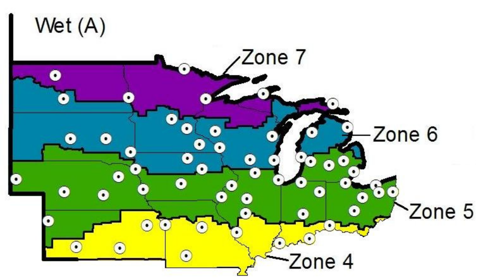
NIST Special Publication 1148-2

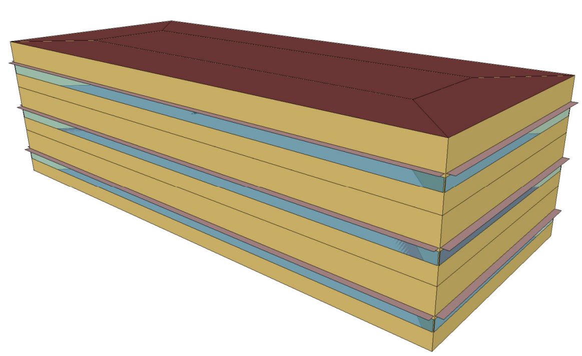
Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: Midwest Census Region

Joshua Kneifel

http://dx.doi.org/10.6028/NIST.SP.1148-2



BIRDS
Building Industry
Reporting and
Design *for*
Sustainability



National Institute of
Standards and Technology
U.S. Department of Commerce

NIST Special Publication 1148-2

Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: Midwest Census Region

Joshua Kneifel
Applied Economics Office
Engineering Laboratory

http://dx.doi.org/10.6028/NIST.SP.1148-2

February 2013

U.S. Department of Commerce
Rebecca Blank, Acting Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Under Secretary of Commerce for Standards and Technology and Director

National Institute of Standards and Technology Special Publication 1148-2
Natl. Inst. Stand. Technol. Spec. Publ. 1148-2, 195 pages (February 2013)
http://dx.doi.org/10.6028/NIST.SP.1148-2
CODEN: NSPUE2

Abstract

Energy efficiency requirements in energy codes for commercial buildings vary across states, and many states have not yet adopted the latest energy efficiency standard edition. As of December 2011, states had adopted energy codes ranging across editions of *American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE) 90.1* (*-2001, -2004,* and *-2007*). Some states do not have a code requirement for energy efficiency, leaving it up to the locality or jurisdiction to set its own requirements. This study considers the impacts that the adoption of newer, more stringent energy codes for commercial buildings would have on building energy use, operational energy costs, building life-cycle costs, and cradle-to-grave energy-related carbon emissions.

The results of this report are based on analysis of the Building Industry Reporting and Design for Sustainability (BIRDS) database, which includes 12 540 whole building energy simulations covering 11 building types in 228 cities across all U.S. states for 9 study period lengths. The performance of buildings designed to meet current state energy codes is compared to their performance when meeting alternative building energy standard editions to determine whether more stringent energy standard editions are cost-effective in reducing energy consumption and energy-related carbon emissions. Each state energy code is also compared to a "Low Energy Case" (LEC) building design that increases energy efficiency beyond the *ASHRAE 90.1-2007* design. The estimated savings for each of the building types are aggregated using new commercial building construction data to calculate the magnitude of the available savings that each state in the Midwest Census Region may realize if it were to adopt a more energy efficient standard as its state energy code.

Keywords

Building economics; economic analysis; life-cycle costing; life-cycle assessment; energy efficiency; commercial buildings

Preface

This study was conducted by the Applied Economics Office in the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST). The study is designed to assess the energy consumption, life-cycle cost, and energy-related carbon emissions impacts from the adoption of new state energy codes based on more stringent building energy standard editions. The intended audience is researchers and policy makers in the commercial building sector, and others interested in building energy efficiency.

Disclaimer

The policy of the National Institute of Standards and Technology is to use metric units in all of its published materials. Because this report is intended for the U.S. construction industry that uses U.S. customary units, it is more practical and less confusing to include U.S. customary units as well as metric units. Measurement values in this report are therefore stated in metric units first, followed by the corresponding values in U.S. customary units within parentheses.

Acknowledgements

The author wishes to thank all those who contributed ideas and suggestions for this report. They include Ms. Barbara Lippiatt and Dr. Robert Chapman of EL's Applied Economics Office, Dr. Kevin Teichman of EL's Energy and Environment Division, and Dr. Nicos S. Martys of EL's Materials and Structural Systems Division. A special thanks to Mr. Nicholas Long and the EnergyPlus Team for generating the initial energy simulations for this project. Thanks to Mr. Brian Presser for adapting the energy simulations to meet the study requirements and generating the final simulations used in the database. Thanks to Mr. Nathaniel Soares for developing the initial version of the Building Industry Reporting and Design for Sustainability (BIRDS) database, and to Ms. Priya Lavappa for enhancing the database for the current analysis. The author would like to thank the NIST Engineering Laboratory for its support of the project.

Author Information

Joshua D. Kneifel
Economist
National Institute of Standards and Technology
Engineering Laboratory
100 Bureau Drive, Mailstop 8603
Gaithersburg, MD 20899-8603
Tel.: 301-975-6857
Email: joshua.kneifel@nist.gov

Table of Contents

List of Figures

List of Tables

List of Acronyms

Acronym	Definition
AEO	Applied Economics Office
AIRR	Adjusted Internal Rate of Return
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIRDS	Building Industry Reporting and Design for Sustainability
CBECS	Commercial Building Energy Consumption Survey
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DOE	Department of Energy
EEFG	EnergyPlus Example File Generator
eGRID	Emissions and Generation Resource Integrated Database
EIA	Energy Information Administration
EL	Engineering Laboaratory
EPA	Environmental Protection Agency
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
HVAC	Heating, Ventilating, and Air Conditioning
I-P	Inch-Pounds (Customary Units)
IECC	International Energy Code Council
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
LCC	Life-Cycle Cost
LEC	Low Energy Case
MRR	Maintenance, Repair, and Replacement
N_2O	Nitrous Oxide
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
ROI	Return On Investment
S-I	System International (Metric Units)
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SPV	Single Present Value

Acronym	Definition
UPV*	Uniform Present Value Modified for Fuel Price Escalation

Executive Summary

Energy efficiency requirements in energy codes for commercial buildings vary across states, and many states have not yet adopted the latest energy standard edition. As of December 2011, state energy code adoptions range across editions of the *American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1-2001, -2004,* and *-2007*). Some states in the United States do not have a code requirement for energy efficiency, leaving it up to the locality or jurisdiction to set its own requirement. There may be significant energy and cost savings to be realized by states, particularly those states that have not yet adopted an energy code, if they were to adopt more energy efficient commercial building energy standard editions.

The results of this report are based on analysis of the twelve states in the Midwest Census Region using the Building Industry Reporting and Design for Sustainability (BIRDS) database. BIRDS includes 12 540 whole-building energy simulation estimates covering 11 building types in 228 cities across all U.S. states for 9 study period lengths. The performance of buildings designed to meet current state energy codes is compared to their performance when meeting alternative building energy standard editions to determine whether more stringent energy standard editions are cost-effective in reducing energy consumption and energy-related carbon emissions. Each state energy code is also compared to a “Low Energy Case” (LEC) building design that increases energy efficiency beyond the *ASHRAE 90.1-2007* design.

Four states in the Midwest Census Region have not yet adopted a state energy code for commercial buildings: Kansas, Missouri, North Dakota, and South Dakota. For these states, adoption of *ASHRAE 90.1-2001* and *-2004* lead to reductions in energy use, energy costs, and energy-related carbon emissions. However, adoption of *ASHRAE 90.1-2001* is not life-cycle cost-effective in any of the four states because the additional costs from implementing the energy efficiency measures overwhelm the future energy cost savings. *ASHRAE 90.1-2004* is not life-cycle cost-effective to adopt in three of the four states, with only South Dakota realizing a reduction in life-cycle costs. Adopting *ASHRAE 90.1-2007* leads to greater reductions in energy use, energy costs, and carbon emissions than *ASHRAE 90.1-2001* or *-2004*, and is life-cycle cost-effective to adopt in three of the four states (Kansas is the exception).

Minnesota is the only state in the Midwest Census Region that has adopted *ASHRAE 90.1-2004* as its state energy code for commercial buildings. Minnesota would realize reductions in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adopting *ASHRAE 90.1-2007*.

The adoption of the LEC design is analyzed for all twelve states. The LEC design goes beyond *ASHRAE 90.1-2007* by setting stricter building envelope requirements, lower lighting densities, and requiring daylighting controls as well as requiring overhangs for warmer climate zones. There are several factors that impact the percentage savings from adopting the LEC design for all states in the Midwest Census Region, including the current state energy code, selected study period length, building type, and climate zone of the location.

The region-wide adoption of the LEC design as the commercial building energy code for all building types significantly decreases energy use (16.1 %), energy costs (21.7 %), and carbon emissions (22.7 %), on average, while reducing life-cycle costs (0.7 %), on average, for a 10-year study period. Although the LEC design leads to reductions for all states, the magnitude of the reductions varies according to each state's adopted energy code. The four states with no energy code realize the greatest percentage savings in energy use, energy costs, and carbon emissions. However, three of the four states realize percentage increases in life-cycle costs and the fourth state realizes a minimal percentage decrease. Meanwhile, the states that have already adopted *ASHRAE 90.1-2007* realize reductions in life-cycle costs.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 5 years to 20 years, the number of building types that are cost-effective increases from 7 to all 11. The retail store is the only building type that is not cost-effective for all study periods longer than 10 years, and is cost-effective for all study period lengths of 20 years or greater. Study period length is an important determinant of cost-effectiveness and size of the percentage changes in life-cycle costs.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, and carbon emissions. After controlling for each state's energy code, cities located in warmer climates tend to realize greater average percentage reductions in these measures. There are no distinct trends in life-cycle costs associated with climate zones.

Different building types realize different regional average percentage reductions in energy use, energy costs, and carbon emissions for a 10-year study period. High schools realize the smallest reductions while restaurants and 3- and 8-story office buildings realize the greatest reductions in energy use and energy costs. The reduction in carbon emissions is not perfectly correlated with reductions in energy use because along with the reduction in energy use, there is a change in the fuel source mix. The greatest percentage reductions in life-cycle costs are realized by restaurants and 3- and 8-story office buildings while the smallest percentage reductions are realized by 16-story office buildings.

The magnitude of a building type's average percentage change is not necessarily correlated with its changes in total energy use, energy costs, and energy-related carbon emissions relative to other building types. For example, high schools tend to realize some of the smallest percentage reductions, but some of the greatest total reductions in energy use, energy costs, and energy-related carbon emissions. Total reductions are driven largely by total new floor area constructed for the building type in a state. The adoption of the LEC design would lead to greater aggregate reductions in energy use in Illinois than in Iowa the amount of newly constructed floor area for 2003 to 2007 was almost five times greater in Illinois.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy rates, and carbon emissions rates. The greatest 10-year reduction in energy use per unit of floor area resulting from adoption of the LEC design is realized by the four states that have no state energy code, ranging from 404 kWh/m^2 (128 kBtu/ft^2) to 456 kWh/m^2 (145 kBtu/ft^2), followed by the state that has adopted *ASHRAE 90.1-2004* and realizes reductions of 351 kWh/m^2 (111 kBtu/ft^2). The states that have adopted *ASHRAE 90.1-2007* realize reductions ranging from 168 kWh/m^2 (53 kBtu/ft^2) to 206 kWh/m^2 (65 kBtu/ft^2). States with the highest electricity rates tend to realize the largest reductions in energy costs per unit of energy consumption reduced. Similarly, states with higher CO_2e emission rates per unit of electricity generated tend to realize greater reductions in emissions per unit of energy consumption reduced. The greater the fraction of the total reduction in energy use that is from electricity consumption, the greater the reduction in both energy costs and carbon emissions per unit of energy consumption reduced.

This study is limited in scope and would be strengthened by including sensitivity analysis, expanding the BIRDS database, and enabling public access to all the results. Combining these results with detailed analysis of the states in the other three census regions would make possible an estimate of the nationwide impact of adopting more stringent building energy codes. Expansion of the environmental assessment beyond energy-related carbon emissions to include building materials and a full range of both life-cycle environmental impacts and life-cycle stages, from cradle to grave, would enable comprehensive sustainability assessment. Additional energy efficiency measures, fuel types, discount rates, and building types would also expand the scope of the database. Also, given that new buildings account for a small fraction of the entire building stock, incorporating analysis of energy retrofits to these same prototype buildings would increase the coverage of the database.

The extensive BIRDS database can be used to answer many more questions than posed in this report, and will be made available to the public through a simple-to-use software tool that allows others access to the database for their own research on building energy efficiency and sustainability. These improvements are underway, with more detailed reporting and release of the BIRDS software scheduled for 2013.

1 Introduction

1.1 Background and Purpose

Energy efficiency requirements in current energy codes for commercial buildings vary across states, and many states have not yet adopted the latest energy efficiency standard editions. As of December 2011, state energy code adoptions range across editions of the *American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1-2001, -2004,* and *-2007*). *ASHRAE Standard 90.1* is the industry consensus standard to establish the minimum energy-efficient requirements of buildings, other than low-rise residential buildings. Some states do not have a code requirement for energy efficiency, leaving it up to the locality or jurisdiction to set its own requirement. There may be significant energy and cost savings to be realized by states if they were to adopt more energy efficient commercial building energy standard editions.

The purpose of this study is to estimate the impacts that the adoption of more stringent energy codes for commercial buildings would have on building energy use, operational energy costs, building life-cycle costs, and energy-related carbon emissions for states located in the Midwest Census Region. The results are analyzed for each state and across all states in the region to answer the following questions:

- How much does each more stringent energy standard edition decrease building energy consumption, energy costs, and energy-related carbon emissions, in percentage terms, relative to the state's current energy code?
- Is adopting a more stringent energy standard edition life-cycle cost-effective?
- Based on new construction in each state, how much can a state save in total energy consumption, energy costs, and energy-related carbon emissions over time? Are these savings obtained life-cycle cost-effectively?
- Which states would realize the most significant savings from adopting newer energy standard editions, and what factors drive the relative savings across states?

1.2 Literature Review

Pacific Northwest National Laboratory (2009) estimates the impacts for each state of adopting the most recent edition of the *ASHRAE 90.1* Standard as of 2009, *ASHRAE 90.1-2007*, as the commercial building energy code relative to the state's current energy code. For states without a state commercial building energy code, the baseline is assumed to be *ASHRAE 90.1-1999* because it is considered to represent common practice in the industry. The annual energy use savings and energy cost savings are estimated for three Department of Energy (DOE) benchmark buildings -- a medium-sized office building, a non-refrigerated warehouse, and a mid-rise apartment building -- to represent non-residential, semi-heated, and residential uses, respectively. The buildings are simulated in the *EnergyPlus* whole building energy software (DOE, 2009a) for 97 cities located across the U.S., ensuring that each climate zone in each state is represented. The study reports annual electricity and natural gas consumption per square foot of floor area for the buildings, assuming they are built to meet both the state's current code and *ASHRAE 90.1-2007*. Based on these results, the percentage savings in energy and energy costs are calculated for the three building types for each state. The study does not compare energy use and energy costs across states. Life-cycle costs and carbon emissions are not considered in the study.

Kneifel (2010) creates a framework to simultaneously analyze the impacts of improving energy efficiency on energy use, energy costs, life-cycle costs, and carbon emissions through an integrated design context for new commercial buildings. The paper compares the savings of constructing 11 prototype commercial buildings to meet the building envelope requirements of *ASHRAE 90.1-2007* and a "Low Energy Case," relative to *ASHRAE 90.1-2004*, for 16 cities in different climate zones across the contiguous United States. The paper finds minimal improvements in energy efficiency from building to meet *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004* while significant savings is found by building to meet the "Low Energy Case." The "Low Energy Case" is often cost-effective on a first cost basis and is always cost-effective over the longer study period lengths.

Kneifel (2011a) expands on the framework and analysis in Kneifel (2010) by analyzing the impact of adopting the building envelope requirements of *ASHRAE 90.1-2007* and a "Low Energy Case" relative to *ASHRAE 90.1-2004* in terms of energy use, energy costs, energy-related carbon emissions, and life-cycle costs for 228 cities across the U.S. with at least one city in each state. Analysis includes 4 study period lengths (1, 10, 25, and 40 years). The paper finds that, on average, the more energy efficient building designs are cost-effective. However, there is significant variation across states in terms of energy use savings and life-cycle cost-effectiveness driven by both climate and construction costs. There is also significant variation across cities within a state, even cities located within the same climate zone. These variations are a result of differences in local material and labor costs as well as energy costs.

Kneifel (2013) analyzes 12 540 whole-building energy simulations in the Building Industry Reporting and Design for Sustainability (BIRDS) database covering 11 building types in 228 cities across all U.S. states for 9 study period lengths (1, 5, 10, 15, 20, 25, 30, 35, and 40 years). Current state energy code performance is compared to the performance of alternative *ASHRAE 90.1 Standard* editions to determine whether more stringent energy standard editions are cost-effective in reducing energy consumption and energy-related carbon emissions. This analysis includes a "Low Energy Case" (LEC) building design that increases energy efficiency beyond the *ASHRAE 90.1-2007* design. Results are analyzed in detail for the *ASHRAE 90.1-2007* and LEC designs. Results are aggregated at the state level for seven states, Alaska, Colorado, Florida, Maryland, Oregon, Tennessee, and Wisconsin, to estimate the magnitude of total energy use savings, energy cost savings, life-cycle cost savings and energy-related carbon emissions reductions that could be attained by adoption of a more stringent state energy code for commercial buildings.

1.3 Approach

This study uses the BIRDS database to analyze the benefits and costs of increasing building energy efficiency for 58 cities located in the 12 states of the Midwest Census Region. BIRDS is a compilation of whole building energy simulations, building construction cost data, maintenance, repair, and replacement rates and costs, and energy-related carbon emissions data for 11 building types in 228 cities across all U.S. states. The present analysis compares energy performance of buildings designed to each state's current energy code for commercial buildings to the performance of more energy efficient building designs to determine the energy use savings, energy cost savings, and energy-related carbon emissions reductions, and the associated life-cycle costs, resulting from adopting stricter standards as the state's energy code.

Results are analyzed both in percentage and total value terms. The percentage savings results allow for direct comparisons across energy standard editions, building types, study period lengths, climate zones, and cities both within each state and across states in the Midwest Census Region. Results are aggregated to the state level to estimate the magnitude of total energy use savings, energy cost savings, and energy-related carbon emissions reductions that could be attained by adoption of a more stringent state energy code, and the associated total life-cycle costs.

Results are summarized using both tables and figures. In cases where the material being discussed is of secondary importance, the associated table or figure is placed in the Appendices. The order in which tables and figures appear in the Appendices corresponds to the order in which they are cited in the text.

2 Study Design

The BIRDS database used in this study was built following the framework developed in Kneifel (2010) and further expanded in Kneifel (2011a) and Kneifel (2013). This study analyzes whole building energy simulations, life-cycle costs, and life-cycle carbon emissions for 5 energy efficiency designs for 11 building types, 58 cities across the twelve states in the Midwest Census Region of the United States, and 9 study period lengths.[1]

2.1 Building Types

The building characteristics in Table 2-1 describe the 11 building types used in this study, which include 2 dormitories, 2 apartment buildings, a hotel, 3 office buildings, a school, a retail store, and a restaurant. The building types were selected based on a combination of factors, including fraction of building stock represented, variation in building characteristics, and ease of simulation design. These building types represent 46 % of the existing U.S. commercial building stock floor space.[2] The prototype buildings range in size from 465 m^2 (5000 ft^2) to 41 806 m^2 (450 000 ft^2). The building abbreviations defined in Table 2-1 are used to represent the building types in tables throughout this study.

Table 2-1 Building Characteristics

Building Type	Bldg. Abbr.	Floors	Floor Height m (ft)	Wall	Roof†	Pct. Glazing	Building Size m^2 (ft^2)	Occupancy Type	U.S. Floor Space (%)
Dormitory	DORMI04	4	3.66 (12)	Mass	IEAD	20 %	3097 (33 333)	Lodging	7.1 %
Dormitory	DORMI06	6	3.66 (12)	Steel	IEAD	20 %	7897 (85 000)		
Hotel	HOTEL15	15	3.05 (10)	Steel	IEAD	100 %	41 806 (450 000)		
Apartment	APART04	4	3.05 (10)	Mass	IEAD	12 %	2787 (30 000)		
Apartment	APART06	6	3.15 (10)	Steel	IEAD	14 %	5574 (60 000)		
School, High	HIGHS02	2	4.57 (15)	Mass	IEAD	25 %	12 077 (130 000)	Education	13.8 %
Office	OFFIC03	3	3.66 (12)	Mass	IEAD	20 %	1858 (20 000)	Office	17.0 %
Office	OFFIC08	8	3.66 (12)	Mass	IEAD	20 %	7432 (80 000)		
Office	OFFIC16	16	3.05 (10)	Steel	IEAD	100 %	24 155 (260 000)		
Retail Store	RETAIL1	1	4.27 (14)	Mass	IEAD	10 %	743 (8000)	Mercantile*	6.0 %
Restaurant	RSTRNT1	1	3.66 (12)	Wood	IEAD	30 %	465 (5000)	Food Service	2.3 %

*Only includes non-mall floor area.
†IEAD = Insulation Entirely Above Deck

[1] See Kneifel (2011b) for additional details on the whole building energy simulations used in the BIRDS database.
[2] Based on the Commercial Building Energy Consumption Survey (CBECS) database

2.2 Building Designs

Current state energy codes are based on different editions of the *International Energy Conservation Code (IECC)* or *ASHRAE 90.1 Standard*, which have requirements that vary based on a building's characteristics and the climate zone of the building location. For this study, the prescriptive requirements of the *ASHRAE 90.1 Standard*-equivalent design are used to meet current state energy codes and to define the alternative building designs. States that have not yet adopted a state energy code are assumed to meet *ASHRAE 90.1-1999* building energy efficiency requirements. A "Low Energy Case" design based on *ASHRAE 189.1-2009*, which goes beyond *ASHRAE 90.1-2007*, is included as an additional building design alternative.

