacting Benefits and Costs

There are numerous areas of ASHRAE 90.1-2001 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 90.1-2001 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 90.1-2001 are difficult to evaluate. Air leakage requirements for windows are more stringent in the 2001 edition for four window types and less stringent in one other window type. In addition, some door types are more stringent in the 2001 edition, while others are not. ASHRAE 90.1-2001, however, also includes requirements for loading dock weather seals and vestibules, which would be applicable in North Dakota. The impact of air leakage requirement differences between ASHRAE 90.1-1989 and 90.1-2001 are difficult to evaluate. However, the net effect of these requirements is expected to improve energy efficiency with the ASHRAE 90.1-2001 relative to the 1989 edition.

ASHRAE 90.1-2001 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 2001 edition bans installation of insulation on suspended ceilings with removable ceiling panels. The 1989 edition does not address these subjects. The ASHRAE 90.1-2001 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 90.1-2001 has no such requirements. This is expected to result in higher heating loads in cold climates with ASHRAE 90.1-2001 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 90.1-2001 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 90.1-2001 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 90.1-2001 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 2001 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 90.1-2001. On the other hand, there are also a number of narrowly-targeted exemptions in the 2001 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 90.1-2001 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 90.1-2001; 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 90.1-2001 within a relatively short time frame. Chillers, however, which are not covered under manufacturing standards, have significantly higher efficiencies under 90.1-2001. In addition, 90.1-2001 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 90.1-2001 include more stringent performance requirements for variable speed fan systems as well as the addition of requirements for heat recovery. In terms of usability, the 90.1-2001 Standard has dropped much of the non-enforceable language as well as some difficult to enforce requirements (like system sizing) that were in the 90.1-1989 standard. A description of these and other differences between the mechanical system requirements 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 90.1-2001 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 additions, alterations, or reconstruction in North Dakota was about $200 million in 1997, as compared to new building construction valued at $350 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 nearly 60% more savings than if it were applied exclusively to new buildings.

6.0 Qualitative Considerations

In comparing ASHRAE 90.1-2001 to ASHRAE 90.1-1989, various revisions have been made in an effort to make the standard clearer and easier to enforce. For example, the inclusion of specific direction on how to calculate luminaire power in Standard 90.1-2001 is expected to eliminate some under-calculation of lighting power, which may lead to greater energy savings. In addition, various language and formatting changes have been made to make the standard easier to apply.

While the ASHRAE 90.1-1989 Standard provided climate-specific guidance by using example cities, the ASHRAE 90.1-2001 Standard provides requirements in terms of "climate bins" that cover a larger area. This allows builders to more easily find an appropriate climate for the area in which they are building. The ASHRAE 90.1-2001 Standard also simplifies the code compliance for smaller-scale construction by providing a "Simplified Approach Option for HVAC Systems." This section condenses the mechanical system requirements for a large class of simple systems.

ASHRAE Standard 90.1-2001 is written in mandatory, enforceable language. ASHRAE Standard 90.1-1989 contains guidance written as suggestive statements, which may complicate enforcement and compliance if not properly defined and revised. ASHRAE 90.1-2001 also provides specific guidance for applying the code to existing building alterations and additions. From an energy savings standpoint, changes that make ASHRAE Standard 90.1-2001 easier to understand and enforce may have a positive impact on energy savings.

7.0 Conclusions

The results of this limited study appear to suggest that even though there is currently no mandatory statewide energy code in North Dakota, many architectural and engineering firms design and construct commercial buildings that meet or exceed these requirements prescribed in the latest edition of ASRHAE, 90.1-2001. Windows may be the one exception in that adoption of 90.1-2001 would require improvements in the thermal integrity and SHGC of windows installed in High-Efficiency buildings. Although the net economic impact of these higher-efficiency windows appeared negligible for the large office building with a lower moderate window-to-wall ratio that was modeled in the study, the net economic benefits appear to be positive for the education building and offices with high window-to-wall ratio. In general, it appears that updating the current recommended standard would have small positive impacts, both in terms of economic and energy savings for buildings conforming to our High-Efficiency prototypes.

However, there appears to be a portion of the new commercial construction market for which many buildings are built with lower overall efficiency (Low-Efficiency buildings). For these building types--smaller offices, retail strip malls, and other small commercial buildings--the updated ASHRAE 90.1-2001 standard would have net benefits. These benefits are most likely achieved only if the code is adopted and enforced at a local level. Figure 6 provides a comparison of the LCC savings per square foot by building type for the lighting requirements and envelope requirements, individually and together for building prototypes in North Dakota, assuming a High-Efficiency building as the base case, while Figure 7 illustrates LCC savings for buildings simulated using the Low-Efficiency Building as the base case.