Table 2-2 shows the variation in commercial building energy codes across the 12 states in the Midwest Census Region.[3] Four states currently do not have a statewide energy code while one state and 7 states have adopted *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007*, respectively. Two cities in the Midwest Census Region (St. Louis, MO and Huron, SD) have adopted newer editions of *ASHRAE 90.1* than the state in which they are located.

[3] Since the publication of Kneifel (2011b) and Kneifel (2012), the BIRDS database has been updated to include subsequent changes in state energy codes through December 2011.

Table 2-2 Energy Code by State/City for the Midwest Census Region[4]

State	City	Zone	Code
IA	Burlington	5A	2007
	Des Moines	5A	2007
	Mason City	6A	2007
	Sioux City	5A	2007
	Waterloo	6A	2007
IL	Chicago	5A	2007
	Moline	5A	2007
	Peoria	5A	2007
	Rockford	5A	2007
	Springfield	5A	2007
IN	Evansville	4A	2007
	Fort Wayne	5A	2007
	Indianapolis	5A	2007
	South Bend	5A	2007
KS	Dodge City	4A	None
	Goodland	5A	None
	Topeka	4A	None
	Wichita	4A	None

State	City	Zone	Code
MI	Alpena	6A	2007
	Detroit	5A	2007
	Flint	5A	2007
	Grand Rapids	5A	2007
	Houghton	7	2007
	Lansing	5A	2007
	Muskegon	5A	2007
	Sault Sainte Marie	7	2007
	Traverse City	6A	2007
MN	Duluth	7	2004
	International Falls	7	2004
	Minneapolis	6A	2004
	Rochester	6A	2004
	Saint Cloud	6A	2004
MO	Columbia	4A	None
	Kansas City	4A	None
	St. Louis	4A	2001
	Springfield	4A	None
ND	Bismarck	6A	None
	Fargo	7	None
	Minot	7	None

State	City	Zone	Code
NE	Grand Island	5A	2007
	Norfolk	5A	2007
	North Platte	5A	2007
	Omaha	5A	2007
	Scottsbluff	5A	2007
OH	Akron	5A	2007
	Cleveland	5A	2007
	Columbus	5A	2007
	Mansfield	5A	2007
	Toledo	5A	2007
	Youngstown	5A	2007
SD	Huron	6A	2001
	Pierre	6A	None
	Sioux Falls	6A	None
WI	Eau Claire	6A	2007
	Green Bay	6A	2007
	La Crosse	6A	2007
	Madison	6A	2007
	Milwaukee	6A	2007

The 12 states, 58 cities, and *ASHRAE* climate zones listed in Table 2-2 are shown in Figure 2-1. States with more significant population centers have more cities included in the BIRDS database. For example, Michigan has 9 cities while South Dakota has 3 cities. The climate zone(s) for each state vary across the Midwest Census Region from *ASHRAE* Climate Zone 4 in Springfield, Missouri to Climate Zone 7 in Houghton, Michigan.

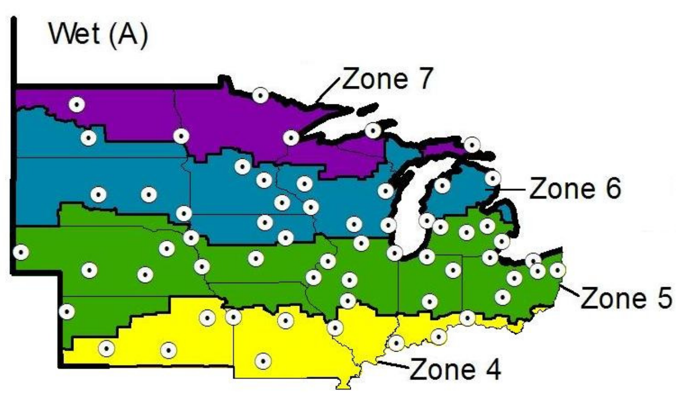


Figure 2-1 Cities and Climate Zones

[4] State energy codes as of December 2011.

2.3 Study Period Lengths

Nine study period lengths are chosen for this analysis: 1 year, 5 years, 10 years, 15 years, 20 years, 25 years, 30 years, 35 years, and 40 years. The wide variation in investment time horizons allows this report to analyze the impact the study period length has on the benefits and costs of more stringent state energy code adoption. A 1-year study period is more representative of a developer that intends to sell a property soon after it is constructed. A 5-year to 15-year study period more closely represents a building owner's time horizon because few owners are concerned about costs realized beyond a decade into the future. The 20-year to 40-year study periods better represents institutions, such as colleges or government agencies, because these entities will own or lease buildings for 20 or more years. Most of the analysis in this study uses a 10-year study period.

3 Cost Data

The cost data collected to estimate life-cycle costs for the BIRDS database originates from multiple sources, including RS Means databases (RS Means, 2009), Whitestone (2008), and the U.S. Energy Information Administration (EIA) (EIA, 2010).[5] Costs are grouped into two categories, first costs that include initial building construction costs and future costs that include operational costs, maintenance, repair, and replacement costs, and building residual value. Both of these cost categories are described below.

3.1 First Costs

Building construction costs are obtained from the RS Means *CostWorks* online databases (RS Means, 2009). The costs of a prototypical building are estimated by the RS Means *CostWorks Square Foot Estimator* to obtain the default costs for each building type for each component. The RS Means default building is the baseline used to create a building that is compliant with each of the five energy efficiency design alternatives: *ASHRAE 90.1-1999*, *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the higher efficiency “Low Energy Case" (LEC) design. The RS Means default buildings are adapted to match the five prototype building designs by using the RS Means *CostWorks Cost Books* databases.

Five components -- roof insulation, wall insulation, windows, lighting, and HVAC efficiency -- are changed to make the prototypical designs *ASHRAE 90.1-1999, -2001, -2004, and -2007* compliant. A summary of the minimum requirement ranges, excluding HVAC efficiency, for each building design are shown in Table 3-1. The windows are selected to meet the minimum window characteristics (U-factor, solar heat gain coefficient (SHGC), and visible transmittance (VT)) required by the building design at the lowest possible cost. The lighting density in watts per unit of conditioned floor area is adjusted to meet each standard edition’s requirements.

[5] See Kneifel (2012) for additional details of the cost data used in the BIRDS database.

Table 3-1 Energy Efficiency Component Requirements for Alternative Building Designs

Design Component	Parameter	Units	ASHRAE 90.1-1999	ASHRAE 90.1-2001	ASHRAE 90.1-2004	ASHRAE 90.1-2007	Low Energy Case*
Roof Insulation	R-Value	$m^2·K/W$ ($ft^2·°F·h/Btu$)	1.7 to 4.4 (10.0 to 25.0)	1.7 to 4.4 (10.0 to 25.0)	2.6 to 3.5 (15.0 to 20.0)	2.6 to 3.5 (15.0 to 20.0)	4.4 to 6.2 (25.0 to 35.0)
Wall Insulation	R-Value	m^2*K/W ($ft^2·°F·h/Btu$)	0.0 to 3.8 (0.0 to 21.6)	0.0 to 3.8 (0.0 to 21.6)	0.0 to 2.7 (0.0 to 15.2)	0.0 to 2.7 (0.0 to 15.2)	0.7 to 5.5 (3.8 to 31.3)
Windows	U-Factor	W/(m2·K) ($Btu/(h·ft^2·°F)$)	1.42 to 7.21 (0.25 to 1.27)	1.42 to 7.21 (0.25 to 1.27)	1.99 to 6.47 (0.35 to 1.14)	2.50 to 6.47 (0.44 to 1.14)	1.97 to 6.42 (0.35 to 1.13)
	SHGC	Fraction	0.14 to NR†	0.14 to NR†	0.17 to NR†	0.25 to NR	0.25 to 0.47
Lighting	Power Density	W/m^2 (W/ft^2)	14.0 to 20.5 (1.3 to 1.9)	14.0 to 20.5 (1.3 to 1.9)	10.8 to 16.1 (1.0 to 1.5)	10.8 to 16.1 (1.0 to 1.5)	8.6 to 16.1 (0.8 to 1.5)
Overhangs			None	None	None	None	Zones 1 to 5
Daylighting			None	None	None	None	Zones 1 to 8

†North facing SHGC requirements are less restrictive than the requirements for the other 3 orientations.
* Low Energy Case design requirements are taken from the EnergyPlus simulations.
NR = No Requirement for one or more climate zones. The value of SHGC cannot exceed 1.0.

The LEC design increases the thermal efficiency of insulation and windows beyond *ASHRAE 90.1-2007*, further reduces the lighting power density, and adds daylighting and window overhangs. The lighting density of the lighting system is decreased by first increasing the efficiency of the lighting system and then decreasing the number of fixtures in the lighting system.[6] Daylighting is included for all building types and climate zones. Overhangs are placed on the east, west, and south sides of the building for each floor in Climate Zone 1 through Climate Zone 5 because these warmer climates are the zones that benefit from blocking solar radiation.[7]

Table 3-2 summarizes the HVAC efficiency requirements for each building design option across the different types of HVAC equipment.[8] Note that the LEC design assumes the same equipment efficiencies as *ASHRAE 90.1-2007*. This study assumes that cooling equipment is run on electricity while heating equipment is run on natural gas. The most significant increases in HVAC efficiency requirements occur between *ASHRAE 90.1-1999* and *ASHRAE 90.1-2001* except for rooftop packaged units, which have consistently increasing requirements across the *ASHRAE 90.1 Standard* editions.

[6] First, incandescent lighting is replaced with compact fluorescent lighting while typical T-12 fluorescent tube lighting is replaced with more efficient T-8 fluorescent tube lighting to decrease the lighting density of the lighting system. Second, the number of fixtures is reduced to meet the remainder of the required reduction in watts per unit of floor area. Increasing the efficiency of the lighting increases the costs of construction. The first approach increases first costs while the second approach decreases first costs for the lighting system. This approach is based on Belzer et al. (2005) and Halverson et al. (2006).

[7] Overhang cost source is Winiarski et al. (2003)

[8] This study does not account for new HVAC efficiency requirements set by federal regulations.

Table 3-2 HVAC Energy Efficiency Requirements for Alternative Building Designs

HVAC Type	Equipment Type	Unit	ASHRAE 90.1-1999	ASHRAE 90.1-2001	ASHRAE 90.1-2004	ASHRAE 90.1-2007	Low Energy Case
Cooling	Rooftop Packaged Unit	EER	8.2 to 9.0	9.0 to 9.9	9.2 to 10.1	9.5 to 13.0	9.5 to 13.0
	Air-Cooled Chiller	COP	2.5 to 2.7	2.8	2.8	2.8	2.8
	Water-Cooled Chiller	COP	3.80 to 5.20	4.45 to 5.50	4.45 to 5.50	4.45 to 5.50	4.45 to 5.50
	Split System with Condensing Unit	EER	8.7 to 9.9	9.9 to 10.1	10.1	10.1	10.1
Heating	Hot Water Boiler	E_t	75 % to 80 %	75 % to 80 %	75 % to 80 %	75 % to 80 %	75 % to 80 %
	Furnace	E_t	80 %	75 % to 80 %	75 % to 80 %	75 % to 80 %	75 % to 80 %

Assume that E_c = 75% E_t and AFUE = E_t, where E_c = combustion efficiency; E_t = thermal efficiency; AFUE = Annual Fuel Utilization Efficiency
EER = Energy Efficiency Ratio
COP = Coefficient of Performance
Note: Efficiency requirement ranges are based only on the system sizes calculated in the whole building energy simulations.

The HVAC system size varies across the five building designs because changing the thermal characteristics of the building envelope alters the heating and cooling loads of the building. The *EnergyPlus* whole building energy simulations “autosize” the HVAC system to determine the appropriate system size to efficiently maintain the thermal comfort while dealing with ventilation requirements. For each building design, the HVAC cost for the default HVAC system is replaced with the cost of the “autosized” HVAC system. An HVAC efficiency cost multiplier is used to adjust the HVAC equipment costs in accordance with the standard efficiency requirements shown in Table 3-2.

Construction costs for a building in each location are estimated by summing the baseline costs for the RS Means default building and the changes in costs required to meet the alternative prototype designs. National average construction costs are adjusted with the 2009 RS Means *CostWorks City Indexes* to control for local material and labor price variations. The “weighted average” city construction cost index is used to adjust the costs for the baseline default building while “component” city indexes are used to adjust the costs for the design changes. Once the indexed construction cost of the building is calculated, it is multiplied by the contractor “mark-up” rate, 25 %, and architectural fees rate, 7 %, to estimate the building's “first costs” of construction for the prototype buildings. These rates are the default values used by the RSMeans *Square Foot Estimator*.

3.2 Future Costs

Component and building lifetimes and component repair requirements are based on data from Whitestone (2008). Building service lifetimes are assumed constant across climate zones: apartment buildings lasting for 65 years; dormitories for 44 years; and hotels, schools, office buildings, retail stores, and restaurants for 41 years.

Building component maintenance, repair, and replacement (MRR) rates are from Kneifel (2010) and Kneifel (2011a). Insulation and windows are assumed to have a lifespan greater than 40 years and have no maintenance requirements. Insulation is assumed to have no repair costs. Windows have an assumed annual repair cost equal to replacing 1 % of all window panes, with costs that vary depending on the required window specifications (RS Means, 2009). The heating and cooling units have different lifespans and repair rates based on climate, ranging from 4 to 33 years for repairs and 13 to 50 years for replacements.

MRR cost data are collected from two sources. The total maintenance and repair costs per square foot of conditioned floor area (minus the HVAC maintenance and repair costs) represent the baseline MRR costs per unit of floor area, which occur for a building type regardless of the energy efficiency measures incorporated into the design. These data are collected from Whitestone (2008), which reports average maintenance and repair costs per unit of floor area by building component for each year of service life for each building type. The building types in Whitestone do not match exactly to the 11 building types selected for this study, and the most comparable profile is selected.

RS Means *CostWorks* is the source of MRR costs for the individual components for which MRR costs change across alternative building designs, which in this analysis are the HVAC system, lighting system, and windows. Lighting systems, including daylighting controls for the LEC design, are assumed to be replaced every 20 years. The HVAC system size varies based on the thermal performance of the alternative building design, which results in varying MRR costs because smaller systems are relatively cheaper to maintain, repair, and replace.

Future MRR costs are discounted to equivalent present values using the Single Present Value (SPV) factors for future non-fuel costs reported in Rushing and Lippiatt (2008), which are calculated using the U.S. Department of Energy's 2008 real discount rate for energy conservation projects (3 %).

A building's residual value is its value at the end of the study period. It is estimated in three parts, for the building (excluding components replaced during the study period), the HVAC system, and the lighting system based on the approach defined in Fuller et al. (1996). The building's residual value is assumed to be equal to the building's first cost (minus any components replaced over the study period) multiplied by the ratio of the study period to the service life of the building, and discounted from the end of the study period.

Two components may be replaced during the study period, the lighting and HVAC systems. Residual values for these components are computed for each location in a similar manner to the building residual value. The remaining "life" of the component is determined by taking its service life minus the number of years since its last installation, whether it occurred during building construction or replacement. The ratio of remaining life to service life is multiplied by the installed cost of the lighting and HVAC systems, and discounted from the end of the study period. The lighting system service life is 20 years while the HVAC system service life varies by location based on Towers et al. (2008).

Annual energy costs are estimated by multiplying annual electricity and natural gas use predicted by the whole building energy simulation by the average state retail commercial electricity and natural gas prices, respectively. Average state commercial electricity and natural gas prices for 2009 are collected from the Energy Information Administration (EIA) Electric Power Annual State Data Tables (EIA, 2010a) and Natural Gas Navigator (EIA, 2010b), respectively. The electricity and natural gas prices are assumed to change over time according to EIA forecasts from 2009 to 2039. These forecasts are embodied in the Federal Energy Management Program (FEMP) Uniform Present Value Discount Factors for energy price estimates (UPV*) reported in Rushing and Lippiatt (2009).[9] The UPV* values are used to discount future energy costs to equivalent present values. The discount factors vary by Census region, building sector, and fuel type.

[9] The escalation rates for years 31-40 are assumed to be the same as for year 30.

4 Building Stock Data

Aggregating the savings for individual newly constructed commercial buildings to the state level requires new construction data for each building type within each state. This study uses the commercial building weighting factors reported in Jarnagin and Bandyopadhyay (2010) to estimate the total energy use savings, energy cost savings, life-cycle cost savings, and carbon emissions reduction resulting from adopting newer energy standard editions for each state. Jarnagin and Bandyopadhyay (2010) use two databases to generate the commercial building weighting factors: the 2003Commercial Buildings Energy Consumption Survey (CBECS) and a McGraw-Hill construction dataset. The databases and the resulting weighting factors are described below.

4.1 Databases

The Commercial Buildings Energy Consumption Survey (CBECS) is a sample survey that collects information on the existing stock of U.S. commercial buildings. The sample includes 5215 buildings across the U.S. and 14 building type categories: education, food sales, food service, health care, lodging, mercantile, office, public assembly, public order and safety, religious worship, service, warehouse and storage, other, and vacant. Each category includes up to 12 subcategories as shown in Table A-1 in Appendix A. The survey data do not report the age or specific location of the building to protect the confidentiality of the respondents.

The McGraw-Hill dataset includes data for all new commercial buildings and additions, over 254 000 records and 761.8 million m^2 (8.2 billion ft^2) of new construction, for 2003 through 2007. The data are more detailed than the CBECS data, and include year of construction and location.

4.2 Weighting Factors

Jarnagin and Bandyopadhyay (2010) maps the more detailed McGraw-Hill dataset to the CBECS categories and subcategories shown in Table 4-1. The prototype commercial buildings analyzed in this study, shown in bold, represent 46.5 % of new commercial building stock floor area for 2003 through 2007 for the Midwest Census Region. The McGraw-Hill dataset is aggregated at the CBECS category-level. For this study, a prototype building is assumed to represent its entire CBECS category, which implies the prototypes together represent 57.8 % of the new commercial building stock.

Table 4-1 New Commercial Building Construction (Midwest, 2003 through 2007)

Category	Subcategory	Conditioned Floor Area 1000 m^2 (1000 ft^2)	Percentage in Category	Percentage of Total
Office	**Large**	3632 (39 100)	**22.2 %**	**2.5 %**
Office	**Medium**	6610 (71 155)	**40.4 %**	**4.5 %**
Office	**Small**	6120 (65 871)	**37.4 %**	**4.1 %**
Retail		20 974 (225 765)	**72.9 %**	**14.2 %**
Strip Mall		7797 (83 927)	27.1 %	5.3 %
School	Primary	6 215 (66 898)	32.5 %	4.2 %
School	**Secondary**	12 908 (138 941)	**67.5 %**	**8.7 %**
Hospital		5769 (62 093)	44.1 %	3.9 %
Other Health Care		7312 (78 708)	55.9 %	5.0 %
Restaurant	**Sit Down**	903 (9725)	**52.9 %**	**0.6 %**
Restaurant	Fast Food	804 (8658)	47.1 %	0.5 %
Hotel	**Large**	5190 (55 862)	**74.2 %**	**3.5 %**
Hotel/Motel	Small	1805 (19 424)	25.8 %	1.2 %
Warehouse		18 614 (200 364)		12.6 %
Public Assembly		9238 (99 434)		6.3 %
Apartment	**High-rise**	6816 (73 370)	**55.1 %**	**4.6 %**
Apartment	**Mid-rise**	5554 (59 788)	**44.9 %**	**3.8 %**
No Prototype		21 286 (229 124)		14.4 %
Total (2003 to		147 549 (1 588 205)		100.0 %

Note: Subcategory weighting is based on national construction data.

The types and floor area of buildings being constructed vary across states. Table A-2 and Table A-3 in Appendix A report new building construction for 2003 through 2007 by building type and state, in total new floor area and percentage of new floor area, respectively. The data in Table A-2 are used to aggregate the total savings for the new construction in the CBECS categories represented by the prototype building analyzed in this study. Nine of the eleven prototype commercial buildings analyzed in this study are covered by data reported in Table 4-1. No data for dormitories are reported, which limites the ability to estimate statewide impacts for the two types of dormitories.

5 Analysis Approach

The analysis in this report compares benefits and costs of the current state energy codes to more stringent alternatives. The relative changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs use the current energy code for a state as the baseline and uses each *ASHRAE 90.1 Standard* edition that is newer than that required by the current state energy code as an alternative design. The results are considered on both a percentage change and an aggregate change basis.

5.1 Energy Use

The analysis uses each state's current energy code as the baseline energy efficiency design. For any state without a state energy code, *ASHRAE 90.1-1999* is assumed to be the baseline because it represents minimum energy-related industry practices. The baseline for each state is compared to the higher energy efficiency building designs to determine the relative annual energy use savings resulting from adopting a more recent standard edition as the state's energy code. For example, if a state's energy code has adopted *ASHRAE 90.1-2001* as its energy standard requirement, this baseline energy use is compared to the energy use of all newer energy standard editions, *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007*, as well as a "Low Energy Case" that increases building energy efficiency beyond *ASHRAE 90.1-2007*.

It is assumed that the building maintains its energy efficiency performance throughout the study period, resulting in energy consumption remaining constant over the entire study period. This assumption is justified by the maintenance, repair, and replacement costs included in the analysis to ensure the building and its equipment performs as expected.

5.2 Life-Cycle Costing

Life-cycle costing (LCC) takes into account all relevant costs throughout the chosen study period, including construction costs, maintenance, repair, and replacement costs, energy costs, and residual values. A cost's present value (PV) is calculated by discounting its nominal value into today's dollars based on the year the cost occurs and the assumed discount rate. LCC of buildings typically compares the costs for a baseline building design to the costs for alternative, more energy-efficient building designs to determine if future operational savings justify higher initial investments.[10] For this study, the design based on any *ASHRAE 90.1 Standard* edition that is newer than the standard edition required by the current state energy code is compared to the baseline state energy code compliant design to determine the changes in life-cycle costs.

[10] All life-cycle cost calculations are based on ASTM Standards of Building Economics (2012).

Two metrics are used to analyze changes in life-cycle costs: net LCC savings and net LCC savings as a percentage of base case LCC. Net LCC savings is the difference between the base case and alternative design's LCCs.

5.3 Carbon Assessment

The BIRDS database expands on Kneifel (2011a) by conducting a life-cycle assessment (LCA) of energy-related greenhouse gas emissions, following guidance in the International Organization for Standardization (ISO) 14040 series of standards for LCA. The analysis quantifies the greenhouse gas emissions from electricity and natural gas use on a cradle-to-grave basis, including emissions from raw materials acquisition, materials processing, generation, transmission, distribution, use, and end-of-life.

The assessment of cradle-to-grave energy-related carbon emissions considers a number of greenhouse gases for two types of energy consumption, electricity and natural gas. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the most prevalent. While carbon emissions from natural gas use can be assessed on a national average basis, those from electricity use are highly dependent upon the fuel mixes of regional electricity grids. For this reason, electricity emissions are assessed at the state-level using North American Electric Reliability Corporation (NERC) sub-region level data.[11] The life-cycle data sets for natural gas production and combustion as well as for all fuel sources in the electricity grid come from the U.S. Life-Cycle Inventory (LCI) database (LCI, 2012). The state-level average emissions rates per GWh (MBtu) of electricity generated are obtained from the 2007 Emissions and Generation Resource Integrated Database (eGRID2007), which is a collection of data from the EIA, the Federal Energy Regulatory Commission (FERC), and the Environmental Protection Agency (EPA).[12] Table A-4 in Appendix A shows variation in the emissions rates for the top three greenhouse gases by state, which results from differing fuel mixes used for electricity generation in a state.[13]

These greenhouse gas emissions are converted into a common unit of measure called carbon dioxide equivalents (CO_2e) using equivalency factors reported in Table 5-1, which represent the global warming potential (GWP) of one unit of greenhouse gas relative to that of the same amount of carbon dioxide. For example, one unit of methane has 25 times the GWP as the same amount of carbon dioxide, and nitrous oxide has 298 times the GWP as carbon dioxide. The aggregated CO_2e is calculated by taking the amount of

[11] For states located in more than one NERC sub-region, a weighted average of emissions rates for the multiple sub-regions is implemented.
[12] Emissions rates are held constant over all study periods.
[13] While carbon assessment of building construction, maintenance, repair, and replacement is currently excluded from the analysis, it is currently under development and will be included in future analysis of this work.

each flow multiplied by its CO_2e factor, and summing the resulting CO_2 equivalencies. The results are analyzed in metric tons of CO_2e emissions, and will be referred to as “carbon emissions” for the remainder of the report.

Table 5-1 Greenhouse Gas Global Warming Potentials

Environmental Flow	GWP (CO_2e)
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298
Ethane, 1,1-difluoro-, HFC-152a	124
Ethane, 1,1,1-trichloro-, HCFC-140	146
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	1430
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	6130
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	10 000
Ethane, hexafluoro-, HFC-116	12 200
Methane, bromo-, Halon 1001	5
Methane, bromochlorodifluoro-, Halon 1211	1890
Methane, bromotrifluoro-, Halon 1301	7140
Methane, chlorodifluoro-, HCFC-22	1810
Methane, dichloro-, HCC-30	9
Methane, dichlorodifluoro-, CFC-12	10 900
Methane, monochloro-, R-40	13
Methane, tetrachloro-, CFC-10	1400
Methane, tetrafluoro-, CFC-14	7390
Methane, trichlorofluoro-, CFC-11	4750
Methane, trifluoro-, HFC-23	14 800

5.4 Analysis Metrics

The average percentage energy use savings, energy cost savings, energy-related carbon emissions reductions, and life-cycle cost savings are calculated by taking the simple average of the percentage savings for each location-building type combination in the state or nation. The average of the percentage change is used instead of using the average change in total values for the state or nation because the latter approach would in effect give greater weight to buildings or locations with greater total changes. The simple average approach used in this study weights each location-building type equally.

The estimated change in total energy use, energy costs, energy-related carbon emissions, and life-cycle costs for each of the building types is combined with new commercial building construction data to calculate the magnitude of the available total savings a state may realize if it were to adopt a more energy efficient standard as its state energy code. The total change per unit of floor area is multiplied by the average annual floor area of new construction for 2003 to 2007, discussed in Section 4.2, which results in the total savings over the study period for a single year's worth of new construction in a state.

In order to compare total savings across states for a 10-year study period, the aggregate savings in energy use and life-cycle costs are divided by the annual new floor area. Aggregate savings in energy costs and energy-related carbon emissions are divided by aggregate savings in energy use for a 10-year study period to create a comparable metric to determine the factors that impact the relative savings across states.

6 Illinois

Illinois has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the East North Central Census Division, and spans two climate zones (Zone 4A and Zone 5A). Table 6-1 provides an overview of Illinois's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 87 kWh/m^2 to 106 kWh/m^2 (28 kBtu/ft^2 to 34 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 242 kWh/m^2 to 257 kWh/m^2 (77 kBtu/ ft^2 to 81 kBtu/ft^2) annually.

Table 6-1 Average Annual Energy Use by Building Type and Standard Edition, Illinois

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	173	55	156	50
APART06	171	54	153	49
DORMI04	134	42	119	38
DORMI06	189	60	170	54
HOTEL15	179	57	158	50
HIGHS02	257	81	242	77
OFFIC03	117	37	97	31
OFFIC08	106	34	87	28
OFFIC16	168	53	145	46
RETAIL1	130	41	114	36
RSTRNT1	179	57	137	44

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

6.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in the LEC design in the state of Illinois.

6.1.1 Statewide Building Comparison

Table 6-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*.

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -5.6 % to -23.3 % depending on the building type with an overall average of -13.1 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

Table 6-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Illinois

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.4	-17.1	-17.1	0.3
APART06	-10.5	-20.0	-20.1	0.1
DORMI04	-11.1	-17.8	-17.8	-0.3
DORMI06	-10.3	-19.4	-19.4	-0.2
HOTEL15	-11.8	-19.2	-19.2	0.2
HIGHS02	-5.6	-16.4	-16.5	-1.1
OFFIC03	-17.5	-23.0	-23.0	-2.4
OFFIC08	-17.8	-21.0	-21.0	-2.2
OFFIC16	-13.9	-19.8	-19.8	0.2
RETAIL1	-12.5	-16.9	-16.9	-0.4
RSTRNT1	-23.3	-32.6	-32.6	-4.5
Average	**-13.1**	**-20.3**	**-20.3**	**-0.9**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.4 % to -32.6 % depending on the building type with an average of -20.3 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 8 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 41.9 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is nearly three times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.5 % to -32.6 % with an average of -20.3 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity

consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 8 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -4.5 % to 0.3 % for a 10-year study period. Seven of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage reduction in life-cycle costs of 0.9 %, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

6.1.2 City Comparisons

Simulations are run for five cities located in Illinois, all located in Zone 5A: Chicago, Moline, Peoria, Rockford, and Springfield. While the five cities are located in the same climate zone, the results may still vary for two reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality.

Table 6-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for adoption of the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design do not vary significantly across cities, ranging from -12.7 % to -13.9 % with an overall average of -13.1 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 6-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Illinois

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Chicago	5A	-12.7	-20.1	-20.3	-0.6
Moline	5A	-13.3	-20.4	-20.7	-0.9
Peoria	5A	-13.1	-20.3	-20.5	-0.8
Rockford	5A	-12.4	-20.0	-20.3	-0.8
Springfield	5A	-13.9	-20.7	-20.9	-1.5
Average		**-13.1**	**-20.3**	**-20.6**	**-0.9**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -20.0 % to -20.7 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across all cities, ranging from -20.3 % to -20.9 %. Reductions in life-cycle costs vary across building types, with the percentage change in life-cycle costs ranging from -0.6 % to -1.5 %. Springfield realizes much larger reductions in life-cycle costs than the other 4 cities.

6.2 Total Savings

How much can Illinois save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

6.2.1 Energy Use

Table 6-4 reports the average per unit change in annual energy use by building type and building design in the state.[14] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 6-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[15]

[14] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.

[15] State-level subcategory data are not available.

Table 6-4 Average Per Unit Change in Annual Energy Use, Illinois

Building Type	Standard Edition LEC	
	kWh/m^2	kBtu/ft^2
APART04	-17.5	-5.5
APART06	-16.8	-5.3
DORMI04	-17.6	-5.6
DORMI06	-16.7	-5.3
HOTEL15	-17.8	-5.6
HIGHS02	-21.6	-6.9
OFFIC03	-17.5	-5.6
OFFIC08	-18.0	-5.7
OFFIC16	-20.2	-6.4
RETAIL1	-22.0	-7.0
RSTRNT1	-44.0	-14.0

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 71.8 GWh (245.1 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 59.2 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 121.3 GWh (414.1 GBtu) per year. These savings imply 1212.7 GWh (4140.6 GBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions in energy use are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest changes in energy use. The greatest total reductions are realized by retail stores and 6-story apartments because they represent 27.6 % and 19.6 %, respectively, of the new construction in the state while all other building types represent 16.0 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and 6-story apartment buildings -- only rank 5th and 8th in percentage reduction, respectively, among the 11 building types, as reported in Table 6-2.

Table 6-5 Statewide Change in Annual Energy Use for One Year of Construction, Illinois

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	656.5	7066	-10 695 560	-36 519 240
APART06	55.1 %	804.1	8655	-14 477 986	-49 434 069
HOTEL15	100.0 %	260.8	2807	-5 503 035	-18 789 727
HIGHS02	100.0 %	616.5	6636	-8 830 677	-30 151 730
OFFIC03	37.4 %	219.3	2361	-4 495 869	-15 350 829
OFFIC08	40.4 %	236.5	2546	-4 462 289	-15 236 174
OFFIC16	22.2 %	130.2	1401	-3 036 937	-10 369 408
RETAIL1	100.0 %	1132.1	12 186	-18 360 017	-62 688 994
RSTRNT1	100.0 %	46.4	499	-1 928 277	-6 583 968
Total		**4102.5**	**44 159**	**-71 790 647**	**-245 124 139**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

6.2.2 Energy Costs

Table 6-6 reports the average per unit change in energy costs by building type for the LEC design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 6-6 Average Per Unit Change in Energy Costs, 10-Year, Illinois

Building Type	Standard Edition LEC	
	$/m²	$/ft²
APART04	-$16.11	-$1.50
APART06	-$19.02	-$1.77
DORMI04	-$13.27	-$1.23
DORMI06	-$20.25	-$1.88
HOTEL15	-$19.09	-$1.77
HIGHS02	-$20.03	-$1.86
OFFIC03	-$20.35	-$1.89
OFFIC08	-$17.99	-$1.67
OFFIC16	-$22.92	-$2.13
RETAIL1	-$14.83	-$1.38
RSTRNT1	-$38.88	-$3.61

Table 6-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $73.6 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 59.2 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $124.4 million over the 10-year study period.

Table 6-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Illinois

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	656.5	7066	-$10 574 507
APART06	55.1 %	804.1	8655	-$15 294 462
HOTEL15	100.0 %	260.8	2807	-$4 979 630
HIGHS02	100.0 %	616.5	6636	-$12 543 163
OFFIC03	37.4 %	219.3	2361	-$4 392 912
OFFIC08	40.4 %	236.5	2546	-$4 256 760
OFFIC16	22.2 %	130.2	1401	-$2 982 916
RETAIL1	100.0 %	1132.1	12 186	-$16 788 997
RSTRNT1	100.0 %	46.4	499	-$1 803 993
Total		**4102.5**	**44 159**	**-$73 617 341**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

6.2.3 Energy-related Carbon Emissions

Table 6-8 reports the average energy-related carbon emissions reduction over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

Table 6-8 Average Per Unit Change in Carbon Emissions, 10-Year, Illinois

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-174.0	-35.6
APART06	-205.5	-42.1
DORMI04	-143.3	-29.3
DORMI06	-218.8	-44.8
HOTEL15	-206.2	-42.2
HIGHS02	-220.0	-45.1
OFFIC03	-216.3	-44.3
OFFIC08	-194.4	-39.8
OFFIC16	-247.6	-50.7
RETAIL1	-160.2	-32.8
RSTRNT1	-420.0	-86.0

Table 6-9 applies the Table 6-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The adoption of the LEC design decreases carbon emissions for all building types and results in total savings of 795 350 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the statewide reductions in carbon emissions of 1.3 million metric tons over the 10-year study period.

Table 6-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Illinois – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	656.5	7066	-114 232
APART06	55.1 %	804.1	8655	-165 254
HOTEL15	100.0 %	260.8	2807	-53 776
HIGHS02	100.0 %	616.5	6636	-135 617
OFFIC03	37.4 %	219.3	2361	-47 453
OFFIC08	40.4 %	236.5	2546	-45 978
OFFIC16	22.2 %	130.2	1401	-32 226
RETAIL1	100.0 %	1132.1	12 186	-181 344
RSTRNT1	100.0 %	46.4	499	-19 471
Total		**4102.5**	**44 159**	**-795 350**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

6.2.4 Life-Cycle Costs

Table 6-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 6-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Illinois

Building Type	Standard Edition LEC $/m^2	$/ft^2
APART04	$3.56	$0.33
APART06	$1.77	$0.16
DORMI04	-$2.67	-$0.25
DORMI06	-$1.74	-$0.16
HOTEL15	$2.16	$0.20
HIGHS02	-$10.70	-$0.99
OFFIC03	-$22.08	-$2.05
OFFIC08	-$20.37	-$1.89
OFFIC16	$1.64	$0.15
RETAIL1	-$3.26	-$0.30
RSTRNT1	-$68.51	-$6.36

Table 6-11 applies the Table 6-10 results to one year's worth of new building construction in the state to estimate change in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 5 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $18.6 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools, 3-story office buildings, and 8-story office buildings realize the greatest statewide decrease in life-cycle costs ($6.6 million, $4.8 million, and $4.8 million, respectively). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $31.4 million over the 10-year study period.

Table 6-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Illinois

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	656.5	7066	$2 337 211
APART06	55.1 %	804.1	8655	$1 420 712
HOTEL15	100.0 %	260.8	2807	$563 277
HIGHS02	100.0 %	616.5	6636	-$6 595 166
OFFIC03	37.4 %	219.3	2361	-$4 844 198
OFFIC08	40.4 %	236.5	2546	-$4 817 556
OFFIC16	22.2 %	130.2	1401	$213 398
RETAIL1	100.0 %	1132.1	12 186	-$3 691 062
RSTRNT1	100.0 %	46.4	499	-$3 178 642
Total		**4102.5**	**44 159**	**-$18 592 026**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

6.3 State Summary

Illinois has adopted *ASHRAE 90.1-2007* as its state commercial building energy code. On average, adopting the LEC design reduces energy use, energy costs and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 1212.7 GWh (4140.6 GBtu), energy cost savings of $124.4 million, and carbon emissions reductions of 1.3 million metric tons while decreasing life-cycle costs by $31.4 million for one year's worth of commercial building construction.

7 Indiana

Indiana has adopted *ASHRAE 90.1-2007* as its state energy code, is located in the East North Central Census Division, and spans two climate zones (Zone 4A and Zone 5A). Table 7-1 provides an overview of Indiana's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 84 kWh/m^2 to 103 kWh/m^2 (27 kBtu/ft^2 to 33 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 221 kWh/m^2 to 236 kWh/m^2 (70 kBtu/ft^2 to 75 kBtu/ft^2) annually.

Table 7-1 Average Annual Energy Use by Building Type and Standard Edition, Indiana

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	163	52	146	46
APART06	162	51	143	45
DORMI04	125	40	110	35
DORMI06	178	56	158	50
HOTEL15	168	53	147	47
HIGHS02	236	75	221	70
OFFIC03	113	36	92	29
OFFIC08	103	33	84	27
OFFIC16	160	51	136	43
RETAIL1	122	39	106	34
RSTRNT1	171	54	128	41

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

7.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in the LEC design in the state of Indiana.

7.1.1 Statewide Building Comparison

Table 7-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*. There is significant variation in the change in energy use for the LEC design relative to

ASHRAE 90.1-2007, ranging from -6.4 % to -24.8 % depending on the building type with an overall average of -13.9 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

Table 7-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Indiana

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.1	-16.0	-17.1	0.6
APART06	-11.3	-18.7	-20.1	0.5
DORMI04	-11.8	-16.9	-17.9	-0.4
DORMI06	-11.0	-18.1	-19.4	0.2
HOTEL15	-12.3	-18.1	-19.2	0.5
HIGHS02	-6.4	-14.8	-16.6	-0.8
OFFIC03	-18.3	-22.4	-23.0	-2.1
OFFIC08	-18.5	-20.8	-21.1	-2.0
OFFIC16	-15.0	-19.7	-20.4	0.6
RETAIL1	-13.5	-16.8	-17.4	0.5
RSTRNT1	-24.8	-31.9	-33.1	-4.3
Average	**-13.9**	**-19.5**	**-20.5**	**-0.6**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -14.8 % to -31.9 % depending on the building type with an average of -19.5 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 10 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 40.6 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over two times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.6 % to -33.1 % with an average of -20.5 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 10 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -4.3 % to 0.6 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -0.6 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

7.1.2 City Comparisons

Simulations are run for five cities located in Indiana: Evansville in Zone 4A and Fort Wayne, Indianapolis, and South Bend in Zone 5A. The results may vary across cities within Indiana for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and may impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 7-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design vary minimally across cities, ranging from -13.0 % to -15.5 % with an overall average of -13.9 %. The city in Zone 4A (Evansville) realizes slightly greater reductions in energy consumption than cities in Zone 5A.

Table 7-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Indiana

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Evansville	4A	-15.5	-20.4	-21.4	-0.7
Fort Wayne	5A	-13.0	-18.9	-20.2	-0.7
Indianapolis	5A	-14.1	-19.8	-21.0	-0.6
South Bend	5A	-13.0	-18.8	-20.1	-0.5
Average		**-13.9**	**-19.5**	**-20.7**	**-0.6**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -18.8 % to -20.4 % for 10 years of operation. The city in Zone 4A (Evansville) realizes slightly greater reductions in energy costs than the cities in Zone 5A. For all cities, percentage reductions in energy costs are greater than percentage reductions in energy use because the percentage reduction in electricity is greater than the reduction in natural gas. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -20.1 % to -21.4 %. Reductions in life-cycle costs for all building types vary minimally across cities, with the percentage change in life-cycle costs ranging from -0.5 % to -0.7 %.

7.2 Total Savings

How much can Indiana save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

7.2.1 Energy Use

Table 7-4 reports the average per unit change in annual energy use by building type and building design in the state.[16] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 7-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[17]

[16] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[17] State-level subcategory data are not available.

Table 7-4 Average Per Unit Change in Annual Energy Use, Indiana

Building Type	Standard Edition LEC	
	kWh/m^2	kBtu/ft^2
APART04	-16.31	-5.17
APART06	-18.14	-5.75
DORMI04	-14.67	-4.65
DORMI06	-19.49	-6.18
HOTEL15	-20.52	-6.51
HIGHS02	-20.62	-6.54
OFFIC03	-14.82	-4.70
OFFIC08	-18.97	-6.02
OFFIC16	-23.92	-7.59
RETAIL1	-16.45	-5.22
RSTRNT1	-42.29	-13.41

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 32.6 GWh (111.2 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 49.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 65.7 GWh (224.3 GBtu) per year. These savings imply 656.9 GWh (2242.9 GBtu) in energy use savings over the 10-year study period.

The total change in energy use varies across building types. The building types that have the greatest percentage reductions in energy use are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest reductions in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 36.4 % and 28.2 %, respectively, of the new construction in the state while all other building types represent 9.4 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and high schools -- only rank 5th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 7-2.

Table 7-5 Statewide Change in Annual Energy Use for One Year of Construction, Indiana

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	32.3	348	-527 760	-1 802 001
APART06	55.1 %	39.7	427	-718 938	-2 454 765
HOTEL15	100.0 %	171.1	1842	-3 512 056	-11 991 668
HIGHS02	100.0 %	511.6	5507	-7 582 543	-25 890 062
OFFIC03	37.4 %	130.7	1407	-2 694 285	-9 199 448
OFFIC08	40.4 %	140.9	1517	-2 672 818	-9 126 150
OFFIC16	22.2 %	77.6	835	-1 854 780	-6 333 016
RETAIL1	100.0 %	660.4	7108	-10 859 260	-37 078 183
RSTRNT1	100.0 %	51.0	549	-2 158 534	-7 370 162
Total		**1815.2**	**19 539**	**-32 580 974**	**-111 245 456**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

7.2.2 Energy Costs

Table 7-6 reports the average per unit change in energy costs by building type for the LEC design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 7-6 Average Per Unit Change in Energy Costs, 10-Year, Indiana

Building Type	Standard Edition LEC $/m^2$	Standard Edition LEC $/ft^2$
APART04	-$11.85	-$1.10
APART06	-$13.89	-$1.29
DORMI04	-$9.86	-$0.92
DORMI06	-$14.79	-$1.37
HOTEL15	-$13.96	-$1.30
HIGHS02	-$14.69	-$1.37
OFFIC03	-$14.47	-$1.34
OFFIC08	-$13.23	-$1.23
OFFIC16	-$17.23	-$1.60
RETAIL1	-$11.17	-$1.04
RSTRNT1	-$29.14	-$2.71

Table 7-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $24.7 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 49.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $49.8 million over the 10-year study period.