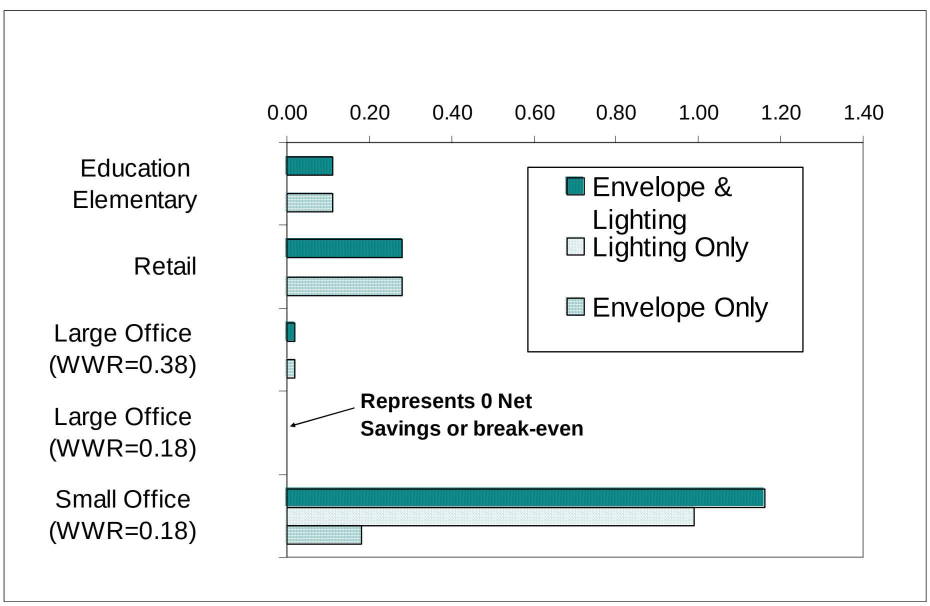

Figure 6. *A Comparison of Life Cycle Cost Saving Per Square Foot for Different Types of Buildings (Under the High-Efficiency Base Case Scenario)*

The lighting requirements of 90.1-2001 appear to be highly cost-effective for these building types, particularly those that are being built at a Low-Efficiency level. When lighting and envelope requirements are combined, all of the Low-Efficiency buildings simulated display savings in energy use, annual fuel cost, and life-cycle costs.

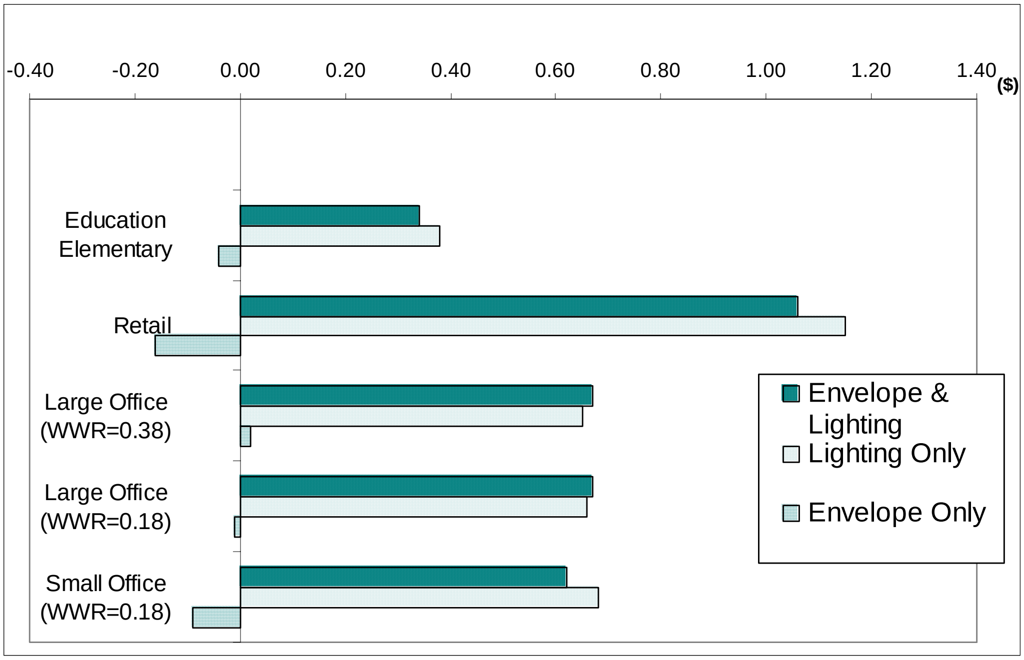

Figure 7. *A Comparison of Life Cycle Cost Saving Per Square Foot for Different Types of Buildings (Under the Low-Efficiency base case scenario)*

Perhaps one of the most compelling arguments for considering the adoption of the updated 90.1-2001 standard would include the qualitative benefits described in Section 6. Considering that North Dakota's building energy standard is voluntary, some of the changes that have been made to the standard to make it easier to understand and use may make it a more desirable standard for local jurisdictions to adopt.