Table 7-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Indiana

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	32.3	348	-$383 546
APART06	55.1 %	39.7	427	-$550 457
HOTEL15	100.0 %	171.1	1842	-$2 388 096
HIGHS02	100.0 %	511.6	5507	-$7 403 619
OFFIC03	37.4 %	130.7	1407	-$1 920 306
OFFIC08	40.4 %	140.9	1517	-$1 864 299
OFFIC16	22.2 %	77.6	835	-$1 335 702
RETAIL1	100.0 %	660.4	7108	-$7 375 366
RSTRNT1	100.0 %	51.0	549	-$1 487 185
Total		**1815.2**	**19 539**	**-$24 708 576**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

7.2.3 Energy-related Carbon Emissions

Table 7-8 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

Table 7-8 Average Per Unit Change in Carbon Emissions, 10-Year, Indiana

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-154.6	-31.7
APART06	-182.1	-37.3
DORMI04	-127.4	-26.1
DORMI06	-193.7	-39.7
HOTEL15	-180.6	-37.0
HIGHS02	-194.1	-39.8
OFFIC03	-191.2	-39.2
OFFIC08	-171.7	-35.2
OFFIC16	-224.4	-46.0
RETAIL1	-144.5	-29.6
RSTRNT1	-377.7	-77.4

Table 7-9 applies the Table 7-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 339 945 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 652 713 metric tons over the 10-year study period.

Table 7-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Indiana – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	32.3	348	-5002
APART06	55.1 %	39.7	427	-7220
HOTEL15	100.0 %	171.1	1842	-47 109
HIGHS02	100.0 %	511.6	5507	-99 293
OFFIC03	37.4 %	130.7	1407	-24 991
OFFIC08	40.4 %	140.9	1517	-24 202
OFFIC16	22.2 %	77.6	835	-17 403
RETAIL1	100.0 %	660.4	7108	-95 447
RSTRNT1	100.0 %	51.0	549	-19 279
Total		**1815.2**	**19 539**	**-339 945**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

7.2.4 Life-Cycle Costs

Table 7-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 7-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Indiana

Building Type	Standard Edition LEC $/m^2	Standard Edition LEC $/ft^2
APART04	$5.82	$0.54
APART06	$4.61	$0.43
DORMI04	-$3.73	-$0.35
DORMI06	$1.61	$0.15
HOTEL15	$4.76	$0.44
HIGHS02	-$6.50	-$0.60
OFFIC03	-$16.63	-$1.54
OFFIC08	-$16.84	-$1.56
OFFIC16	$4.41	$0.41
RETAIL1	$3.43	$0.32
RSTRNT1	-$57.55	-$5.35

Table 7-11 applies the Table 7-10 results to one year's worth of new building construction in the state to estimate changes in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $6.6 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools and restaurants realize the greatest statewide decreases in life-cycle costs ($3.3 million and $2.9 million, respectively) while 16-story office buildings realize the greatest increase in life-cycle costs ($341 733) followed by the 4- and 6-story apartment buildings ($188 320 and $182 538, respectively). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $13.3 million over the 10-year study period.

Table 7-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Indiana

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	32.3	348	$188 320
APART06	55.1 %	39.7	427	$182 538
HOTEL15	100.0 %	171.1	1842	$1 242 497
HIGHS02	100.0 %	511.6	5507	-$3 326 796
OFFIC03	37.4 %	130.7	1407	-$2 173 058
OFFIC08	40.4 %	140.9	1517	-$2 373 101
OFFIC16	22.2 %	77.6	835	$341 733
RETAIL1	100.0 %	660.4	7108	$2 265 648
RSTRNT1	100.0 %	51.0	549	-$2 937 651
Total		**1815.2**	**19 539**	**-$6 589 870**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

7.3 State Summary

Indiana has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 656.9 GWh (2242.9 GBtu), energy cost savings of $49.8 million, and carbon emissions reductions of 652 713 metric tons while decreasing life-cycle costs by $13.3 million for one year's worth of commercial building construction.

8 Iowa

Iowa has adopted *ASHRAE 90.1-2007* as its state energy code, is located in the West North Central Census Division, and spans two climate zones (Zone 5A and Zone 6A). Table 8-1 provides an overview of Iowa's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 91 kWh/m^2 to 110 kWh/m^2 (29 $kBtu/ft^2$ to 35 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 258 kWh/m^2 to 275 kWh/m^2 (87 $kBtu/ft^2$ to 82 $kBtu/ft^2$) annually.

Table 8-1 Average Annual Energy Use by Building Type and Standard Edition, Iowa

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	180	57	162	52
APART06	179	57	160	51
DORMI04	142	45	125	40
DORMI06	199	63	179	57
HOTEL15	190	60	169	54
HIGHS02	275	87	258	82
OFFIC03	122	39	100	32
OFFIC08	110	35	91	29
OFFIC16	178	56	155	49
RETAIL1	138	44	118	37
RSTRNT1	189	60	144	46

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

8.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in the LEC design in the state of Iowa.

8.1.1 Statewide Building Comparison

Table 8-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*. There is significant variation in the change in energy use for the LEC design relative to

ASHRAE 90.1-2007, ranging from -6.1 % to -23.7 % depending on the building type with an overall average of -13.2 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 8-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Iowa

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.8	-15.8	-16.8	0.5
APART06	-10.6	-17.6	-18.7	0.5
DORMI04	-11.7	-16.7	-17.5	-0.2
DORMI06	-10.0	-16.4	-17.4	0.2
HOTEL15	-11.0	-15.3	-16.0	0.5
HIGHS02	-6.1	-13.8	-15.2	-0.8
OFFIC03	-17.7	-21.4	-21.9	-1.7
OFFIC08	-17.3	-19.6	-19.8	-1.5
OFFIC16	-13.0	-16.2	-16.6	0.6
RETAIL1	-14.3	-17.2	-17.6	0.6
RSTRNT1	-23.7	-30.3	-31.2	-4.4
Average	**-13.2**	**-18.2**	**-19.0**	**-0.5**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.3 % to -30.3 % depending on the building type with an average of -18.2 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 4 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 28.7 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over two times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.2 % to -31.2 % with an average of -19.0 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 4 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -4.4 % to 0.6 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs with restaurants realizing the greatest percentage reduction in life-cycle costs while retail stores and 16-story office buildings realizing the largest increase in life-cycle costs (0.6 %). Based on the overall average percentage change of -0.5 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

8.1.2 City Comparisons

Simulations are run for five cities located in Iowa: Burlington, Des Moines, and Sioux City in Zone 5A, and Mason City and Waterloo in Zone 6A. The results may vary across cities within Iowa for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 8-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design varies minimally across cities, ranging from -12.7 % to -13.9 % with an overall average of -13.2 %. The cities in Zone 5A realize slightly greater changes, on average, than cities in Zone 6A (-13.4 % versus -12.9 %).

Table 8-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Iowa

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Burlington	5A	-13.9	-19.6	-20.7	-0.6
Des Moines	5A	-13.4	-19.4	-20.5	-0.5
Sioux City	5A	-13.0	-19.1	-20.2	-0.4
Mason City	6A	-12.7	-16.3	-17.1	-0.5
Waterloo	6A	-13.1	-16.6	-17.4	-0.4
Average		**-13.2**	**-18.2**	**-19.2**	**-0.5**

The average percentage change in energy costs for all building types varies across cities, ranging from -16.3 % to -19.6 % for 10 years of operation. Cities in the warmer climate zone (Zone 5A) realize a greater reduction in energy costs than cities in the colder climate zone (Zone 6A). For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies across cities, ranging from -17.1 % to -20.7 % with cities in the warmer climate zone realizing greater reductions in carbon emissions. Changes in life-cycle costs for all building types vary minimally across cities, with the percentage change in life-cycle costs ranging from -0.4 % to -0.6 %. There are no distinct trends across cities within different climate zones.

8.2 Total Savings

How much can Iowa save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

8.2.1 Energy Use

Table 8-4 reports the average per unit change in annual energy use by building type and building design in the state.[18] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 8-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[19]

[18] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[19] State-level subcategory data are not available.

Table 8-4 Average Per Unit Change in Annual Energy Use, Iowa

Building Type	Standard Edition	
	LEC	
	kWh/m²	kBtu/ft²
APART04	-17.7	-5.6
APART06	-18.9	-6.0
DORMI04	-16.6	-5.3
DORMI06	-19.7	-6.3
HOTEL15	-20.7	-6.6
HIGHS02	-21.6	-6.9
OFFIC03	-16.8	-5.3
OFFIC08	-19.0	-6.0
OFFIC16	-23.0	-7.3
RETAIL1	-19.7	-6.3
RSTRNT1	-44.7	-14.2

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 16.7 GWh (57.0 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 58.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 28.4 GWh (96.9 GBtu) per year. These savings imply 283.7 GWh (968.6 GBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest changes in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 31.7 % and 29.7 %, respectively, of the new construction in the state while all other building types represent 10.0 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated total reductions in energy use for the LEC design – retail stores and high schools -- only rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 8-2.

Table 8-5 Statewide Change in Annual Energy Use for One Year of Construction, Iowa

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	12.9	139	-228 180	-779 104
APART06	55.1 %	15.8	170	-298 046	-1 017 658
HOTEL15	100.0 %	85.4	920	-1 766 677	-6 032 195
HIGHS02	100.0 %	252.4	2,717	-4 236 977	-14 466 863
OFFIC03	37.4 %	74.8	805	-1 617 890	-5 524 174
OFFIC08	40.4 %	80.6	868	-1 530 617	-5 226 186
OFFIC16	22.2 %	44.4	477	-1 019 674	-3 481 606
RETAIL1	100.0 %	270.1	2,907	-5 320 922	-18 167 916
RSTRNT1	100.0 %	14.8	159	-661 793	-2 259 645
Total		**851.1**	**9,161**	**-16 680 777**	**-56 955 346**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

8.2.2 Energy Costs

Table 8-6 reports the average per unit change in energy costs by building type for the LEC design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 8-6 Average Per Unit Change in Energy Costs, 10-Year, Iowa

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$10.94	-$1.02
APART06	-$12.18	-$1.13
DORMI04	-$9.16	-$0.85
DORMI06	-$12.59	-$1.17
HOTEL15	-$11.29	-$1.05
HIGHS02	-$12.97	-$1.20
OFFIC03	-$13.07	-$1.21
OFFIC08	-$11.47	-$1.07
OFFIC16	-$13.39	-$1.24
RETAIL1	-$10.74	-$1.00
RSTRNT1	-$25.70	-$2.39

Table 8-7 reports the statewide changes in total energy costs by building type and building design, which account for one year’s worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with statewide reductions in energy costs of $10.4 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 58.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $17.6 million over the 10-year study period.

Table 8-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Iowa

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	12.9	139	-$140 931
APART06	55.1 %	15.8	170	-$192 129
HOTEL15	100.0 %	85.4	920	-$964 872
HIGHS02	100.0 %	252.4	2717	-$3 300 522
OFFIC03	37.4 %	74.8	805	-$969 233
OFFIC08	40.4 %	80.6	868	-$924 268
OFFIC16	22.2 %	44.4	477	-$593 818
RETAIL1	100.0 %	270.1	2907	-$2 899 061
RSTRNT1	100.0 %	14.8	159	-$380 105
Total		**851.1**	**9161**	**-$10 364 938**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

8.2.3 Energy-related Carbon Emissions

Table 8-8 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

Table 8-8 Average Per Unit Change in Carbon Emissions, 10-Year, Iowa

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-159.1	-32.6
APART06	-177.8	-36.4
DORMI04	-131.7	-27.0
DORMI06	-183.6	-37.6
HOTEL15	-162.2	-33.2
HIGHS02	-193.8	-39.7
OFFIC03	-188.0	-38.5
OFFIC08	-166.3	-34.1
OFFIC16	-193.5	-39.6
RETAIL1	-154.1	-31.6
RSTRNT1	-371.0	-76.0

Table 8-9 applies the Table 8-8 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of the LEC design. The total reductions in carbon emissions ranges widely across building designs and is highly correlated with total reductions in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 150 791 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 256 448 metric tons over the 10-year study period.

Table 8-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Iowa – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	12.9	139	-2049
APART06	55.1 %	15.8	170	-2805
HOTEL15	100.0 %	85.4	920	-13 855
HIGHS02	100.0 %	252.4	2717	-48 934
OFFIC03	37.4 %	74.8	805	-14 051
OFFIC08	40.4 %	80.6	868	-13 410
OFFIC16	22.2 %	44.4	477	-8584
RETAIL1	100.0 %	270.1	2907	-41 617
RSTRNT1	100.0 %	14.8	159	-5487
Total		851.1	9,161	-150 791

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

8.2.4 Life-Cycle Costs

Table 8-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 8-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Iowa

Building Type	Standard Edition LEC	
	$/m²	$/ft²
APART04	$5.17	$0.48
APART06	$4.68	$0.43
DORMI04	-$1.99	-$0.18
DORMI06	$2.07	$0.19
HOTEL15	$4.39	$0.41
HIGHS02	-$5.85	-$0.54
OFFIC03	-$12.47	-$1.16
OFFIC08	-$11.37	-$1.06
OFFIC16	$4.41	$0.41
RETAIL1	$3.97	$0.37
RSTRNT1	-$54.48	-$5.06

Table 8-11 applies the Table 8-10 results to one year's worth of new building construction in the state to estimate changes in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $2.3 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools, 3-story office buildings, and 8-story office buildings realize the greatest statewide decrease in life-cycle costs ($1.5 million, $932 258, and $916 947, respectively) while retail stores realize the largest increase in life-cycle costs of $1.1 million. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $4.0 million over the 10-year study period.

Table 8-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Iowa

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	12.9	139	$66 586
APART06	55.1 %	15.8	170	$73 778
HOTEL15	100.0 %	85.4	920	$374 685
HIGHS02	100.0 %	252.4	2717	-$1 476 955
OFFIC03	37.4 %	74.8	805	-$932 258
OFFIC08	40.4 %	80.6	868	-$916 947
OFFIC16	22.2 %	44.4	477	$195 513
RETAIL1	100.0 %	270.1	2907	$1 073 263
RSTRNT1	100.0 %	14.8	159	-$805 723
Total		**851.1**	**9161**	**-$2 348 057**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

8.3 State Summary

Iowa has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 283.7 GWh (968.6 GBtu), energy cost savings of $17.6 million, and carbon emissions reductions of 256 448 metric tons while decreasing life-cycle costs by $4.0 million for one year's worth of commercial building construction.

9 Kansas

Kansas is located in the West North Central Census Division and spans the warmest climate zones in the Midwest Census Region (Zone 4A and Zone 5A). The state does not have a commercial building energy code, and is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements. Table 9-1 provides an overview of Kansas's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 84 kWh/m^2 to 124 kWh/m^2 (27 kBtu/ft^2 to 39 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 205 kWh/m^2 to 238 kWh/m^2 (65 kBtu/ft^2 to 75 kBtu/ft^2) annually.

Table 9-1 Average Annual Energy Use by Building Type and Standard Edition, Kansas

Building Type	Standard Edition									
	1999		2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	183	58	181	58	160	51	154	49	137	44
APART06	181	57	179	57	158	50	153	48	134	42
DORMI04	143	45	140	44	124	39	118	38	103	33
DORMI06	197	62	194	62	171	54	169	53	148	47
HOTEL15	171	54	169	54	151	48	159	50	137	44
HIGHS02	238	75	236	75	229	73	221	70	205	65
OFFIC03	132	42	129	41	121	38	112	36	90	29
OFFIC08	124	39	121	38	111	35	104	33	84	27
OFFIC16	158	50	157	50	148	47	157	50	131	42
RETAIL1	152	48	150	48	137	44	123	39	106	33
RSTRNT1	213	67	208	66	190	60	174	55	126	40

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of increasingly stringent energy standard editions. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

9.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in more energy efficient designs for the state of Kansas.

9.1.1 Energy Use

Table 9-2 shows minimal change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types having reductions in energy use of 2.5 % or less. There is a small decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from -3.5 % to -13.1 % with an average of -10.3 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -1.0 % to -19.4 %, with an overall average of -13.3 %. The smallest reductions in energy use are realized by the buildings with the greatest window-to-wall ratios: the 16-story office building, 15-story hotel, and high school.

Table 9-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Kansas

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.7	-12.5	-15.7	-24.9
APART06	-0.7	-12.7	-15.4	-25.9
DORMI04	-2.1	-13.1	-17.2	-27.6
DORMI06	-1.2	-13.0	-14.3	-24.8
HOTEL15	-1.0	-11.7	-7.0	-19.7
HIGHS02	-0.6	-3.5	-7.1	-13.7
OFFIC03	-2.1	-8.7	-15.0	-31.9
OFFIC08	-2.5	-10.5	-16.0	-32.5
OFFIC16	-1.1	-6.5	-1.0	-17.1
RETAIL1	-1.5	-9.8	-19.4	-30.6
RSTRNT1	-2.5	-10.8	-18.5	-40.8
Average	**-1.5**	**-10.3**	**-13.3**	**-26.3**

For the high-rise buildings (15-story hotel and 16-story office building), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC in Zone 4 and Zone 5 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007*, making the requirement less strict. Additionally, the maximum U-factor is relaxed for Zone 4. The 100 % glazing amplifies the impact of these requirement relaxations enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

The LEC design realizes the greatest reductions in energy use, with the change in energy use relative to *ASHRAE 90.1-1999* ranging from -13.7 % to -40.8 % with an average of -26.3 %. Similar to the *ASHRAE 90.1-2007* design, the lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratios due to the less strict window SHGC requirement.

9.1.2 Energy Costs

Table 9-3 shows a minimal percentage change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.9 % to -3.0 %), which mirrors the energy use results described above. There is a significant variation in the percentage change in average energy costs for *ASHRAE 90.1-2004*, ranging from -7.5 % to -22.1 % depending on the building type with an average of -15.8 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -2.2 % to -24.4 %, with an overall average of -17.1 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -21.6 % to -46.4 % with an average of -33.5 % overall.

Table 9-3 Average Percentage Change in Energy Costs, 10-Year, Kansas

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.9	-20.8	-23.0	-35.3
APART06	-0.9	-20.9	-22.7	-37.4
DORMI04	-2.6	-22.1	-24.4	-37.1
DORMI06	-1.5	-21.1	-21.9	-36.3
HOTEL15	-1.2	-19.3	-13.6	-29.4
HIGHS02	-0.9	-7.5	-10.3	-23.4
OFFIC03	-2.4	-11.2	-14.4	-34.3
OFFIC08	-2.7	-12.5	-14.9	-33.1
OFFIC16	-1.2	-8.8	-2.2	-21.6
RETAIL1	-1.7	-14.4	-20.2	-33.9
RSTRNT1	-3.0	-15.7	-20.1	-46.4
Average	**-1.7**	**-15.8**	**-17.1**	**-33.5**

For all building designs, the average reductions in energy costs are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. For 7 of the 11 building types, adopting the LEC design increases natural gas consumption while decreasing electricity consumption. The buildings use electricity for all energy consumption except for the heating component of the HVAC system, which uses natural gas. The energy efficiency measures adopted lead to a decrease in energy use for both lighting and cooling the building, but an increase in heating loads. Since electricity is more expensive than natural gas on a per unit of energy basis, the shift in energy use from cooling to heating magnifies the decrease in energy costs for the building.

9.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small percentage reductions (3.1 % or less) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 9-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -9.3 % to -25.2 % with an average of -17.8 %. The *ASHRAE 90.1-2007* design leads to slightly greater reductions overall than *ASHRAE 90.1-2004*, with the average change in carbon emissions ranging from -2.7 % to -26.9 % with an overall average of -18.4 %. The LEC design leads to the greatest average changes in carbon emissions, ranging from -27.7 % to -48.3 % depending on the building type with an average of -36.1 % across all building types.

Table 9-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Kansas

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-1.0	-23.8	-25.6	-39.1
APART06	-1.0	-23.8	-25.3	-41.4
DORMI04	-2.7	-25.2	-26.9	-40.4
DORMI06	-1.6	-24.0	-24.7	-40.4
HOTEL15	-1.3	-22.1	-15.9	-32.9
HIGHS02	-1.1	-9.3	-11.6	-27.7
OFFIC03	-2.5	-12.0	-14.3	-35.1
OFFIC08	-2.8	-13.0	-14.6	-33.3
OFFIC16	-1.3	-9.6	-2.7	-23.1
RETAIL1	-1.8	-16.0	-20.5	-35.1
RSTRNT1	-3.1	-17.3	-20.6	-48.3
Average	**-1.8**	**-17.8**	**-18.4**	**-36.1**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage changes in carbon emissions are greater than the percentage changes in energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity further decreases carbon emissions because electricity has a higher carbon emissions rate per unit of energy than natural gas in Kansas.

9.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 9-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for 10 of 11 building types over a 10-year study period. Across all building designs, the current state energy code is the lowest cost option for four building types (4-story dormitory, 3-story office building, 8-story office building, and retail store). *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building designs for two and three building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -2.7 % to 6.2 % depending on building type. The LEC design is the lowest cost building design for two building types and realizes a reduction in life-cycle costs for 6 of 11 building types, with the percentage change in life-cycle costs ranging from -2.6 % to 1.0 %. Based on the overall average percentage reduction in life-cycle costs of 0.7 %, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings, while the other three designs may not be cost effective.

Table 9-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Kansas

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.0	-1.9	**-2.2**	-1.6
APART06	0.0	-2.0	**-2.3**	-1.8
DORMI04	4.5	0.9	0.3	0.3
DORMI06	-0.1	-2.6	**-2.7**	-2.6
HOTEL15	0.0	**-2.5**	-2.0	-1.5
HIGHS02	0.5	-0.4	-0.8	**-1.5**
OFFIC03	6.3	3.9	3.3	0.7
OFFIC08	6.4	4.0	3.0	0.3
OFFIC16	0.0	**-1.0**	-0.2	0.3
RETAIL1	3.7	1.2	0.2	1.0
RSTRNT1	8.3	6.2	4.9	**-1.2**
Average	**2.7**	**0.5**	**0.1**	**-0.7**

9.1.5 City Comparisons

Simulations are run for four cities located in Kansas: Dodge City, Topeka, and Wichita in Climate Zone 4A and Goodland in Climate Zone 5A. The results may vary across cities within Kansas for three reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

As can be seen in Table 9-6, average reductions in energy use for all building types from adopting newer energy standard editions varies minimally across climate zones. The adoption of *ASHRAE 90.1-2001*, *-2004, -2007,* or the LEC design leads to slightly greater reductions for Zone 4A than for Zone 5A. There is also minimal variation within a climate zone.

Table 9-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Kansas

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Dodge City	4A	-1.5	-10.3	-13.5	-26.8
Topeka	4A	-1.6	-10.3	-13.3	-26.1
Wichita	4A	-1.6	-10.8	-13.8	-27.2
Goodland	5A	-1.2	-9.6	-12.7	-25.2
Average		**-1.5**	**-10.3**	**-13.3**	**-26.3**

The variations in energy costs across cities are a result of two factors, the reductions in energy use and the fuel source of the reductions. Table 9-7 shows that the climate zone with the greatest reduction in energy use realizes the greatest reduction in energy costs for each of the building designs. Both climate zones realize larger percentage reductions in energy costs than percentage reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Since electricity is more expensive than natural gas on a per unit basis, the greater reduction in electricity leads to an additional reduction in energy costs.

Table 9-7 Average Percentage Change in Energy Costs by City, 10-Year, Kansas

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Dodge City	4A	-1.8	-15.8	-17.1	-33.7
Topeka	4A	-1.9	-15.8	-16.9	-33.1
Wichita	4A	-1.8	-16.0	-17.1	-33.8
Goodland	5A	-1.5	-15.8	-17.1	-33.3
Average		**-1.7**	**-15.8**	**-17.1**	**-33.5**

Table 9-8 reports changes in energy-related carbon emissions by city for Kansas. For all cities, the more stringent standard editions result in greater reductions in carbon emissions. The cities that realize the greatest reductions in energy use do not necessarily realize the greatest reductions in carbon emissions due to the variation in the fuel source of the energy use reductions.

Table 9-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Kansas

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Dodge City	4A	-1.7	-17.0	-18.0	-36.2
Topeka	4A	-1.8	-17.0	-17.9	-35.6
Wichita	4A	-1.7	-17.0	-18.0	-36.0
Goodland	5A	-1.4	-17.2	-18.3	-36.2
Average		**-1.7**	**-17.1**	**-18.1**	**-36.0**

The data reported in Table 9-9 show that, over a 10-year period, average life-cycle costs increase for all cities for the *ASHRAE 90.1-2001* and *-2004* designs compared to *ASHRAE 90.1-1999*. Adoption of the *ASHRAE 90.1-2007* design results in average reductions in life-cycle costs for two of the four cities relative to *ASHRAE 90.1-1999*. Adoption of the LEC design realizes the greatest average percentage reductions in life-cycle costs for all cities in both climate zones. For the LEC design, buildings in Wichita and Goodland realize greater reductions in life-cycle costs than buildings in Dodge City and Topeka.

Table 9-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Kansas

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Dodge City	4A	3.2	0.8	0.4	**-0.4**
Topeka	4A	3.0	1.0	0.5	**-0.4**
Wichita	4A	2.5	0.3	-0.1	**-1.0**
Goodland	5A	2.1	0.0	-0.3	**-1.0**
Average		**2.7**	**0.5**	**0.1**	**-0.7**

9.2 Total Savings

How much can Kansas save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

9.2.1 Energy Use

Table 9-10 reports the average per unit change in annual energy use by building type and building design in the state.[20] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 9-11 reports the estimated average annual floor area of new construction and the total annual change in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[21]

Table 9-10 Average Per Unit Change in Annual Energy Use, Kansas

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-1.31	-0.41	-22.82	-7.24	-28.65	-9.09	-45.43	-14.41
APART06	-1.34	-0.43	-22.97	-7.29	-27.81	-8.82	-46.83	-14.86
DORMI04	-3.02	-0.96	-18.75	-5.95	-24.57	-7.80	-39.54	-12.54
DORMI06	-2.44	-0.77	-25.67	-8.14	-28.27	-8.97	-48.93	-15.52
HOTEL15	-1.68	-0.53	-19.96	-6.33	-11.99	-3.80	-33.66	-10.68
HIGHS02	-1.53	-0.49	-11.45	-3.63	-19.83	-6.29	-42.22	-13.39
OFFIC03	-2.80	-0.89	-8.39	-2.66	-16.97	-5.38	-32.43	-10.29
OFFIC08	-3.13	-0.99	-13.05	-4.14	-19.88	-6.31	-40.29	-12.78
OFFIC16	-1.67	-0.53	-10.28	-3.26	-1.54	-0.49	-27.05	-8.58
RETAIL1	-2.22	-0.70	-14.96	-4.74	-29.56	-9.38	-46.63	-14.79
RSTRNT1	-5.29	-1.68	-23.07	-7.32	-39.27	-12.46	-86.72	-27.51

The annual reduction in energy use shown in Table 9-11 ranges widely across building designs, but all building designs decrease overall energy use across the state relative to *ASHRAE 90.1-1999*. Adopting the *ASHRAE 90.1-2001, ASHRAE 90.1-2004*, and *ASHRAE 90.1-2007* designs result in annual decreases of 1.5 GWh (5.0 GBtu), 9.1 GWh (31.1 GBtu), and 14.4 GWh (49.0 GBtu), respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 27.5 GWh (93.7 GBtu) of total energy use annually for one year's worth of new construction for these building types.

[20] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[21] State-level subcategory data are not available.

Table 9-11 Statewide Change in Annual Energy Use for One Year of Construction, Kansas

Building Type	Subcat. Weight.	m² (1000s)	ft² (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	8.8	95	-12	-39	-201	-688	-253	-864	-401	-1369
APART06	55.1 %	10.8	116	-15	-49	-248	-848	-301	-1027	-506	-1729
HOTEL15	100.0 %	70.5	759	-118	-404	-1407	-4804	-845	-2886	-2374	-8104
HIGHS02	100.0 %	165.2	1778	-253	-864	-1385	-4730	-2804	-9575	-5358	-18 295
OFFIC03	37.4 %	65.7	707	-184	-627	-752	-2568	-1302	-4445	-2773	-9467
OFFIC08	40.4 %	70.8	762	-222	-757	-924	-3155	-1408	-4807	-2853	-9741
OFFIC16	22.2 %	39.0	419	-65	-222	-400	-1367	-60	-205	-1054	-3599
RETAIL1	100.0 %	224.4	2415	-498	-1700	-3356	-11 459	-6633	-22 648	-10 462	-35 722
RSTRNT1	100.0 %	19.3	208	-102	-349	-445	-1521	-758	-2588	-1674	-5716
Total		**674.5**	**7260**	**-1468**	**-5012**	**-9120**	**-31 140**	**-14 364**	**-49 046**	**-27 454**	**-93 741**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

Assuming that the buildings considered in this study, which represent 62.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from adopting the LEC design in new commercial buildings to be 43.9 GWh (149.8 GBtu) per year. These savings imply 438.6 GWh (1497.5 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 22.9 GWh (78.3 GBtu) annually or 229.5 GWh (783.5 GBtu) over the 10-year study period.

The variation in The statewide change in energy use across the 9 building types with reported floor area data is consistent across the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2007*, and LEC designs. Building types that represent the greatest amount of new floor area realize the largest changes in aggregate energy use. The greatest total reductions are realized by retail stores and high schools because they represent 33.2 % and 24.5 %, respectively, of the new construction in the state while all other building types represent 10.5 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and high schools -- rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 9-2.

9.2.2 Energy Costs

Table 9-12 reports the average per unit change in energy costs by building type and building design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 9-12 Average Per Unit Change in Energy Costs, 10-Year, Kansas

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	-$0.84	-$0.08	-$19.30	-$1.79	-$21.35	-$1.98	-$32.83	-$3.05
APART06	-$0.86	-$0.08	-$19.37	-$1.80	-$21.05	-$1.96	-$34.69	-$3.22
DORMI04	-$1.93	-$0.18	-$16.55	-$1.54	-$18.29	-$1.70	-$27.81	-$2.58
DORMI06	-$1.56	-$0.15	-$21.46	-$1.99	-$22.33	-$2.07	-$36.95	-$3.43
HOTEL15	-$1.07	-$0.10	-$16.84	-$1.56	-$11.82	-$1.10	-$25.62	-$2.38
HIGHS02	-$1.79	-$0.17	-$8.39	-$0.78	-$10.80	-$1.00	-$25.67	-$2.39
OFFIC03	-$0.98	-$0.09	-$7.92	-$0.74	-$10.80	-$1.00	-$24.63	-$2.29
OFFIC08	-$2.00	-$0.19	-$9.13	-$0.85	-$10.92	-$1.01	-$24.27	-$2.25
OFFIC16	-$1.07	-$0.10	-$7.77	-$0.72	-$1.97	-$0.18	-$19.03	-$1.77
RETAIL1	-$1.42	-$0.13	-$11.72	-$1.09	-$16.42	-$1.53	-$27.58	-$2.56
RSTRNT1	-$3.39	-$0.31	-$17.93	-$1.67	-$22.92	-$2.13	-$52.95	-$4.92

Table 9-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. All building types realize reductions in energy costs for all building designs. The *ASHRAE 90.1-2001* design realizes small reductions in energy costs ($939 628). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $7.4 million, $8.7 million, and $17.9 million respectively.

Assuming that the buildings considered in this study, which represent 62.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of $1.5 million, $11.7 million, $13.9 million, and $28.6 million over the 10-year study period, respectively.

Table 9-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Kansas

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	8.8	95	-$7391	-$170 327	-$188 472	-$289 790
APART06	55.1 %	10.8	116	-$9274	-$209 447	-$227 611	-$375 075
HOTEL15	100 %	70.5	759	-$75 735	-$1 187 351	-$833 740	-$1 806 462
HIGHS02	100 %	165.2	1778	-$161 934	-$1 309 336	-$1 783 969	-$4 068 696
OFFIC03	37.4 %	65.7	707	-$117 629	-$550 673	-$708 946	-$1 685 793
OFFIC08	40.4 %	70.8	762	-$141 917	-$646 728	-$773 558	-$1 718 268
OFFIC16	22.2 %	39.0	419	-$41 605	-$302 631	-$76 836	-$741 333
RETAIL1	100 %	224.4	2415	-$318 772	-$2 628 930	-$3 684 580	-$6 188 319
RSTRNT1	100 %	19.3	208	-$65 372	-$346 100	-$442 439	-$1 022 302
Total		**674.5**	**7260**	**-$939 628**	**-$7 351 522**	**-$8 720 153**	**-$17 896 038**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

9.2.3 Energy-related Carbon Emissions

Table 9-14 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type and building design. The carbon emissions estimation approach is defined in Section 5.3.

Table 9-14 Average Per Unit Change in Carbon Emissions, 10-Year, Kansas

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-12.7	-2.6	-312.0	-63.9	-336.4	-68.9	-513.6	-105.2
APART06	-13.0	-2.7	-313.0	-64.1	-332.8	-68.2	-545.8	-111.8
DORMI04	-29.3	-6.0	-269.8	-55.3	-288.1	-59.0	-432.3	-88.6
DORMI06	-23.7	-4.9	-346.2	-70.9	-356.2	-72.9	-583.8	-119.6
HOTEL15	-16.3	-3.3	-272.1	-55.7	-196.4	-40.2	-405.5	-83.0
HIGHS02	-14.9	-3.0	-130.7	-26.8	-163.7	-33.5	-389.6	-79.8
OFFIC03	-27.2	-5.6	-131.6	-27.0	-156.2	-32.0	-384.3	-78.7
OFFIC08	-30.4	-6.2	-141.8	-29.0	-158.5	-32.5	-362.2	-74.2
OFFIC16	-16.2	-3.3	-122.8	-25.1	-33.9	-7.0	-295.8	-60.6
RETAIL1	-21.6	-4.4	-186.6	-38.2	-239.1	-49.0	-409.5	-83.9
RSTRNT1	-51.4	-10.5	-285.0	-58.4	-338.9	-69.4	-793.6	-162.5

Table 9-15 applies the Table 9-14 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs all decrease carbon emissions for all building types. The adoption of *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in savings of

117 733 metric tons and 130 442 metric tons over a 10-year study period, respectively. The adoption of the LEC design as the state's energy code decreases carbon emissions by 272 962 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide reductions in carbon emissions of 188 136 metric tons, 208 374 metric tons, and 436 042 metric tons over the 10-year study period, respectively.

Table 9-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Kansas – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	8.8	95	-112	-2753	-2969	-4533
APART06	55.1 %	10.8	116	-140	-3373	-3586	-5882
HOTEL15	100.0 %	70.5	759	-1150	-19 190	-13 846	-28 591
HIGHS02	100.0 %	165.2	1778	-2458	-21 588	-27 032	-64 349
OFFIC03	37.4 %	65.7	707	-1786	-8 644	-10 261	-25 239
OFFIC08	40.4 %	70.8	762	-2154	-10 040	-11 223	-25 641
OFFIC16	22.2 %	39.0	419	-631	-4778	-1321	-11 515
RETAIL1	100.0 %	224.4	2415	-4839	-41 859	-53 655	-91 878
RSTRNT1	100.0 %	19.3	208	-993	-5507	-6549	-15 335
Total		**674.5**	**7260**	**-14 264**	**-117 733**	**-130 442**	**-272 962**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

9.2.4 Life-Cycle Costs

Table 9-16 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type and building design. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 9-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Kansas

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	$0.43	$0.04	-$18.20	-$1.69	-$21.07	-$1.96	-$14.89	-$1.38
APART06	-$0.10	-$0.01	-$18.88	-$1.75	-$21.17	-$1.97	-$16.63	-$1.55
DORMI04	$39.69	$3.69	$8.09	$0.75	$3.09	$0.29	$2.65	$0.25
DORMI06	-$1.02	-$0.10	-$25.11	-$2.33	-$26.16	-$2.43	-$24.84	-$2.31
HOTEL15	-$0.35	-$0.03	-$23.04	-$2.14	-$17.76	-$1.65	-$13.58	-$1.26
HIGHS02	$3.75	$0.35	-$3.14	-$0.29	-$6.43	-$0.60	-$11.78	-$1.09
OFFIC03	$45.97	$4.27	$28.70	$2.67	$23.93	$2.22	$5.48	$0.51
OFFIC08	$48.47	$4.50	$29.86	$2.77	$22.53	$2.09	$2.76	$0.26
OFFIC16	$0.14	$0.01	-$6.76	-$0.63	-$1.47	-$0.14	$2.15	$0.20
RETAIL1	$22.24	$2.07	$7.25	$0.67	$1.40	$0.13	$6.33	$0.59
RSTRNT1	$99.66	$9.26	$75.14	$6.98	$59.04	$5.49	-$14.50	-$1.35

Table 9-17 applies the Table 9-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. Total changes in life-cycle costs over the 10-year study period vary across building designs. Adoption of the *ASHRAE 90.1-2001* design results in an increase in life-cycle costs for 7 of 9 building types and increases total life-cycle costs by $14.0 million. The *ASHRAE 90.1-2004* and -*2007* designs result in a decrease in life-cycle costs for 5 of 9 building types, but increase total life-cycle costs by $4.3 million and $1.8 million, respectively. The LEC design decreases life-cycle costs for 5 of 9 building types, and decreases total life-cycle costs by $1.4 million. For a 10-year study period, it is not cost-effective to adopt newer editions of *ASHRAE 90.1*, but it is cost-effective to adopt the LEC design as Kansas's state energy code for commercial buildings. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the adoption of the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC design can be extrapolated to estimate statewide changes in life-cycle costs of $22.3 million, $6.9 million, $2.9 million, and -$2.3 million over the 10-year study period, respectively.

Table 9-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Kansas

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2001	2004	2007	LEC
APART04	44.9 %	8.8	95	$3813	-$160 625	-$185 973	-$131 421
APART06	55.1 %	10.8	116	-$1093	-$204 094	-$228 849	-$179 819
HOTEL15	100.0 %	70.5	759	-$24 452	-$1 624 573	-$1 252 262	-$957 451
HIGHS02	100.0 %	165.2	1778	$619 737	-$519 066	-$1 063 139	-$1 945 659
OFFIC03	37.4 %	65.7	707	$3 018 537	$1 884 409	$1 571 500	$360 112
OFFIC08	40.4 %	70.8	762	$3 431 942	$2 114 500	$1 595 667	$195 169
OFFIC16	22.2 %	39.0	419	$5367	-$263 494	-$57 242	$83 896
RETAIL1	100.0 %	224.4	2415	$4 989 089	$1 626 047	$313 796	$1 419 893
RSTRNT1	100.0 %	19.3	208	$1 923 956	$1 450 591	$1 139 824	-$279 970
Total		**674.5**	**7260**	**$13 966 895**	**$4 303 694**	**$1 833 322**	**-$1 435 249**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

9.3 State Summary

Kansas is one of four states in the Midwest Census Region that has not yet adopted a state energy code for commercial buildings, and is located in the warmest climates in the region. On average, adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions, but does not do so in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 229.5 GWh (783.5 GBtu), energy cost savings of $13.9 million, and 208 374 metric tons of carbon emissions reductions at a life-cycle cost of $2.9 million for one year's worth of commercial building construction.

The adoption of the LEC design leads to savings in total energy use, energy costs, and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design would lead to even greater impacts than adopting *ASHRAE 90.1-2007*, with savings of 438.6 GWh (1497.5 GBtu), $28.6 million of energy costs, and 436 042 metric tons of carbon emissions while decreasing life-cycle costs by $2.3 million for one year's worth of commercial building construction.

10 Michigan

Michigan is located in the East North Central Census Division and has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. Michigan spans three climate zones with the southern portion of the state located in Zone 5A, the central portion in Zone 6A, and the northern portion in Zone 7. Table 10-1 provides an overview of Michigan's simulated energy use keyed to building types and energy codes. Average energy use varies across building types. The 8-story office building uses the least amount of energy at 88 kWh/m^2 to 106 kWh/m^2 (28 kBtu/ft^2 to 34 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 273 kWh/m^2 to 286 kWh/m^2 (87 kBtu/ft^2 to 91 kBtu/ft^2) annually.

Table 10-1 Average Annual Energy Use by Building Type and Standard Edition, Michigan

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	181	57	165	52
APART06	179	57	163	52
DORMI04	144	46	129	41
DORMI06	198	63	181	57
HOTEL15	191	61	172	55
HIGHS02	286	91	273	87
OFFIC03	120	38	100	32
OFFIC08	106	34	88	28
OFFIC16	174	55	153	48
RETAIL1	136	43	119	38
RSTRNT1	185	59	144	46

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

10.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types within a state. This section discusses the average percentage changes from investing in the LEC design for the state of Michigan.

10.1.1 Statewide Building Comparison

Table 10-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*. The LEC design realizes changes in energy use ranging from -4.6 % to -22.1 % with an average of -12.0 % relative to the *ASHRAE 90.1-2007* design. The greatest reduction in energy use for the LEC design occurs for the restaurant while the smallest reductions occur for the high school.

Table 10-2 Average Percentage Change from Adoption of the LEC Design, 10-Year, Michigan

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-8.5	-15.2	-16.3	0.4
APART06	-8.9	-16.7	-17.9	0.3
DORMI04	-10.7	-16.5	-17.4	-1.2
DORMI06	-8.5	-15.9	-17.1	0.1
HOTEL15	-10.1	-15.5	-16.4	0.2
HIGHS02	-4.6	-12.7	-14.2	-0.8
OFFIC03	-16.4	-21.0	-21.5	-2.6
OFFIC08	-16.7	-19.6	-19.8	-2.2
OFFIC16	-12.6	-16.9	-17.5	0.2
RETAIL1	-12.6	-16.0	-16.4	-0.3
RSTRNT1	-22.1	-30.3	-31.4	-3.0
Average	**-12.0**	**-17.9**	**-18.7**	**-0.8**

The LEC design realizes average changes in energy costs from -12.7 % to -30.3 % depending on the building type, with an average of -17.9 % overall over 10 years of operation. The high school realizes the smallest average reduction in energy costs while the restaurant realizes the greatest average reduction in energy costs. For all building types, the reduction in energy costs is greater than the reduction in energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 6 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The most extreme case is the high school, which realizes a reduction in energy costs that is over twice as large in percentage terms as the energy use reduction. The increase in natural gas consumption offsets 41.3 % of the decrease in electricity consumption resulting from adopting the LEC design. The shift from electricity to natural gas further decreases energy costs, in percentage terms, because electricity is more expensive than natural gas in Michigan.

The LEC design leads to average changes in carbon emissions ranging from -14.2 % to -31.4 % depending on the building type, with an average of -18.7 % across all building types. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 6 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The average change in life-cycle costs for the LEC design over a 10-year study period ranges from -3.0 % to 0.4 %. Four- and 6-story apartment buildings realize the largest increase in life-cycle costs while restaurants, 3-story office buildings, and 8-story office buildings are the building types that realize the greatest reductions in average life-cycle costs. Given that 6 of 11 buildings types realize an average percentage decrease in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

10.1.2 City Comparisons

Simulations are run for 9 cities in Michigan located across three climate zones: Detroit, Flint, Grand Rapids, Lansing, and Muskegon located in Zone 5A, Alpena and Traverse City located in Zone 6A, and Houghton and Sault Ste. Marie located in Zone 7. The results may vary across cities within Michigan for several reasons. First, the state is covered by three climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 13-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design vary across cities, ranging from -9.9 % to -12.6 %. The smallest reduction in energy use is realized by Sault Ste. Marie. Excluding Sault Ste. Marie, any variation across or within climate zones in Michigan appears to have minimal effects on energy consumption.