8.0 References

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Appendix A

Glossary of Selected Terms

Glossary

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

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

(a) ***building envelope, exterior***: the elements of a building that separate conditioned space from the exterior.

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

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

Current Building Practices in North Dakota
Survey for Building Professionals
January 2004

We are trying to collect information on current practices in commercial building construction in the state of North Dakota in order to appropriately design an updated building energy code for the State. The State of North Dakota currently recommends ASHRAE Standard 90.1-1989 as the commercial building energy code. There are different compliance paths that a builder can take to meet the code, so simply assuming that commercial buildings "meet code" is not sufficient to determine how those buildings are being built and what their energy use characteristics will be. The State of North Dakota is working with the U.S. Department of Energy and Pacific Northwest National Laboratory to determine how commercial buildings are really built in North Dakota.

These questions are intended to be answered using your best judgment, based on buildings you have inspected in recent years. Your assistance in collecting this data is greatly appreciated.

Building Envelope (Roofs, walls, and insulation)

E-1) Generally speaking, what is the percentage split between dark and light-colored roofs for new commercial construction?

____% dark

____% light

____ don't know.

E-2) In your opinion, to what level are the roofs of new commercial buildings insulated? Please estimate the percentage of buildings that are insulated at the following levels (estimate the R-Value of the insulation by itself without other roofing material factored in):

Built-up Flat Roof (insulation above deck)	**% of buildings**	**Metal Roof Deck, Low-Slope**	**% of buildings**	**Attics and Other**	**% of buildings**
Less than R-6		Less than R-6		R-11	
R-6 to R-9		R-6		R-13	
R-10 to R-13		R-10		R-15	
R14-R-18		R-11		R-19	
R-19-R-22		R-16		R-21	
R-23 to R-29		R-19		R-30 or greater	
Greater than R-29		Other		Other	
Don't know		Don't know		Don't know	

E-3) In your opinion, to what level are the walls of new commercial steel-framed buildings (i.e. buildings where insulation is installed within a cavity between steel framing members with no metal exterior surface spanning member) insulated? Please estimate R-value of wall insulation alone without factoring in other insulating characteristics of wall assembly (i.e., a building with no insulation has an R-value of R-0). Please estimate the percentage of buildings that are insulated at the following levels:

STEEL-FRAMED BUILDINGS			
Wall Cavity Insulation Thickness	**% of buildings**	**Exterior Insulation**	If you do not feel you have enough information to answer the questions in this column, please fill in blanks with question marks (?).
R-0 ➔		Of all the buildings with R-0 wall cavity insulation, what percent of these buildings have: ➔	No continuous insulation on exterior? ______% One inch or more on exterior wall? ________%
R-1 to R-5 ➔		Of all the buildings with R-1 to R-5 wall cavity insulation, what percent of these buildings have: ➔	No continuous insulation on exterior? ______% One inch or more on exterior wall? ________%
R-6 to R-9 ➔		Of all the buildings with R-6 to R-9 wall cavity insulation, what percent of these buildings have: ➔	No continuous insulation on exterior? ______% One inch or more on exterior wall? ________%
R-10 to R-13 ➔		Of all the buildings with R-10 to R-13 wall cavity insulation, what percent of these buildings have: ➔	No continuous insulation on exterior? ______% One inch or more on exterior wall? ________%
R-14 to R-18 ➔		Of all the buildings with R-14 to R-18 wall cavity insulation, what percent of these buildings have: ➔	No continuous insulation on exterior? ______% One inch or more on exterior wall? ________%
R-19 to R-21 ➔		Of all the buildings with R-19 to R-21 wall cavity insulation, what percent of these buildings have: ➔	No continuous insulation on exterior? ______% One inch or more on exterior wall? ________%
Above R-21 ➔		Of all the buildings with wall cavity insulation above R-21, what percent of these buildings have: ➔	No continuous insulation on exterior? ______% One inch or more on exterior wall? ________%
Don't know			Don't know _____

E-4) In your opinion, to what level are the walls of new commercial masonry or concrete (mass) buildings insulated? Please estimate R-value of wall insulation alone without factoring in other insulating characteristics of wall assembly (i.e,. a building with no insulation has an R-value of R-0). Please estimate the percentage of buildings that are insulated at the following levels:

MASONRY/CONCRETE BUILDINGS			
Insulation Thickness	**% of buildings**	**Technique**	If you do not feel you have enough information to answer the questions in this column, please fill in blanks with question marks (?).
R-0 ➔		Of all the buildings with R-0 wall insulation, what percent of these buildings have: ➔	Inside fibrous or cavity insulation? ______% Continuous insulation? ________%
R-1 to R-5 ➔		Of all the buildings with R-1 to R-5 wall insulation, what percent of these buildings have: ➔	Inside fibrous or cavity insulation? ______% Continuous insulation? ________%
R-6 to R-9 ➔		Of all the buildings with R-6 to R-9 wall insulation, what percent of these buildings have: ➔	Inside fibrous or cavity insulation? ______% Continuous insulation? ________%
R-10 to R-13 ➔		Of all the buildings with R-10 to R-13 wall insulation, what percent of these buildings have: ➔	Inside fibrous or cavity insulation? ______% Continuous insulation? ________%
R-14 to R-18 ➔		Of all the buildings with R-14 to R-18 wall insulation, what percent of these buildings have: ➔	Inside fibrous or cavity insulation? ______% Continuous insulation? ________%
R-19 to R-21 ➔		Of all the buildings with R-19 to R-21 wall insulation, what percent of these buildings have: ➔	Inside fibrous or cavity insulation? ______% Continuous insulation? ________%
Above R-21 ➔		Of all the buildings with wall insulation above R-21, what percent of these buildings have: ➔	Inside fibrous or cavity insulation? ______% Continuous insulation? ________%
Don't know			Don't know _____

E-5) Is it common practice to insulate the slab of commercial buildings?

Yes _______

No ________

Don't know ______

E-6) Please describe the characteristics of windows that are installed and estimate the percentage of buildings that have window-to-wall ratios (WWR) that are: (1) Less than 10%; (2) Between 11% and 40%; or (3) Above 40% for the following building types:

OFFICE BUILDINGS

	WWR less than 10%	**WWR Between 11% and 40%**	**WWR Above 40%**
Estimate the % ➔	______________%	_____________%	_____________%
	Check one for each question below.	Check one for each question below.	Check one for each question below.
Are the windows in the following WWR categories typically single pane or double pane? ➔	_____single pane _____double pane _____about 50/50 split _____don't know	_____single pane _____double pane _____about 50/50 split _____don't know	_____single pane _____double pane _____about 50/50 split _____don't know
Are the windows in the following WWR categories typically tinted or clear? ➔	_____tinted _____clear _____about 50/50 split	_____tinted _____clear _____about 50/50 split	_____tinted _____clear _____about 50/50 split
Are most of the windows in the following WWR categories Low-E windows? ➔	____Yes ____No ____About half are low-e and half are not ____Don't know	____Yes ____No ____About half are low-e and half are not ____Don't know	____Yes ____No ____About half are low-e and half are not ____Don't know
Are the windows in the following WWR categories typically framed with wood, vinyl, or metal? ➔	____wood ____vinyl ____metal ____Don't know	____wood ____vinyl ____metal ____Don't know	____wood ____vinyl ____metal ____Don't know
	Fill in blanks below if information available.	Fill in blanks below if information available.	Fill in blanks below if information available.
If you are comfortable estimating an average solar heat gain coefficient (SHGC), shading coefficient (SC) and/or U-Value , please list: ➔	_______U-Value _______SHGC _______SC	_______U-Value _______SHGC _______SC	_______U-Value _______SHGC _______SC

SCHOOL BUILDINGS

	WWR less than 10%	WWR Between 11% and 40%	WWR Above 40%
Estimate the % ➔	______________%	______________%	______________%
	Check one for each question below.	Check one for each question below.	Check one for each question below.
Are the windows in the following WWR categories typically single pane or double pane? ➔	_____single pane _____double pane _____about 50/50 split _____don't know	_____single pane _____double pane _____about 50/50 split _____don't know	_____single pane _____double pane _____about 50/50 split _____don't know
Are the windows in the following WWR categories typically tinted or clear? ➔	_____tinted _____clear _____about 50/50 split	_____tinted _____clear _____about 50/50 split	_____tinted _____clear _____about 50/50 split
Are most of the windows in the following WWR categories Low-E windows? ➔	____Yes ____No ____About half are low-e and half are not ____Don't know	____Yes ____No ____About half are low-e and half are not ____Don't know	____Yes ____No ____About half are low-e and half are not ____Don't know
Are the windows in the following WWR categories typically framed with wood, vinyl, or metal? ➔	____wood ____vinyl ____metal ____Don't know	____wood ____vinyl ____metal ____Don't know	____wood ____vinyl ____metal ____Don't know
Are the windows in these buildings typically designed with shading projection factors or overhangs?	____Yes ____No	____Yes ____No	____Yes ____No
	Fill in blanks below if information available.	Fill in blanks below if information available.	Fill in blanks below if information available.
If you are comfortable estimating an average solar heat gain coefficient (SHGC), shading coefficient (SC) and/or U-Value , please list: ➔	_______U-Value _______SHGC _______SC	_______U-Value _______SHGC _______SC	_______U-Value _______SHGC _______SC