Table 10-3 Average Percentage Change from Adoption of the LEC Design by City, 10- Year, Michigan

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Detroit	5A	-12.4	-18.9	-20.0	-0.5
Flint	5A	-12.2	-18.8	-20.0	-0.7
Grand Rapids	5A	-11.9	-18.6	-19.8	-0.9
Lansing	5A	-12.2	-18.8	-20.0	-0.9
Muskegon	5A	-12.2	-18.9	-20.1	-0.7
Alpena	6A	-12.3	-16.5	-17.3	-0.7
Traverse City	6A	-12.6	-16.6	-17.4	-0.9
Houghton	7	-12.3	-16.4	-17.3	-0.5
Sault Ste Marie	7	-9.9	-17.1	-18.3	-1.3
Average		**-12.0**	**-17.9**	**-18.9**	**-0.8**

The average percentage change in energy costs for all building types also varies across cities, ranging from -16.4 % to -18.9 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Cities located in Zone 5A realize greater reductions in energy costs than cities in Zone 6A and Zone 7. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies across cities, ranging from -17.3 % to -20.1 %. All cities realize average percentage reductions in life-cycle costs. However, the percentage change in life-cycle costs varies across cities, ranging from -1.3 % to -0.5 %. Sault Ste. Marie realizes the greatest reduction in life-cycle costs. Excluding Sault Ste. Marie, there are no trends in the percentage change in life-cycle costs across climate zones.

10.2 Total Savings

How much can Michigan save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

10.2.1 Energy Use

Table 10-4 reports the average per unit change in annual energy use by building type for the LEC design in the state.[22] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 10-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[23]

Table 10-4 Average Per Unit Change in Annual Energy Use, Michigan

Building Type	Standard Edition	
	LEC	
	kWh/m²	kBtu/ft²
APART04	-15.4	-4.9
APART06	-15.8	-5.0
DORMI04	-15.4	-4.9
DORMI06	-16.8	-5.3
HOTEL15	-19.2	-6.1
HIGHS02	-19.6	-6.2
OFFIC03	-13.2	-4.2
OFFIC08	-17.7	-5.6
OFFIC16	-21.9	-7.0
RETAIL1	-17.1	-5.4
RSTRNT1	-40.7	-12.9

The annual reduction in energy use shown in Table 10-5 ranges widely across building types with reported floor area data, but the LEC design decreases overall energy use across the state for all building types. The adoption of the LEC design as the state's energy code would save 28.9 GWh (98.6 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 56.4 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings to be 51.2 GWh (174.8 GBtu) per year. These savings imply 511.9 GWh (1747.7 GBtu) in energy use savings over the 10-year study period.

[22] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[23] State-level subcategory data are not available.

Table 10-5 Statewide Change in Annual Energy Use for One Year of Construction, Michigan

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	40.1	431	-615 436	-2 101 363
APART06	55.1 %	49.1	529	-777 709	-2 655 432
HOTEL15	100.0 %	142.5	1534	-2 738 428	-9 350 170
HIGHS02	100.0 %	411.6	4430	-5 418 638	-18 501 561
OFFIC03	37.4 %	126.9	1366	-2 492 758	-8 511 349
OFFIC08	40.4 %	136.9	1473	-2 419 426	-8 260 961
OFFIC16	22.2 %	75.3	811	-1 650 113	-5 634 194
RETAIL1	100.0 %	649.1	6987	-11 128 288	-37 996 762
RSTRNT1	100.0 %	40.0	431	-1 627 879	-5 558 278
Total		**1671.5**	**17 992**	**-28 868 675**	**-98 570 070**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

The relative reduction in energy use varies across the 9 building types with reported floor area data for the LEC design relative to *ASHRAE 90.1-2007*. The greatest reductions are realized by the retail store followed by the high school. The smallest reductions are realized by the 4- and 6-story apartment buildings. Building types that represent a greater amount of new floor area realize the largest changes in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 38.8 % and 24.6 %, respectively, of the new construction in the state while all other building types represent 8.5 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. The building types that lead to the greatest estimated reduction in energy use -- retail stores and high schools -- only rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 10-2.

10.2.2 Energy Costs

Table 10-6 reports the average per unit change in energy costs by building type. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 10-6 Average Per Unit Change in Energy Costs, 10-Year, Michigan

Building Type	Standard Edition LEC $/m^2	Standard Edition LEC $/ft^2
APART04	-$11.99	-$1.11
APART06	-$13.15	-$1.22
DORMI04	-$10.65	-$0.99
DORMI06	-$13.80	-$1.28
HOTEL15	-$13.21	-$1.23
HIGHS02	-$14.89	-$1.38
OFFIC03	-$14.60	-$1.36
OFFIC08	-$13.37	-$1.24
OFFIC16	-$16.23	-$1.51
RETAIL1	-$11.77	-$1.09
RSTRNT1	-$29.71	-$2.76

Table 10-7 reports the statewide changes in total energy costs by building type, which account for one year's worth of new construction evaluated over 10 years of building operation. All building types realize energy cost savings for the LEC design, with the energy cost savings being highly correlated with energy use savings. Any variation is a result of the greater percentage reduction in electricity consumption relative to the reduction in natural gas consumption. Overall, the reduction in energy costs totals $22.8 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study, which represent 56.4 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total energy cost savings of $40.4 million over the 10-year study period.

Table 10-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Michigan

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	40.1	431	-$480 648
APART06	55.1 %	49.1	529	-$645 430
HOTEL15	100.0 %	142.5	1534	-$1 882 477
HIGHS02	100.0 %	411.6	4430	-$6 009 073
OFFIC03	37.4 %	126.9	1366	-$1 890 295
OFFIC08	40.4 %	136.9	1473	-$1 829 521
OFFIC16	22.2 %	75.3	811	-$1 222 430
RETAIL1	100.0 %	649.1	6987	-$7 637 343
RSTRNT1	100.0 %	40.0	431	-$1 188 431
Total		**1671.5**	**17 992**	**-$22 785 647**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

10.2.3 Energy-related Carbon Emissions

Table 10-8 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

Table 10-8 Average Per Unit Change in Carbon Emissions, 10-Year, Michigan

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-145.6	-29.8
APART06	-160.4	-32.9
DORMI04	-128.0	-26.2
DORMI06	-168.2	-34.5
HOTEL15	-158.5	-32.5
HIGHS02	-181.7	-37.2
OFFIC03	-180.4	-36.9
OFFIC08	-161.8	-33.1
OFFIC16	-196.2	-40.2
RETAIL1	-141.2	-28.9
RSTRNT1	-358.5	-73.4

Table 10-9 applies the Table 10-8 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building types, and is correlated with each building's total reduction in energy use. However, there is not a perfect correlation because the magnitude of the offsetting natural gas increase varies across building types. The adoption of the LEC design as the state's energy code decreases carbon emissions by 276 887 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 490 935 metric tons over the 10-year study period.

Table 10-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Michigan – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	40.1	431	-5836
APART06	55.1 %	49.1	529	-7875
HOTEL15	100.0 %	142.5	1534	-22 592
HIGHS02	100.0 %	411.6	4430	-74 785
OFFIC03	37.4 %	126.9	1366	-22 892
OFFIC08	40.4 %	136.9	1473	-22 150
OFFIC16	22.2 %	75.3	811	-14 773
RETAIL1	100.0 %	649.1	6987	-91 641
RSTRNT1	100.0 %	40.0	431	-14 343
Total		**1671.5**	**17 992**	**-276 887**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

10.2.4 Life-Cycle Costs

Table 10-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 10-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Michigan

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$3.86	$0.36
APART06	$3.49	$0.32
DORMI04	-$10.58	-$0.98
DORMI06	$0.71	$0.07
HOTEL15	$2.35	$0.22
HIGHS02	-$6.81	-$0.63
OFFIC03	-$19.89	-$1.85
OFFIC08	-$17.17	-$1.60
OFFIC16	$1.51	$0.14
RETAIL1	-$1.73	-$0.16
RSTRNT1	-$38.52	-$3.58

Table 10-11 applies the Table 10-10 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of the LEC design. The change in life-cycle costs varies widely across building types. High schools realize the greatest decrease in life-cycle costs ($2.8 million) followed by 3- and 8-story office buildings ($2.5 million and $2.4 million, respectively). The hotel realizes the greatest increase in life-cycle costs ($335 351). Adopting the LEC design leads to a reduction in statewide life-cycle costs of $9.6 million relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total decrease in statewide life-cycle costs of $17.0 million over the 10-year study period.

Table 10-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Michigan

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	40.1	431	$154 868
APART06	55.1 %	49.1	529	$171 364
HOTEL15	100.0 %	142.5	1534	$335 351
HIGHS02	67.5 %	411.6	4430	-$2 804 667
OFFIC03	37.4 %	126.9	1366	-$2 524 206
OFFIC08	40.4 %	136.9	1473	-$2 350 402
OFFIC16	22.2 %	75.3	811	$113 480
RETAIL1	100.0 %	649.1	6987	-$1 121 682
RSTRNT1	100.0 %	40.0	431	-$1 540 823
Total		**1671.5**	**17 992**	**-$9 566 716**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

10.3 State Summary

Michigan has adopted *ASHRAE 90.1-2007* as its energy code for commercial buildings. The adoption of the LEC design, which goes beyond *ASHRAE 90.1-2007*, leads to reductions in energy use, energy cost, and energy-related carbon emissions in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code would lead to energy use savings of 511.9 GWh (1747.7 GBtu), energy cost savings of $40.4 million, and carbon emissions reductions of 490 935 metric tons while decreasing life-cycle costs by $17.0 million for one year's worth of commercial building construction.

11 Minnesota

Minnesota is located in the West North Central Census Division, and spans two climate zones with the southern portion of the state located in Zone 6A and the northern portion in Zone 7. Minnesota is the only state in the Midwest Census Region that has adopted *ASHRAE 90.1-2004* as its state energy code for commercial buildings. Table 11-1 provides an overview of Minnesota's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 95 kWh/m^2 to 121 kWh/m^2 (30 kBtu/ ft^2 to 38 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 316 kWh/m^2 to 348 kWh/m^2 (100 kBtu/ft^2 to 110 kBtu/ft^2) annually.

Table 11-1 Average Annual Energy Use by Building Type and Standard Edition, Minnesota

Building Type	Standard Edition					
	2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	214	68	204	65	184	59
APART06	210	67	201	64	183	58
DORMI04	176	56	163	52	142	45
DORMI06	230	73	221	70	204	65
HOTEL15	209	66	214	68	194	62
HIGHS02	348	110	336	107	316	100
OFFIC03	143	45	130	41	105	33
OFFIC08	121	38	114	36	95	30
OFFIC16	187	59	193	61	171	54
RETAIL1	175	56	155	49	127	40
RSTRNT1	245	78	203	64	151	48

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of increasingly stringent energy codes. The results are reported in terms of average percentage savings on a statewide and city-by-city basis, and as total savings on a statewide basis.

11.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building type and location within a state. This section discusses the average percentage changes from investing in more energy efficient designs in the state of Minnesota.

11.1.1 Energy Use

Table 11-2 shows a large variation in percentage changes in energy use for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 3.0 % to -17.0 % with an average of -5.6 %. For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2007* is actually less energy efficient than *ASHRAE 90.1-2004* because the maximum SHGC requirement in Zone 6A and Zone 7 for buildings with fenestration accounting for greater than 40 % of wall surface area is less stringent for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*. The 100 % glazing amplifies the impact of this requirement relaxation enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

Table 11-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Minnesota

Building Type	Standard Edition	
	2007	LEC
APART04	-4.9	-13.8
APART06	-4.4	-13.0
DORMI04	-7.3	-19.0
DORMI06	-3.6	-11.3
HOTEL15	2.7	-6.8
HIGHS02	-3.4	-9.2
OFFIC03	-9.2	-26.1
OFFIC08	-5.6	-21.4
OFFIC16	3.0	-8.7
RETAIL1	-11.7	-27.3
RSTRNT1	-17.0	-37.9
Average	**-5.6**	**-17.7**

The LEC design realizes percentage changes in energy use relative to *ASHRAE 90.1-2004,* ranging from -6.8% to -37.9 % with an average of -17.7 %. Similar to the *ASHRAE 90.1-2007* design, the smallest reductions in energy use for the LEC design occur in the 16-story office building and hotel. The high school also realizes smaller reductions in energy use, which is driven by the seasonality of its assumed building occupancy. Some of the additional energy efficiency measures adopted by the LEC design, particularly daylighting, decrease electricity use while increasing natural gas use during the school year.

11.1.2 Energy Costs

Table 11-3 shows significant variation in the percentage changes in average energy costs for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 4.7 % to -10.1 % depending on the building type, with an average of -2.8 %. As with energy use savings, adopting *ASHRAE 90.1-2007* results in an increase in energy costs relative to *ASHRAE*

90.1-2004 for the two high-rise buildings. For these two building types, the percentage increase in energy costs is smaller than the increase in energy use because electricity consumption increases while decreasing natural gas consumption. The offset of natural gas with electricity increases energy costs because electricity is more expensive per unit of energy. The remaining nine building types realize smaller percentage reductions in energy costs than the reductions in energy use because adopting the *ASHRAE 90.1-2007* design decreases natural gas consumption by a greater percentage than electricity consumption.

Table 11-3 Average Percentage Change in Energy Costs, 10-Year, Minnesota

Building Type	Standard Edition	
	2007	LEC
APART04	-3.5	-18.0
APART06	-3.1	-17.3
DORMI04	-4.7	-20.7
DORMI06	-2.5	-15.2
HOTEL15	4.7	-6.8
HIGHS02	-2.6	-14.1
OFFIC03	-4.3	-23.7
OFFIC08	-2.2	-19.8
OFFIC16	4.7	-7.8
RETAIL1	-6.9	-23.9
RSTRNT1	-10.1	-36.3
Average	**-2.8**	**-18.5**

The LEC design realizes greater reductions in energy costs than the *ASHRAE 90.1-2007* design, with the average percentage change by building type ranging from -6.8 % to -36.3 % with an overall average of -18.5 % for 10 years of building operation. The reductions in energy costs are greater than the reductions in energy use for 5 of 11 building types. For these building types, electricity consumption is decreased by a greater percentage than natural gas consumption, which leads to additional reductions in energy costs. Similar to *ASHRAE 90.1-2007*, the remaining six building types see percentage reductions in energy costs that are marginally smaller than the reductions in energy use because adoption of the LEC design decreases natural gas consumption by a greater percentage than electricity consumption.

11.1.3 Energy-related Carbon Emissions Reduction

Table 11-4 shows significant variation in the average percentage change in energy-related carbon emissions for the *ASHRAE 90.1-2007* design across building types, ranging from 5.0 % to -9.2 % with an average of -2.4 %. The LEC design leads to significant changes in average carbon emissions, ranging from -6.8 % to -36.1 % depending on the building type with an average of -18.6 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions.

However, the carbon emissions reductions (increases) are smaller (larger) than the energy use reductions (increases) for all 11 building types for the *ASHRAE 90.1-2007* design. Similar to the changes in energy costs, this result is due to the fuel source of the changes in energy use. For the nine building types that realize smaller reductions in carbon emissions than energy use, the percentage reduction in natural gas consumption are greater than the reduction in electricity. For the two building types that realize a greater percentage increase in carbon emissions than energy use, natural gas consumption is decreased while electricity consumption is increased. The results are mixed from adopting the LEC design, with five building types realizing smaller reductions and six building types realizing greater reductions in carbon emissions than in energy use.

Table 11-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Minnesota

Building Type	Standard Edition	
	2007	LEC
APART04	-3.3	-18.6
APART06	-2.9	-17.9
DORMI04	-4.3	-20.9
DORMI06	-2.3	-15.7
HOTEL15	5.0	-6.8
HIGHS02	-2.4	-14.9
OFFIC03	-3.8	-23.4
OFFIC08	-1.9	-19.6
OFFIC16	4.9	-7.7
RETAIL1	-6.3	-23.5
RSTRNT1	-9.2	-36.1
Average	**-2.4**	**-18.6**

11.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 11-5. Based on the life-cycle costs over a 10-year study period, the *ASHRAE 90.1-2007* design realizes the lowest life-cycle costs for 3 building types while the LEC design has the lowest life-cycle costs for 6 building types. The current state energy code, *ASHRAE 90.1-2004*, results in the lowest life-cycle costs for the hotel and 16-story office building.

For 9 building types, *ASHRAE 90.1-2007* leads to percentage reductions in life-cycle costs. The high-rise buildings are the only buildings that realize increases in life-cycle costs. Given that 9 building types realize a percentage decrease in life-cycle costs, it is likely that adopting *ASHRAE 90.1-2007* will decrease total life-cycle costs.

The LEC design results in reductions in life-cycle costs for 6 of the 11 building types for a 10-year study period. The percentage change in life-cycle costs ranges from -5.0 % to 1.0 %. Based on the overall average percentage change of -0.8 % in life-cycle costs, the

LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

Table 11-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Minnesota

Building Type	Standard Edition	
	2007	LEC
APART04	**-0.5**	0.2
APART06	**-0.4**	0.4
DORMI04	-0.7	**-1.5**
DORMI06	**-0.3**	0.2
HOTEL15	0.3	0.9
HIGHS02	-0.5	**-1.1**
OFFIC03	-0.5	**-1.8**
OFFIC08	-0.3	**-1.3**
OFFIC16	0.4	1.0
RETAIL1	-0.3	**-0.8**
RSTRNT1	-2.2	**-5.0**
Average	**-0.4**	**-0.8**

11.1.5 City Comparisons

Simulations are run for five cities located in Minnesota: Minneapolis, Rochester, and Saint Cloud in Zone 6A and Duluth and International Falls in Zone 7. The results may vary across cities within the state for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zone, and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

As can be seen in Table 11-6, the average reduction in energy use for all building types from adopting newer energy standard editions is greater for Zone 7 relative to Zone 6A. For the *ASHRAE 90.1-2007* design, the percentage change in average energy use averages -7.4 % in Zone 7 and -4.4 % in Zone 6A. For the LEC design, the percentage change in average energy use is -20.1 % in Zone 7 and -16.1 % in Zone 6A. There is insignificant variation in percentage changes in energy use within either climate zone.

Table 11-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Minnesota

Cities	Zone	Standard Edition	
		2007	LEC
Minneapolis	6A	-4.3	-16.2
Rochester	6A	-4.4	-16.2
Saint Cloud	6A	-4.4	-15.8
Duluth	7	-7.4	-20.2
International Falls	7	-7.4	-20.0
Average		**-5.6**	**-17.7**

The variations in energy costs across cities are a result of two factors, the reduction in energy use and the fuel source of the reduction. Table 11-7 shows that the average reduction in energy costs for all building types varies across, but not within climate zones. For the *ASHRAE 90.1-2007* design, the percentage change in average energy costs ranges from -1.8 % to -4.1 % with an average of -2.8 %. The average percentage change in energy costs are greater in Zone 7 (-4.1 %) than Zone 6A (-1.9 %). For the LEC design, the percentage change in average energy costs ranges from -17.7 % to -19.8 % with an average of -18.5 %. The colder climate zone (Zone 7) realizes slightly greater changes in energy use than the warmer climate zone (Zone 6A).

Table 11-7 Average Percentage Change in Energy Costs by City, 10-Year, Minnesota

Cities	Zone	Standard Edition	
		2007	LEC
Minneapolis	6A	-1.9	-17.7
Rochester	6A	-1.8	-17.7
Saint Cloud	6A	-1.9	-17.6
Duluth	7	-4.1	-19.8
International Falls	7	-4.1	-19.7
Average		**-2.8**	**-18.5**

Table 11-8 reports energy-related carbon emissions by city for the state. For all cities, the more energy efficient designs result in greater reductions in carbon emissions. The cities in Zone 7 realize slightly greater average percentage changes in carbon emissions than the cities in Zone 6A for both *ASHRAE 90.1-2007* and the LEC design (-4.0 % versus -1.9 % and -20.2 % versus -18.4 %, respectively).

Table 11-8 Average Percentage Change in Carbon Emissions by City, Minnesota

Cities	Zone	Standard Edition	
		2007	LEC
Minneapolis	6A	-1.9	-18.4
Rochester	6A	-1.8	-18.3
Saint Cloud	6A	-2.0	-18.3
Duluth	7	-3.9	-20.2
International Falls	7	-4.0	-20.1
Average		**-2.7**	**-19.1**

The data reported in Table 11-9 show that adoption of the *ASHRAE 90.1-2007* design decreases life-cycle costs across all cities, with changes in life-cycle costs ranging minimally from -0.4 % to -0.6 %, with Zone 7 realizing slightly greater reductions in life-cycle costs than Zone 6A. The LEC design realizes the greatest reduction in life-cycle costs across all cities in the state. There is no significant difference between the average percentage changes in life-cycle costs both within and across climate zones.

Table 11-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Minnesota

Cities	Zone	Standard Edition	
		2007	LEC
Minneapolis	6A	-0.4	-0.7
Rochester	6A	-0.4	-0.8
Saint Cloud	6A	-0.4	-0.8
Duluth	7	-0.5	-0.8
International Falls	7	-0.6	-0.9
Average		**-0.4**	**-0.8**

11.2 Total Savings

How much can Minnesota save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

11.2.1 Energy Use

Table 11-10 reports the average per unit change in annual energy use by building type and building design in the state.[24] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 11-11 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[25]

Table 11-10 Average Per Unit Change in Annual Energy Use, Minnesota

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	-10.43	-3.31	-29.52	-9.37
APART06	-9.24	-2.93	-27.47	-8.72
DORMI04	-12.89	-4.09	-33.44	-10.61
DORMI06	-8.49	-2.69	-26.25	-8.33
HOTEL15	5.30	1.68	-14.37	-4.56
HIGHS02	-13.28	-4.21	-37.41	-11.87
OFFIC03	-12.03	-3.81	-32.27	-10.23
OFFIC08	-6.73	-2.13	-25.91	-8.22
OFFIC16	5.51	1.75	-16.60	-5.26
RETAIL1	-20.56	-6.52	-48.16	-15.28
RSTRNT1	-41.87	-13.28	-93.18	-29.56

The annual reduction in energy use shown in Table 11-11 ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs both decrease total statewide energy use. The adoption of the *ASHRAE 90.1-2007* design results in reductions of 16.9 GWh (57.6 GBtu) annually. *ASHRAE 90.1-2007* increases total energy use for the two high-rise buildings and decreases total energy use for the other 7 building types with retail stores realizing the greatest reduction. The adoption of the LEC design as the state's energy code for commercial buildings would save 48.8 GWh (166.5 GBtu) of total statewide energy use annually for one year's worth of new construction for these building types.

[24] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[25] State-level subcategory data are not available.

Table 11-11 Statewide Change in Annual Energy Use for One Year of Construction, Minnesota

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2007		LEC	
				kWh	kBtu	kWh	kBtu
APART04	44.9 %	129.2	1390	-1 346 987	-4 599 192	-3 813 272	-13 020 152
APART06	55.1 %	158.2	1703	-1 461 445	-4 990 000	-4 346 283	-14 840 079
HOTEL15	100.0 %	94.6	1019	501 858	1 713 560	-1 360 271	-4 644 549
HIGHS02	100.0 %	234.9	2529	-2 824 972	-9 645 670	-7 579 550	-25 879 842
OFFIC03	37.4 %	122.2	1316	-1 623 750	-5 544 180	-4 572 656	-15 613 014
OFFIC08	40.4 %	131.8	1419	-886 887	-3 028 213	-3 414 529	-11 658 671
OFFIC16	22.2 %	72.5	781	399 320	1 363 449	-1 203 553	-4 109 448
RETAIL1	100.0 %	427.1	4597	-8 778 852	-29 974 775	-20 566 401	-70 222 538
RSTRNT1	100.0 %	20.4	220	-854 184	-2 916 550	-1 901 047	-6 490 991
Total		**1390.9**	**14 972**	**-16 875 897**	**-57 621 570**	**-48 757 563**	**-166 479 284**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

Assuming that the buildings considered in this study, which represent 59.7 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the statewide savings to be 28.3 GWh (96.5 GBtu) and 81.7 GWh (278.9 GBtu) per year for adoption of the *ASHRAE 90.1-2007* and LEC designs, respectively. These savings imply 282.7 GWh (965.2 GBtu) and 816.7 GWh (2788.6 GBtu) in energy use savings over the 10-year study period.

The relative reduction in energy use across building types is consistent across building designs. The greatest total reductions are realized by retail stores and high schools because they represent 30.7 % and 16.9 %, respectively, of the new construction in the state while all other building types represent less than 12 %. The amount of new construction overwhelms the relative percentage changes in energy use. For example, the building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- rank 2nd and 9th in percentage reduction, respectively, among the 11 building types, as reported in Table 11-2.

11.2.2 Energy Costs

Table 11-12 reports the average per unit change in energy costs by building type and building design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 11-12 Average Per Unit Change in Energy Costs, 10-Year, Minnesota

Building Type	Standard Edition			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$2.62	-$0.24	-$13.44	-$1.25
APART06	-$2.29	-$0.21	-$12.86	-$1.19
DORMI04	-$2.88	-$0.27	-$12.81	-$1.19
DORMI06	-$2.04	-$0.19	-$12.33	-$1.15
HOTEL15	$3.51	$0.33	-$5.17	-$0.48
HIGHS02	-$2.84	-$0.26	-$15.54	-$1.44
OFFIC03	-$2.88	-$0.27	-$15.79	-$1.47
OFFIC08	-$1.38	-$0.13	-$12.22	-$1.13
OFFIC16	$3.92	$0.36	-$6.50	-$0.60
RETAIL1	-$4.94	-$0.46	-$17.14	-$1.59
RSTRNT1	-$9.86	-$0.92	-$35.38	-$3.29

Table 11-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. Overall, reductions in energy costs are greater for the more energy efficient building designs: $3.6 million and $20.0 million for adopting *ASHRAE 90.1-2007* and LEC, respectively. The increase in energy use for the high-rise buildings leads to an increase in energy costs for those buildings for *ASHRAE 90.1-2007*. All building types realize energy cost savings for the LEC design. The energy cost savings are highly correlated with the energy use savings. Assuming that the buildings considered in this study, which represent 59.7 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2007* and LEC can be extrapolated to estimate the total statewide energy cost savings of $6.0 million and $33.5 million over the 10-year study period, respectively.

Table 11-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Minnesota

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	129.2	1390	-$337 813	-$1 735 539
APART06	55.1 %	158.2	1703	-$362 436	-$2 033 600
HOTEL15	100.0 %	94.6	1019	$332 378	-$489 530
HIGHS02	100.0 %	234.9	2529	-$677 586	-$3 710 447
OFFIC03	37.4 %	122.2	1316	-$347 673	-$1 899 802
OFFIC08	40.4 %	131.8	1419	-$181 402	-$1 610 264
OFFIC16	22.2 %	72.5	781	$284 396	-$471 054
RETAIL1	100.0 %	427.1	4597	-$2 110 264	-$7 320 168
RSTRNT1	100.0 %	20.4	220	-$201 063	-$721 740
Total		**1390.9**	**14 972**	**-$3 601 463**	**-$19 992 143**

Note: Dormitories are excluded because no such floor area category is reported in the construction

11.2.3 Energy-related Carbon Emissions

Table 11-14 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type and building design. The carbon emissions estimation approach is defined in Section 5.3.

Table 11-14 Average Per Unit Change in Carbon Emissions, 10-Year, Minnesota

Building Type	Standard Edition			
	2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-31.9	-6.5	-180.3	-36.9
APART06	-27.9	-5.7	-173.0	-35.4
DORMI04	-34.3	-7.0	-168.3	-34.5
DORMI06	-24.7	-5.1	-166.0	-34.0
HOTEL15	48.8	10.0	-67.4	-13.8
HIGHS02	-34.9	-7.1	-213.6	-43.7
OFFIC03	-33.4	-6.8	-206.3	-42.3
OFFIC08	-16.0	-3.3	-164.5	-33.7
OFFIC16	54.7	11.2	-85.6	-17.5
RETAIL1	-59.7	-12.2	-222.9	-45.6
RSTRNT1	-118.6	-24.3	-464.2	-95.1

Table 11-15 applies the Table 11-14 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs decrease carbon emissions for the state as a whole. The adoption of *ASHRAE 90.1-2007* saves 42 263 metric tons over a 10-year study period. The adoption of the LEC design decreases carbon emissions by 264 972 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC designs can be extrapolated to estimate the statewide reduction in carbon emissions of 70 792 metric tons and 443 839 metric tons over the 10-year study period, respectively.

Table 11-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Minnesota – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	129.2	1390	-4124	-23 286
APART06	55.1 %	158.2	1703	-4413	-27 368
HOTEL15	100.0 %	94.6	1019	4614	-6376
HIGHS02	100.0 %	234.9	2529	-8188	-50 171
OFFIC03	37.4 %	122.2	1316	-4084	-25 221
OFFIC08	40.4 %	131.8	1419	-2104	-21 689
OFFIC16	22.2 %	72.5	781	3968	-6206
RETAIL1	100.0 %	427.1	4597	-25 514	-95 186
RSTRNT1	100.0 %	20.4	220	-2419	-9471
Total		**1390.9**	**14 972**	**-42 263**	**-264 972**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

11.2.4 Life-Cycle Costs

Table 11-16 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type and building design. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 11-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Minnesota

Building Type	Standard Edition			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$5.29	-$0.49	$2.15	$0.20
APART06	-$4.01	-$0.37	$4.33	$0.40
DORMI04	-$7.17	-$0.67	-$15.48	-$1.44
DORMI06	-$2.94	-$0.27	$2.63	$0.24
HOTEL15	$3.60	$0.33	$9.46	$0.88
HIGHS02	-$5.11	-$0.47	-$10.02	-$0.93
OFFIC03	-$3.93	-$0.36	-$15.86	-$1.47
OFFIC08	-$2.80	-$0.26	-$11.96	-$1.11
OFFIC16	$3.44	$0.32	$8.60	$0.80
RETAIL1	-$2.15	-$0.20	-$5.97	-$0.56
RSTRNT1	-$31.64	-$2.94	-$72.36	-$6.72

Table 11-17 applies the Table 11-16 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of more energy-efficient codes. *ASHRAE 90.1-2007* results in total reductions in life-cycle costs of $4.3 million over the 10-year study period relative to *ASHRAE 90.1-2004* for the building types considered in this study. The LEC design leads to a decrease in total statewide life-cycle costs of $7.4 million, while reducing life-cycle costs for 5 of 9 building types. The *ASHRAE 90.1-2007* and the LEC designs both lead to an increase in life-cycle costs for hotels and 16-story office buildings. The LEC design also increases life-cycle costs for the 4- and 6-story apartment buildings. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2007* and LEC design can be extrapolated to estimate the total reductions in life-cycle costs of $7.3 million and $12.4 million over the 10-year study period, respectively.

Table 11-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Minnesota

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	129.2	1390	-$683 726	$277 532
APART06	55.1 %	158.2	1703	-$635 097	$684 399
HOTEL15	100.0 %	94.6	1019	$340 966	$895 302
HIGHS02	100.0 %	234.9	2529	-$1 200 196	-$2 353 524
OFFIC03	37.4 %	122.2	1316	-$479 885	-$1 938 169
OFFIC08	40.4 %	131.8	1419	-$369 390	-$1 576 187
OFFIC16	22.2 %	72.5	781	$249 115	$623 993
RETAIL1	100.0 %	427.1	4597	-$919 484	-$2 551 579
RSTRNT1	100.0 %	20.4	220	-$645 441	-$1 476 209
Total		**1390.9**	**14 972**	**-$4 343 137**	**-$7 414 442**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

11.3 State Summary

Minnesota is the only state in the Midwest Census Region that has adopted *ASHRAE 90.1-2004* as its current state energy code for commercial buildings. On average, adopting *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and energy-related carbon emissions. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code would lead to energy use savings of 282.7 GWh (965.2 GBtu), energy cost savings of $6.0 million, carbon emissions reductions of 70 792 metric tons, and life-cycle cost savings of $7.3 million. The life-cycle cost savings are greater than the energy cost savings. The relaxation of the SHGC requirement from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007* decreases the costs of construction by a greater amount than the other energy efficiency measures increase construction costs, while still reducing total energy costs. The LEC design would lead to even greater impacts with savings of 816.7 GWh (2788.6 GBtu), energy cost savings of $33.5 million, and carbon emissions reductions of 443 839 metric tons for one year's worth of commercial building construction while decreasing life-cycle costs by $12.4 million.

12 Missouri

Missouri is located in the West North Central Census Division, and spans the warmest climate zones in the Midwest Census Region (Zone 4 and Zone 5). The state does not have a commercial building energy code, and is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements. Table 12-1 provides an overview of Missouri's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 84 kWh/m^2 to 124 kWh/m^2 (27 kBtu/ft^2 to 39 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 200 kWh/m^2 to 234 kWh/m^2 (64 kBtu/ft^2 to 74 kBtu/ft^2) annually.

Table 12-1 Average Annual Energy Use by Building Type and Standard Edition, Missouri

Building Type	Standard Edition									
	1999		2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	188	60	187	59	164	52	158	50	140	45
APART06	187	59	185	59	162	51	157	50	137	43
DORMI04	145	46	142	45	125	40	120	38	105	33
DORMI06	205	65	199	63	175	55	172	55	151	48
HOTEL15	173	55	171	54	152	48	160	51	138	44
HIGHS02	234	74	233	74	226	72	217	69	200	64
OFFIC03	133	42	130	41	121	38	113	36	90	29
OFFIC08	124	39	121	38	111	35	104	33	84	27
OFFIC16	157	50	156	49	147	47	156	49	131	42
RETAIL1	151	48	149	47	135	43	121	38	103	33
RSTRNT1	209	66	203	64	185	59	174	55	126	40

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of increasingly stringent energy standard editions. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

12.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in more energy efficient designs for the state of Missouri.

12.1.1 Energy Use

Table 12-2 shows minimal change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types having reductions in energy use of 2.0 % or less. There is a decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from -3.4 % to -14.2 % with an average of -10.3 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -0.7 % to -19.5 %, with an overall average of -13.2 %.

Table 12-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Missouri

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.6	-12.9	-16.0	-25.4
APART06	-0.6	-13.1	-15.7	-26.5
DORMI04	-1.7	-12.9	-16.9	-27.4
DORMI06	-2.0	-14.2	-15.4	-26.0
HOTEL15	-0.8	-11.8	-7.3	-19.8
HIGHS02	-0.3	-3.4	-7.1	-14.3
OFFIC03	-1.7	-8.2	-14.8	-31.6
OFFIC08	-2.0	-9.9	-16.1	-32.3
OFFIC16	-0.8	-6.0	-0.7	-16.3
RETAIL1	-1.2	-9.9	-19.5	-31.3
RSTRNT1	-2.0	-10.9	-16.3	-39.1
Average	**-1.2**	**-10.3**	**-13.2**	**-26.4**

For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC in Zone 4 and Zone 5 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007*, making the requirement less strict. Additionally, the maximum U-factor is relaxed for Zone 4. The 100 % glazing amplifies the impact of these requirement relaxations enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

The LEC design realizes the greatest reductions in energy use, with the change in energy use relative to *ASHRAE 90.1-1999* ranging from -14.3 % to -39.1 % with an average of -26.4 %. Similar to the *ASHRAE 90.1-2007* design, the lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratio. Additionally, the high school realizes smaller reductions in energy use because of its unique occupant activity, with significant occupancy during the school year and minimal occupancy during the summer.

12.1.2 Energy Costs

Table 12-3 shows minimal change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.4 % to -2.4 %), which mirrors the energy use results described above. There is a significant variation in the percentage change in average energy costs for *ASHRAE 90.1-2004*, ranging from -6.4 % to -20.4 % depending on the building type, with an average of -14.6 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -1.7 % to -22.6 %, with an overall average of -16.1 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -20.0 % to -43.9 % with an average of -31.9 % overall.

Table 12-3 Average Percentage Change in Energy Costs, 10-Year, Missouri

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.7	-19.2	-21.6	-33.3
APART06	-0.7	-19.3	-21.2	-35.2
DORMI04	-2.0	-20.0	-22.6	-35.0
DORMI06	-2.4	-20.4	-21.3	-34.9
HOTEL15	-0.9	-17.9	-12.4	-27.5
HIGHS02	-0.4	-6.4	-9.4	-21.7
OFFIC03	-1.8	-10.2	-14.2	-33.4
OFFIC08	-2.1	-11.5	-14.8	-32.5
OFFIC16	-0.9	-7.9	-1.7	-20.0
RETAIL1	-1.3	-13.4	-19.9	-33.5
RSTRNT1	-2.3	-14.7	-18.2	-43.9
Average	**-1.4**	**-14.6**	**-16.1**	**-31.9**

For all building designs, the reductions in energy costs are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. In the most extreme cases, electricity consumption is decreased while natural gas consumption is increased. The buildings use electricity for all energy consumption except for the heating component of the HVAC system, which uses natural gas. The energy efficiency measures adopted can decrease energy use for both lighting and cooling the building while increasing heating loads. Since electricity is more expensive than natural gas on a per unit of energy basis, the shift in energy use from cooling to heating magnifies the decrease in energy costs for the building.

12.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small changes (2.6 % or less) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 12-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -8.9 % to -24.6 % with an average of -17.5 %. The *ASHRAE 90.1-2007* design leads to slightly greater reductions than *ASHRAE 90.1-2004*, with the average change in carbon emissions ranging from -2.3 % to -26.3 % with an overall average of -18.0 %. The LEC design leads to the greatest average carbon emissions changes, ranging from -22.2 % to -46.8 % depending on the building type with an average of -35.6 % across all building types.

Table 12-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Missouri

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.8	-23.4	-25.3	-38.6
APART06	-0.8	-23.4	-24.9	-40.9
DORMI04	-2.2	-24.6	-26.3	-39.8
DORMI06	-2.6	-24.5	-25.2	-40.6
HOTEL15	-1.0	-21.9	-15.8	-32.6
HIGHS02	-0.5	-8.9	-11.2	-27.7
OFFIC03	-1.9	-11.4	-13.9	-34.4
OFFIC08	-2.2	-12.3	-14.1	-32.6
OFFIC16	-1.0	-9.1	-2.3	-22.2
RETAIL1	-1.5	-15.6	-20.1	-34.8
RSTRNT1	-2.5	-17.0	-19.3	-46.8
Average	**-1.5**	**-17.5**	**-18.0**	**-35.6**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage changes in carbon emissions are greater than the percentage changes in energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. In the most extreme cases, there is a shift from electricity to natural gas consumption, which further decreases carbon emissions because electricity has a higher carbon emissions rate per unit of energy than natural gas in Missouri.

12.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 12-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for 10 of 11 building types over a 10-year study period. *ASHRAE 90.1-1999* is the lowest cost building design for three building types while *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building design for two and three building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -2.3 % to 5.7 % depending on building type. The LEC design realizes a reduction in life-cycle costs for 3 of 11 building types, with the percentage change in life-cycle costs ranging from -3.3 % to 1.7 %. Given that the adoption of the LEC design decreases life-cycle costs for 6 of 11 building types, it may be cost-effective to adopt the LEC design as the state's energy code for commercial buildings.

Table 12-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Missouri

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.1	-1.5	**-1.8**	-1.0
APART06	0.0	-1.6	**-1.8**	-1.1
DORMI04	3.9	0.4	-0.1	**0.2**
DORMI06	-0.2	-2.2	**-2.3**	-1.9
HOTEL15	0.0	**-2.1**	-1.6	-0.9
HIGHS02	0.2	-0.5	-0.9	**-1.4**
OFFIC03	5.4	3.5	3.0	1.4
OFFIC08	5.6	3.4	2.4	0.4
OFFIC16	0.1	**-0.7**	-0.1	0.9
RETAIL1	3.1	1.1	0.5	1.7
RSTRNT1	7.1	5.7	4.6	**-3.3**
Average	**2.3**	**0.5**	**0.2**	**-0.5**

12.1.5 City Comparisons

Simulations are run for four cities located in Missouri: Columbia, Kansas City, Springfield, and St. Louis in Climate Zone 4. While the four cities in Missouri selected for this study are located in the same climate zone, the results may still vary across cities within the state for three reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality. Finally, St. Louis has adopted a more stringent energy code than the state.

As can be seen in Table 12-6, the average reduction in energy use for all building types from adopting newer energy standard editions varies across cities. St. Louis realizes smaller percentage reductions in energy use than the other three cities because St. Louis has adopted *ASHRAE 90.1-2001* while the state has not yet adopted a state energy code. Excluding St. Louis, there is minimal variation between cities. For the LEC design, the change in average energy use ranges from -26.2 % to -27.7 %.

Table 12-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Missouri

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Columbia	4A	-1.6	-10.4	-13.5	-26.5
Kansas City	4A	-1.6	-10.3	-13.2	-26.2
Springfield	4A	-1.7	-11.5	-14.3	-27.7
St. Louis	4A	0.0	-9.0	-12.0	-25.1
Average		**-1.2**	**-10.3**	**-13.2**	**-26.4**

The variations in energy costs across cities are a result of three factors, the reduction in energy use, the fuel source of the reduction, and the current local energy code. Table 12-7 shows that the average reduction in energy costs for all building types varies minimally across cities, with St. Louis realizing smaller reductions than the other three cities. Excluding St. Louis, adopting the LEC design results in an average change in energy costs ranging from -31.8 % to -33.1 %. The percentage change in energy costs is greater than the percentage change in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption.

Table 12-7 Average Percentage Change in Energy Costs by City, 10-Year, Missouri

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Columbia	4A	-1.9	-14.9	-16.5	-32.2
Kansas City	4A	-1.9	-14.7	-16.2	-31.8
Springfield	4A	-1.9	-15.7	-17.1	-33.1
St. Louis	4A	0.0	-13.2	-14.7	-30.6
Average		**-1.4**	**-14.6**	**-16.1**	**-31.9**

Table 12-8 reports changes in energy-related carbon emissions by city for Missouri. For all four cities, the more stringent standard editions result in greater reductions in carbon emissions. The percentage change in carbon emissions is greater than the percentage change in energy use because electricity consumption is decreased by a greater percentage than natural gas consumption. As with energy use and energy costs, St. Louis realizes smaller reductions in carbon emissions than the other three cities because the city has adopted *ASHRAE 90.1-2001* as its local energy code.

Table 12-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Missouri

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Columbia	4A	-1.9	-17.6	-18.6	-36.5
Kansas City	4A	-1.8	-17.1	-18.1	-35.9
Springfield	4A	-1.9	-16.9	-17.8	-35.4
St. Louis	4A	0.0	-15.4	-16.4	-34.3
Average		**-1.4**	**-16.7**	**-17.7**	**-35.5**

The data reported in Table 12-9 show that, over a 10-year period, average life-cycle costs increase for all cities for the *ASHRAE 90.1-2001* compared to *ASHRAE 90.1-1999*. St. Louis realizes percentage reductions in life-cycle costs while the other three cities realize increases in life-cycle costs for *ASHRAE 90.1-2004* and *-2007*. Kansas City is the only city that does not realize a percentage reduction in life-cycle costs from adoption of the LEC design. Based on these results, there is significant variation in life-cycle costs across cities in Missouri.

Table 12-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Missouri

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Columbia	4A	3.1	1.2	0.8	-0.1
Kansas City	4A	3.1	1.4	1.1	0.5
Springfield	4A	3.0	1.0	0.8	-0.1
St. Louis	4A	0.0	-1.6	-1.9	-2.0
Average		**2.3**	**0.5**	**0.2**	**-0.5**

12.2 Total Savings

How much can Missouri save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

12.2.1 Energy Use

Table 12-10 reports the average per unit change in annual energy use by building type and building design in the state.[26] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 12-11 reports the estimated average annual floor area of new construction and the total annual change in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[27]

[26] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[27] State-level subcategory data are not available.