RETAIL BUILDINGS

	WWR less than 10%	WWR Between 11% and 40%	WWR Above 40%
Estimate the % ➔	______________%	______________%	______________%
	Check one for each question below.	Check one for each question below.	Check one for each question below.
Are the windows in the following WWR categories typically single pane or double pane? ➔	_____single pane _____double pane _____about 50/50 split _____don't know	_____single pane _____double pane _____about 50/50 split _____don't know	_____single pane _____double pane _____about 50/50 split _____don't know
Are the windows in the following WWR categories typically tinted or clear? ➔	_____tinted _____clear _____about 50/50 split	_____tinted _____clear _____about 50/50 split	_____tinted _____clear _____about 50/50 split
Are most of the windows in the following WWR categories Low-E windows? ➔	____Yes ____No ____About half are low-e and half are not ____Don't know	____Yes ____No ____About half are low-e and half are not ____Don't know	____Yes ____No ____About half are low-e and half are not ____Don't know
Are the windows in the following WWR categories typically framed with wood, vinyl, or metal? ➔	____wood ____vinyl ____metal ____Don't know	____wood ____vinyl ____metal ____Don't know	____wood ____vinyl ____metal ____Don't know
Are the windows in these buildings typically designed with shading projection factors or overhangs?	____Yes ____No	____Yes ____No	____Yes ____No
	Fill in blanks below if information available.	Fill in blanks below if information available.	Fill in blanks below if information available.
If you are comfortable estimating an average solar heat gain coefficient (SHGC), shading coefficient (SC) and/or U-Value , please list: ➔	_______U-Value _______SHGC _______SC	_______U-Value _______SHGC _______SC	_______U-Value _______SHGC _______SC

Lighting

L-1) Do you have any information from plans submittals or discussions with builders that would give us an idea of the lighting power density (LPD) of current commercial construction? Please circle the LPD or Watts/ft^2 category that most appropriately reflects how buildings are currently constructed.

Building Type	**Circle the Category of Watts/ ft^2**			
Offices	2.0 or greater	1.75-2.0	1.25-1.75	1.25 or less
Schools	2.0 or greater	1.75-2.0	1.50 to 1.75	1.5 or less
"Big Box" Retail (e.g., WalMart)	3.0 or greater	2.5-3.0	1.9-2.5	1.9 or less
Other Retail	3.0 or greater	2.5-3.0	1.9-2.5	1.9 or less

L-2) What lighting technologies are being used to achieve these LPDs?

a) Please specify the most predominant fluorescent lamp type used:

Ô T-12

Ô T-8

Ô T-5

Ô Other?

Ô Don't know

Does this vary significantly by building type? ____ Yes ____No. If yes, please explain ____

b) Specify the most predominant type of ballast used in commercial buildings types:

Ô Magnetic ballast

Ô Electronic ballast

Ô Don't know

Does this vary significantly by building type? ____Yes ____No. If yes, please explain ____

c) In fixtures that have traditionally used incandescent lighting, what percentage are now using compact fluorescent lamps (CFLs)?

__________%

__________Don't know

L-3) Are commercial buildings typically constructed with occupancy sensors? Please respond for each building type:

Small office (less than 10,000 S.F.). .Yes____ No ____
Large office (> 10,000 S.F.). . . . . Yes____ No ____
School buildings. . . . . Yes____ No ____
Retail. . . . . Yes____ No ____

Mechanical

M-1) How often are economizers used in commercial buildings? Approximate the percentage of cooling systems that use economizers in buildings that have:

Small systems (e.g., less than 12 ton system) ________%

Large systems (>12 ton package systems and built up systems) _____%

M-2) In buildings that use electric heat, what percentage of the buildings use heat pumps versus electric resistance heating?

_____% heat pumps

_____% resistance heating

_____ don't know

M-3) How often are high efficiency (above national manufacturing standard) cooling units being installed?

_____often

_____not often

_____don't know

APPENDIX C
Low-Efficiency Base Case Results

Small Office (WWR=0.18)

Bldg. Size	10,000 sq. ft.		Standard Level			
			Low Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	1,014	U-factor(std)	0.720	0.460		0.460
		sh. coef.(std)	0.840	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.72	0.461		0.461
		sh. coef.(cost)	0.836	0.423		0.423
		cost ($/sqft)	$4.94	$10.23		$10.23
Opaque Walls	4,619	U-factor	0.1	0.064		0.064
		cost ($/sqft)	$0.59	$0.99		$0.99
Roof	10,000	U-factor	0.074	0.063		0.063
		cost ($/sqft)	$1.08	$1.20		$1.20
	(feet)					
Envelope Cost (incremental)			$18,541	$26,936		$26,936
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.75	$1.75
Total Lighting Cost			$15,670		$17,504	$17,504
Construction Cost			$34,211	$42,606	$36,045	$44,440
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	102	83	93	74
Natural Gas		MMBtu	153	112	171	128
Total Annual Energy Cost			$8,464	$7,844	$7,742	$7,102
Economic Measures						
Life-Cycle Cost Savings				**($900)**	**$6,838**	**$6,225**
Savings-to-Investment Ratio (SIR)				0.9	3.6	1.5
Adjusted IRR				6.7%	10.5%	8.1%

Notes:

1 **No economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /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)

Bldg. Size	60,000 sq. ft.		Standard Level			
			Low Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	4,302	U-factor(std)	0.720	0.460		0.460
		sh. coef.(std)	0.840	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.72	0.461		0.461
		sh. coef.(cost)	0.836	0.423		0.423
		cost ($/sqft)	$4.94	$10.23		$10.23
Opaque Walls	19,598	U-factor	0.1	0.064		0.064
		cost ($/sqft)	$0.59	$0.99		$0.99
Roof	20,000	U-factor	0.074	0.063		0.063
		cost ($/sqft)	$1.08	$1.20		$1.20
Envelope Cost (incremental)			$54,447	$87,386		$87,386
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.75	$1.75
Total Lighting Cost			$94,018		$105,026	$105,026
Construction Cost			$148,465	$181,404	$159,473	$192,412
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,926	1,926	1,687	1,687
Electricity, HVAC		MMBtu	482	390	448	356
Natural Gas		MMBtu	574	421	655	492
Total Annual Energy Cost			$46,105	$43,427	$41,907	$39,140
Economic Measures						
Life-Cycle Cost Savings				**($321)**	**$39,360**	**$40,268**
Savings-to-Investment Ratio (SIR)				1.0	3.5	1.8
Adjusted IRR				7.0%	10.4%	8.5%

Notes:

1 **Economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /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)

Bldg. Size	60,000 sq. ft.		Standard Level			
			Low Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	9,082	U-factor(std)	0.720	0.460		0.460
		sh. coef.(std)	0.840	0.423		0.423
(Window-Wall Ratio = 0.38)		U-factor(cost)	0.72	0.461		0.461
		sh. coef.(cost)	0.836	0.423		0.423
		cost ($/sqft)	$4.94	$10.23		$10.23
Opaque Walls	14,818	U-factor	0.1	0.064		0.064
		cost ($/sqft)	$0.59	$0.99		$0.99
Roof	20,000	U-factor	0.074	0.063		0.063
		cost ($/sqft)	$1.08	$1.20		$1.20
Envelope Cost (incremental)			$75,227	$131,538		$131,538
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.57		$1.75	$1.75
Total Lighting Cost			$94,018		$105,026	$105,026
Construction Cost			$169,245	$225,556	$180,253	$236,564
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,926	1,926	1,687	1,687
Electricity, HVAC		MMBtu	673	488	639	454
Natural Gas		MMBtu	800	573	887	653
Total Annual Energy Cost			$51,034	$46,211	$46,884	$42,006
Economic Measures						
Life-Cycle Cost Savings				**$978**	**$38,712**	**$40,435**
Savings-to-Investment Ratio (SIR)				1.0	3.4	1.5
Adjusted IRR				7.0%	10.4%	8.1%

Notes:

1 **Economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**

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

Life-cycle cost savings includes replacement costs and residual values

Retail

Bldg. Size	24,000 sq. ft.		Standard Level			
			Low Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	624	U-factor(std)	0.720	0.460		0.460
		sh. coef.(std)	0.840	0.570		0.570
(Window-Wall Ratio = 0.07)		U-factor(cost)	0.72	0.517		0.517
		sh. coef.(cost)	0.836	0.490		0.490
		cost ($/sqft)	$4.94	$9.49		$9.49
Opaque Walls	8,292	U-factor	0.1	0.064		0.064
		cost ($/sqft)	$0.59	$0.99		$0.99
Roof	24,000	U-factor	0.074	0.063		0.063
		cost ($/sqft)	$1.08	$1.20		$1.20
Envelope Cost (incremental)			$33,907	$42,916		$42,916
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			$71,629	$80,637	$77,066	$86,075
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	900	900	754	754
Electricity, HVAC		MMBtu	220	217	184	180
Natural Gas		MMBtu	151	98	193	129
Total Annual Energy Cost			$20,616	$20,196	$17,735	$17,213
Economic Measures						
Life-Cycle Cost Savings				**($3,787)**	**$27,718**	**$25,325**
Savings-to-Investment Ratio (SIR)				0.6	3.7	2.3
Adjusted IRR				5.7%	10.6%	9.2%

Notes:

1 **No economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**

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

Life-cycle cost savings includes replacement costs and residual values

Education (elementary)

Bldg. Size	50,000 sq. ft.		Standard Level			
			Low Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	2,991	U-factor(std)	0.720	0.460		0.460
		sh. coef.(std)	0.840	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.72	0.461		0.461
		sh. coef.(cost)	0.836	0.423		0.423
		cost ($/sqft)	$4.94	$10.23		$10.23
Opaque Walls	13,624	U-factor	0.1	0.064		0.064
		cost ($/sqft)	$0.59	$0.99		$0.99
Roof	50,000	U-factor	0.074	0.063		0.063
		cost ($/sqft)	$1.08	$1.20		$1.20
Envelope Cost (incremental)			$76,827	$104,035		$104,035
Lighting						
Lighting Power Density		watts/sqft	1.79		1.50	1.50
Lighting Cost		$/sqft	$1.79		$1.95	$1.95
Total Lighting Cost			$89,599		$97,629	$97,629
Construction Cost			$166,425	$193,633	$174,456	$201,664
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,056	1,056	915	915
Electricity, HVAC		MMBtu	396	339	368	311
Natural Gas		MMBtu	1,554	1,401	1,636	1,485
Total Annual Energy Cost			$36,325	$34,246	$33,950	$31,888
Economic Measures						
Life-Cycle Cost Savings				**($1,826)**	**$19,176**	**$17,110**
Savings-to-Investment Ratio (SIR)				0.9	2.6	1.4
Adjusted IRR				6.8%	9.6%	7.9%

Notes:

1 **No economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**

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

Life-cycle cost savings includes replacement costs and residual values

Appendix D
High-Efficiency Base Case Results

Small Office (WWR=0.18)

Bldg. Size	10,000 sq. ft.		Standard Level			
			High Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	1,014	U-factor(std)	0.650	0.460		0.460
		sh. coef.(std)	0.670	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.67	0.461		0.461
		sh. coef.(cost)	0.564	0.423		0.423
		cost ($/sqft)	$6.13	$10.23		$10.23
Opaque Walls	4,619	U-factor	0.062	0.064		0.064
		cost ($/sqft)	$1.05	$0.99		$0.99
Roof	10,000	U-factor	0.048	0.063		0.063
		cost ($/sqft)	$1.50	$1.20		$1.20
Envelope Cost (incremental)			$26,077	$26,936		$26,936
Lighting						
Lighting Power Density		watts/sqft	1.63		1.30	1.30
Lighting Cost		$/sqft	$1.75		$1.75	$1.75
Total Lighting Cost			$17,504		$17,504	$17,504
Construction Cost			$43,582	$44,440	$43,582	$44,440
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	321	321	281	281
Electricity, HVAC		MMBtu	97	83	87	74
Natural Gas		MMBtu	110	112	125	128
Total Annual Energy Cost			$8,078	$7,844	$7,322	$7,102
Economic Measures						
Life-Cycle Cost Savings				**$1,820**	**$9,944**	**$11,589**
Savings-to-Investment Ratio (SIR)				2.4	Invest. < 0	10.2
Adjusted IRR				9.4%	Invest. < 0	13.4%

Notes:

1 **No economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /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)

Bldg. Size	60,000 sq. ft.		Standard Level			
			High Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	4,302	U-factor(std)	0.650	0.460		0.460
		sh. coef.(std)	0.670	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.67	0.461		0.461
		sh. coef.(cost)	0.564	0.423		0.423
		cost ($/sqft)	$6.13	$10.23		$10.23
Opaque Walls	19,598	U-factor	0.062	0.064		0.064
		cost ($/sqft)	$1.05	$0.99		$0.99
Roof	20,000	U-factor	0.048	0.063		0.063
		cost ($/sqft)	$1.50	$1.20		$1.20
Envelope Cost (incremental)			$76,940	$87,386		$87,386
Lighting						
Lighting Power Density		watts/sqft	1.30		1.30	1.30
Lighting Cost		$/sqft	$1.75		$1.75	$1.75
Total Lighting Cost			$105,026		$105,026	$105,026
Construction Cost			$181,966	$192,412	$181,966	$192,412
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,687	1,687	1,687	1,687
Electricity, HVAC		MMBtu	407	356	407	356
Natural Gas		MMBtu	500	492	500	492
Total Annual Energy Cost			$40,091	$39,140	$40,091	$39,140
Economic Measures						
Life-Cycle Cost Savings				**($126)**	**$0**	**($126)**
Savings-to-Investment Ratio (SIR)				1.0	Invest. < 0	1.0
Adjusted IRR				7.0%	Invest. < 0	7.0%

Notes:

1 **Economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /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)

Bldg. Size	60,000 sq. ft.		Standard Level			
			High 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)	0.610	0.460		0.460
		sh. coef.(std)	0.660	0.423		0.423
(Window-Wall Ratio = 0.38)		U-factor(cost)	0.60	0.461		0.461
		sh. coef.(cost)	0.530	0.423		0.423
		cost ($/sqft)	$7.04	$10.23		$10.23
Opaque Walls	14,818	U-factor	0.062	0.064		0.064
		cost ($/sqft)	$1.05	$0.99		$0.99
Roof	20,000	U-factor	0.048	0.063		0.063
		cost ($/sqft)	$1.50	$1.20		$1.20
Envelope Cost (incremental)			$109,463	$131,538		$131,538
Lighting						
Lighting Power Density		watts/sqft	1.30		1.30	1.30
Lighting Cost		$/sqft	$1.75		$1.75	$1.75
Total Lighting Cost			$105,026		$105,026	$105,026
Construction Cost			$214,489	$236,564	$214,489	$236,564
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	1,687	1,687	1,687	1,687
Electricity, HVAC		MMBtu	558	454	558	454
Natural Gas		MMBtu	692	653	692	653
Total Annual Energy Cost			$44,082	$42,006	$44,082	$42,006
Economic Measures						
Life-Cycle Cost Savings				**$1,490**	**$0**	**$1,490**
Savings-to-Investment Ratio (SIR)				1.1	Invest. < 0	1.1
Adjusted IRR				7.1%	Invest. < 0	7.1%

Notes:

1 **Economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**

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

Life-cycle cost savings includes replacement costs and residual values

Education (elementary)

Bldg. Size	50,000 sq. ft.		Standard Level			
			High Base	*90.1-2001 Envelope Only*	*90.1-2001 Lighting Only*	*90.1-2001 Envelope & Lighting*
Envelope	**Area (sq. ft.)**					
Windows	2,991	U-factor(std)	0.650	0.460		0.460
		sh. coef.(std)	0.670	0.423		0.423
(Window-Wall Ratio = 0.18)		U-factor(cost)	0.67	0.461		0.461
		sh. coef.(cost)	0.564	0.423		0.423
		cost ($/sqft)	$6.13	$10.23		$10.23
Opaque Walls	13,624	U-factor	0.062	0.064		0.064
		cost ($/sqft)	$1.05	$0.99		$0.99
Roof	50,000	U-factor	0.048	0.063		0.063
		cost ($/sqft)	$1.50	$1.20		$1.20
Envelope Cost (incremental)			$107,722	$104,035		$104,035
Lighting						
Lighting Power Density		watts/sqft	1.50		1.50	1.50
Lighting Cost		$/sqft	$1.95		$1.95	$1.95
Total Lighting Cost			$97,629		$97,629	$97,629
Construction Cost			$205,351	$201,664	$205,351	$201,664
Annual Energy Consumption						
Electricity, lights and plugs		MMBtu	915	915	915	915
Electricity, HVAC		MMBtu	301	273	301	273
Natural Gas		MMBtu	1,443	1,481	1,443	1,481
Total Annual Energy Cost			$31,406	$31,194	$31,406	$31,194
Economic Measures						
Life-Cycle Cost Savings				**$5,682**	**$0**	**$5,682**
Savings-to-Investment Ratio (SIR)				Invest. < 0	Invest. < 0	Invest. < 0
Adjusted IRR				Invest. < 0	Invest. < 0	Invest. < 0

Notes:

1 **No economizer used**

2 **2003 electricity price = 6.0 cents/kWh** **2003 gas price = $7.04 /MMBtu**

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

Life-cycle cost savings includes replacement costs and residual values