Table 12-10 Average Per Unit Change in Annual Energy Use, Missouri

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	-1.1	-0.4	-24.2	-7.7	-30.0	-9.5	-47.6	-15.1
APART06	-1.1	-0.4	-24.3	-7.7	-29.1	-9.2	-49.3	-15.6
DORMI04	-2.5	-0.8	-18.5	-5.9	-24.3	-7.7	-39.4	-12.5
DORMI06	-4.1	-1.3	-28.8	-9.1	-31.3	-9.9	-52.8	-16.8
HOTEL15	-1.3	-0.4	-20.2	-6.4	-12.6	-4.0	-34.1	-10.8
HIGHS02	-0.7	-0.2	-10.8	-3.4	-19.5	-6.2	-41.8	-13.3
OFFIC03	-2.2	-0.7	-8.0	-2.5	-16.5	-5.2	-33.3	-10.6
OFFIC08	-2.4	-0.8	-12.2	-3.9	-19.9	-6.3	-40.0	-12.7
OFFIC16	-1.3	-0.4	-9.5	-3.0	-1.1	-0.3	-25.5	-8.1
RETAIL1	-1.8	-0.6	-14.8	-4.7	-29.3	-9.3	-47.1	-14.9
RSTRNT1	-4.2	-1.3	-22.7	-7.2	-33.7	-10.7	-81.1	-25.7

The total annual reduction in energy use ranges widely across building designs, but *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC all decrease energy use across the state for all building types. Adopting *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, and *ASHRAE 90.1-2007* results in an annual decrease of 2.2 GWh (7.4 GBtu), 21.3 GWh (72.7 GBtu), and 32.3 GWh (110.4 GBtu), respectively. The adoption of the LEC design as the state's energy code would save 60.8 GWh (207.4 GBtu) of total energy use annually for one year's worth of new construction for these building types.

Table 12-11 Statewide Change in Annual Energy Use for One Year of Construction, Missouri

Building Type	Subcat. Weight.	m^2 (1000s)	ft^2 (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	kBtu
APART04	44.9 %	79	847	-88	-300	-1906	-6507	-2364	-8071	-3748	-12 796
APART06	55.1 %	96	1037	-110	-374	-2340	-7991	-2805	-9578	-4750	-16 217
HOTEL15	100.0 %	176	1897	-235	-804	-3564	-12 169	-2213	-7556	-6012	-20 526
HIGHS02	100.0 %	325	3499	-221	-754	-2592	-8851	-5352	-18 275	-10 827	-36 968
OFFIC03	37.4 %	92	988	-203	-693	-988	-3375	-1791	-6114	-3836	-13 097
OFFIC08	40.4 %	99	1065	-240	-818	-1207	-4120	-1966	-6711	-3954	-13 501
OFFIC16	22.2 %	54	586	-68	-233	-515	-1758	-58	-197	-1390	-4745
RETAIL1	100.0 %	503	5411	-883	-3016	-7464	-25 487	-14 720	-50 262	-23 671	-80 824
RSTRNT1	100.0 %	32	341	-132	-452	-718	-2451	-1067	-3644	-2570	-8774
Total		**1456**	**15 671**	**-2180**	**-7443**	**-21 295**	**-72 710**	**-32 336**	**-110 408**	**-60 756**	**-207 448**
Note: Dormitories are excluded because no such floor area category is reported in the construction data.											

Assuming that the buildings considered in this study, which represent 61.7 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from adopting the LEC design in new commercial buildings to be 98.5

GWh (336.2 GBtu) per year. These savings imply 984.7 GWh (3362.2 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 52.4 GWh (178.9 GBtu) annually or 524.1 GWh (1789.4 GBtu) over the 10-year study period.

The statewide change in energy use varies across building types within a building design. Building types that represent a greater amount of new floor area realize the largest changes in aggregate energy use. The greatest total reductions are realized by retail stores and high schools because they represent 34.5 % and 22.3 %, respectively, of the new construction in the state while all other building types represent 12.1 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. For example, the building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 12-2.

12.2.2 Energy Costs

Table 12-12 reports the average per unit change in energy costs by building type and building design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 12-12 Average Per Unit Change in Energy Costs, 10-Year, Missouri

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$0.63	-$0.06	-$17.07	-$1.59	-$19.14	-$1.78	-$29.58	-$2.75
APART06	-$0.64	-$0.06	-$17.10	-$1.59	-$18.80	-$1.75	-$31.15	-$2.89
DORMI04	-$1.39	-$0.13	-$13.89	-$1.29	-$15.70	-$1.46	-$24.23	-$2.25
DORMI06	-$2.31	-$0.21	-$19.90	-$1.85	-$20.77	-$1.93	-$33.92	-$3.15
HOTEL15	-$0.76	-$0.07	-$14.44	-$1.34	-$10.05	-$0.93	-$22.23	-$2.07
HIGHS02	-$1.25	-$0.12	-$6.91	-$0.64	-$9.61	-$0.89	-$22.61	-$2.10
OFFIC03	-$0.38	-$0.04	-$6.32	-$0.59	-$9.21	-$0.86	-$21.36	-$1.98
OFFIC08	-$1.37	-$0.13	-$7.52	-$0.70	-$9.71	-$0.90	-$21.32	-$1.98
OFFIC16	-$0.71	-$0.07	-$6.26	-$0.58	-$1.35	-$0.13	-$15.78	-$1.47
RETAIL1	-$0.99	-$0.09	-$9.94	-$0.92	-$14.69	-$1.36	-$24.78	-$2.30
RSTRNT1	-$2.36	-$0.22	-$15.09	-$1.40	-$18.66	-$1.73	-$45.10	-$4.19

Table 12-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. The *ASHRAE 90.1-2001* design realizes the smallest reductions in energy costs ($1.2 million). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of \$14.8 million, \$18.0 million, and \$35.1 million, respectively. Assuming that the buildings considered in this study, which represent 61.7 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of \$2.0 million, \$24.0 million, \$29.1 million, and \$56.9 million over the 10-year study period, respectively.

Table 12-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Missouri

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	79	847	-\$49 689	-\$1 342 647	-\$1 506 136	-\$2 326 931
APART06	55.1 %	96	1037	-\$61 995	-\$1 648 000	-\$1 811 493	-\$3 001 945
HOTEL15	100 %	176	1897	-\$133 295	-\$2 544 720	-\$1 770 554	-\$3 916 929
HIGHS02	100 %	325	3499	-\$124 941	-\$2 055 636	-\$2 995 639	-\$6 943 063
OFFIC03	37.4 %	92	988	-\$114 895	-\$634 646	-\$881 699	-\$2 075 268
OFFIC08	40.4 %	99	1065	-\$135 661	-\$743 870	-\$961 260	-\$2 109 782
OFFIC16	22.2 %	54	586	-\$38 666	-\$340 987	-\$73 316	-\$859 483
RETAIL1	100 %	503	5411	-\$500 050	-\$4 999 133	-\$7 384 263	-\$12 458 820
RSTRNT1	100 %	32	341	-\$74 884	-\$478 143	-\$591 193	-\$1 428 657
Total		**1456**	**15 671**	**-\$1 234 075**	**-\$14 787 783**	**-\$17 975 554**	**-\$35 120 878**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

12.2.3 Energy-related Carbon Emissions

Table 12-14 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type and building design. The carbon emissions estimation approach is defined in Section 5.3.

Table 12-14 Average Per Unit Change in Carbon Emissions, 10-Year, Missouri

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-2.3	-326.0	-66.8	-351.6	-72.0	-537.3	-110.0	-2.3
APART06	-2.3	-326.7	-66.9	-347.2	-71.1	-570.3	-116.8	-2.3
DORMI04	-5.0	-271.1	-55.5	-289.8	-59.4	-438.0	-89.7	-5.0
DORMI06	-8.2	-377.6	-77.3	-388.1	-79.5	-625.0	-128.0	-8.2
HOTEL15	-2.7	-277.2	-56.8	-200.3	-41.0	-412.1	-84.4	-2.7
HIGHS02	-1.4	-125.7	-25.7	-159.4	-32.6	-393.3	-80.6	-1.4
OFFIC03	-4.5	-127.4	-26.1	-154.7	-31.7	-384.3	-78.7	-4.5
OFFIC08	-4.9	-136.1	-27.9	-155.7	-31.9	-359.6	-73.7	-4.9
OFFIC16	-2.5	-116.8	-23.9	-29.9	-6.1	-286.2	-58.6	-2.5
RETAIL1	-3.5	-186.4	-38.2	-239.2	-49.0	-415.0	-85.0	-3.5
RSTRNT1	-8.4	-282.3	-57.8	-321.1	-65.8	-777.5	-159.2	-8.4

Table 12-15 applies the Table 12-14 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs decrease carbon emissions overall. The adoption of *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in savings of 281 003 metric tons and 309 899 metric tons over a 10-year study period, respectively. The adoption of the LEC design as the state's energy code decreases carbon emissions by 617 379 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate statewide reductions in carbon emissions of 455 435 metric tons, 502 267 metric tons, and 1.0 million metric tons over the 10-year study period, respectively.

Table 12-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Missouri – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	79	847	-865	-25 649	-27 663	-42 269
APART06	55.1 %	96	1037	-1079	-31 477	-33 457	-54 949
HOTEL15	100.0 %	176	1897	-2319	-48 849	-35 299	-72 608
HIGHS02	100.0 %	325	3499	-2174	-40 868	-51 824	-127 864
OFFIC03	37.4 %	92	988	-1999	-11 694	-14 195	-35 273
OFFIC08	40.4 %	99	1065	-2360	-13 470	-15 411	-35 593
OFFIC16	22.2 %	54	586	-673	-6 362	-1629	-15 586
RETAIL1	100.0 %	503	5411	-8700	-93 691	-120 247	-208 604
RSTRNT1	100.0 %	32	341	-1303	-8942	-10 174	-24 632
Total		**1456**	**15 671**	**-21 471**	**-281 003**	**-309 899**	**-617 379**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

12.2.4 Life-Cycle Costs

Table 12-16 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type and building design. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 12-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Missouri

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	$0.55	$0.05	-$16.07	-$1.49	-$19.03	-$1.77	-$10.21	-$0.95
APART06	$0.08	$0.01	-$16.75	-$1.56	-$19.11	-$1.77	-$11.77	-$1.09
DORMI04	$38.49	$3.58	$3.35	$0.31	-$2.32	-$0.22	$1.60	$0.15
DORMI06	-$1.77	-$0.16	-$23.95	-$2.23	-$24.97	-$2.32	-$20.84	-$1.94
HOTEL15	$0.05	$0.00	-$21.16	-$1.97	-$16.43	-$1.53	-$9.11	-$0.85
HIGHS02	$1.73	$0.16	-$4.08	-$0.38	-$7.48	-$0.69	-$11.64	-$1.08
OFFIC03	$43.13	$4.01	$27.71	$2.57	$23.85	$2.22	$10.53	$0.98
OFFIC08	$46.97	$4.36	$27.98	$2.60	$19.01	$1.77	$1.97	$0.18
OFFIC16	$0.55	$0.05	-$5.24	-$0.49	-$0.65	-$0.06	$7.27	$0.68
RETAIL1	$21.23	$1.97	$7.12	$0.66	$2.95	$0.27	$11.19	$1.04
RSTRNT1	$97.27	$9.04	$78.27	$7.27	$62.20	$5.78	-$48.30	-$4.49

Table 12-17 applies the Table 12-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. Total reductions in life-cycle costs over the 10-year study period vary across building designs. Adoption of the *ASHRAE 90.1-2001* design results in an increase in life-cycle costs for all 9 building types and increases total statewide life-cycle costs by $23.0 million. The *ASHRAE 90.1-2004* and *-2007* designs result in a decrease in life-cycle costs for 5 of 9 building types, with total life-cycle costs increasing by $3.1 million for *ASHRAE 90.1-2004* and decreasing by $1.2 million for *ASHRAE 90.1-2007*. The LEC design decreases life-cycle costs for 5 of 9 building types, and decreases total life-cycle costs by $1.7 million. The results for the *ASHRAE 90.1-2007* design emphasize the importance of estimating total statewide impacts instead of focusing on the average percentage change in life-cycle costs, because total life-cycle costs are decreased even though the average percentage change in life-cycle costs is positive. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate statewide changes in life-cycle costs of $37.3 million, $5.1 million, -$1.9 million, and -$2.7 million over the 10-year study period, respectively.

Table 12-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Missouri

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	79	847	$42 962	-$1 264 632	-$1 496 810	-$803 128
APART06	55.1 %	96	1037	$7682	-$1 614 481	-$1 840 983	-$1 134 155
HOTEL15	100.0 %	176	1897	$8902	-$3 728 180	-$2 894 223	-$1 604 607
HIGHS02	100.0 %	325	3499	$560 832	-$1 327 736	-$2 431 676	-$3 785 260
OFFIC03	37.4 %	92	988	$3 958 308	$2 543 076	$2 188 712	$966 702
OFFIC08	40.4 %	99	1065	$4 648 800	$2 769 010	$1 881 288	$194 621
OFFIC16	22.2 %	54	586	$29 749	-$285 436	-$35 536	$396 073
RETAIL1	100.0 %	503	5411	$10 674 089	$3 576 708	$1 481 402	$5 624 263
RSTRNT1	100.0 %	32	341	$3 081 362	$2 479 703	$1 970 535	-$1 530 097
Total		**1456**	**15 671**	**$23 012 686**	**$3 148 032**	**-$1 177 291**	**-$1 675 588**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

12.3 State Summary

Missouri is one of the four states in the Midwest Census Region that has no state energy code for commercial buildings, and represents the warmest climates in the Midwest Census Region. Adopting the *ASHRAE 90.1-2001* and *-2004* designs leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions, but not in a life-cycle cost-effective manner, costing $37.3 million and $5.1 million over 10 years, respectively. On average, adopting the *ASHRAE 90.1-2007* and LEC designs leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions while decreasing life-cycle costs. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting

ASHRAE 90.1-2007 as the state's energy code for commercial buildings would lead to energy use savings of 524.1GWh (1789.4 GBtu), energy cost savings of $29.1 million, and 502 267 metric tons of carbon emissions reductions while saving $1.9 million in life-cycle costs for one year's worth of commercial building construction. Adopting the LEC design would lead to even greater impacts than adopting *ASHRAE 90.1-2007*, with savings of 984.7 GWh (3362.2 GBtu), $56.9 million of energy costs, 1.0 million metric tons of carbon emissions while decreasing life-cycle costs by $2.7 million for one year's worth of commercial building construction.

13 Nebraska

Nebraska has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, and is located in the West North Central Census Division and Climate Zone 5A. Table 13-1 provides an overview of Nebraska's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 87 kWh/m^2 to 107 kWh/m^2 (28 kBtu/ft^2 to 34 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 238 kWh/m^2 to 252 kWh/m^2 (75 kBtu/ft^2 to 80 kBtu/ft^2) annually.

Table 13-1 Average Annual Energy Use by Building Type and Standard Edition, Nebraska

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	167	53	151	48
APART06	166	53	147	47
DORMI04	131	41	115	37
DORMI06	184	58	164	52
HOTEL15	176	56	153	49
HIGHS02	252	80	238	75
OFFIC03	117	37	96	30
OFFIC08	107	34	87	28
OFFIC16	168	53	142	45
RETAIL1	132	42	116	37
RSTRNT1	183	58	139	44

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

13.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in the LEC design in the state of Nebraska.

13.1.1 Statewide Building Comparison

Table 13-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*.

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -5.8 % to -24.2 % depending on the building type with an overall average of -13.7 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 13-2 Average Percentage Change from Adoption of the LEC Design, 10-Year, Nebraska

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.8	-16.3	-17.2	0.7
APART06	-11.2	-19.5	-20.5	0.6
DORMI04	-11.7	-17.2	-17.9	-0.2
DORMI06	-10.9	-18.8	-19.8	0.3
HOTEL15	-12.7	-18.9	-19.7	0.6
HIGHS02	-5.8	-15.0	-16.4	-0.6
OFFIC03	-18.2	-23.0	-23.5	-2.3
OFFIC08	-18.5	-21.2	-21.5	-2.2
OFFIC16	-15.2	-20.2	-20.7	0.8
RETAIL1	-12.5	-16.8	-17.2	0.8
RSTRNT1	-24.2	-32.6	-33.5	-3.9
Average	**-13.7**	**-19.9**	**-20.7**	**-0.5**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.0 % to -32.6 % depending on the building type with an average of -19.9 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 9 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 42.2 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is nearly three times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.4 % to -33.5 % with an average of -20.7 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity

consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 9 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -3.9 % to 0.8 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -0.5 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

13.1.2 City Comparisons

Simulations are run for five cities located in Nebraska, all of which are located in Zone 5A: Grand Island, Norfolk, North Platte, Omaha, and Scottsbluff. While the five cities are located in the same climate zone, the results may still vary for two reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality.

Table 13-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage change in energy use for all building types from adopting the LEC design varies minimally across cities, ranging from -13.1 % to -14.1 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 13-3 Average Percentage Change from Adoption of the LEC Design by City, 10-Year, Nebraska

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Grand Island	5A	-13.8	-19.9	-20.9	-0.5
Norfolk	5A	-13.1	-19.4	-20.3	-0.3
North Platte	5A	-13.5	-20.1	-21.1	-0.5
Omaha	5A	-14.0	-19.8	-20.7	-0.5
Scottsbluff	5A	-14.1	-20.6	-21.6	-0.6
Average		**-13.7**	**-19.9**	**-20.9**	**-0.5**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -19.4 % to -20.6 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because of the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -20.3 % to -21.6 %. Percentage changes in life-cycle costs for all building types vary minimally across cities, ranging from -0.3 % to -0.6 %.

13.2 Total Savings

How much can Nebraska save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

13.2.1 Energy Use

Table 13-4 reports the average per unit change in annual energy use by building type and building design in the state.[28] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 13-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[29]

[28] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[29] State-level subcategory data are not available.

Table 13-4 Average Per Unit Change in Annual Energy Use, Nebraska

Building Type	Standard Edition	
	LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-16.3	-5.2
APART06	-18.5	-5.9
DORMI04	-15.3	-4.8
DORMI06	-20.0	-6.4
HOTEL15	-22.3	-7.1
HIGHS02	-21.4	-6.8
OFFIC03	-14.7	-4.7
OFFIC08	-19.7	-6.2
OFFIC16	-25.4	-8.1
RETAIL1	-16.5	-5.2
RSTRNT1	-44.3	-14.1

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 10.4 GWh (35.4 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 60.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 17.1 GWh (58.3 GBtu) per year. These savings imply 170.8 GWh (583.0 GBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest changes in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 41.1 % and 18.4 %, respectively, of the new construction in the state while all other building types represent 10.8 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 6th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 13-2.

Table 13-5 Statewide Change in Annual Energy Use for One Year of Construction, Nebraska

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	13.2	143	-216 456	-739 075
APART06	55.1 %	16.2	175	-299 533	-1 022 735
HOTEL15	100.0 %	60.6	653	-1 353 727	-4 622 206
HIGHS02	100.0 %	102.8	1107	-1 508 953	-5 152 215
OFFIC03	37.4 %	47.2	508	-1 009 922	-3 448 308
OFFIC08	40.4 %	50.9	548	-1 001 908	-3 420 946
OFFIC16	22.2 %	28.0	302	-712 920	-2 434 216
RETAIL1	100.0 %	229.8	2474	-3 803 322	-12 986 176
RSTRNT1	100.0 %	10.7	115	-475 386	-1 623 171
Total		**559.6**	**6024**	**-10 382 128**	**-35 449 048**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

13.2.2 Energy Costs

Table 13-6 reports the average per unit change in energy costs by building type for the LEC design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 13-6 Average Per Unit Change in Energy Costs, 10-Year, Nebraska

Building Type	Standard Edition LEC $/m^2$	Standard Edition LEC $/ft^2$
APART04	-$10.38	-$0.96
APART06	-$12.44	-$1.16
DORMI04	-$8.79	-$0.82
DORMI06	-$13.26	-$1.23
HOTEL15	-$12.92	-$1.20
HIGHS02	-$13.37	-$1.24
OFFIC03	-$13.07	-$1.21
OFFIC08	-$12.04	-$1.12
OFFIC16	-$15.86	-$1.47
RETAIL1	-$9.94	-$0.92
RSTRNT1	-$26.59	-$2.47

Table 13-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $6.7 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 60.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $11.1 million over the 10-year study period.

Table 13-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Nebraska

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	13.2	143	-$137 494
APART06	55.1 %	16.2	175	-$201 839
HOTEL15	100.0 %	60.6	653	-$783 535
HIGHS02	100.0 %	102.8	1107	-$1 343 471
OFFIC03	37.4 %	47.2	508	-$631 499
OFFIC08	40.4 %	50.9	548	-$612 857
OFFIC16	22.2 %	28.0	302	-$444 397
RETAIL1	100.0 %	229.8	2474	-$2 284 163
RSTRNT1	100.0 %	10.7	115	-$285 042
Total		**559.6**	**6024**	**-$6 724 297**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

13.2.3 Energy-related Carbon Emissions

Table 13-8 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

Table 13-8 Average Per Unit Change in Carbon Emissions, 10-Year, Nebraska

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-156.1	-32.0
APART06	-188.0	-38.5
DORMI04	-131.2	-26.9
DORMI06	-200.1	-41.0
HOTEL15	-193.0	-39.5
HIGHS02	-200.8	-41.1
OFFIC03	-200.9	-41.2
OFFIC08	-180.5	-37.0
OFFIC16	-238.2	-48.8
RETAIL1	-148.9	-30.5
RSTRNT1	-398.1	-81.5

Table 13-9 applies the Table 13-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs, and is highly correlated with the total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 101 296 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the statewide reduction in carbon emissions of 166 606 metric tons over the 10-year study period.

Table 13-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Nebraska – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	13.2	143	-2068
APART06	55.1 %	16.2	175	-3049
HOTEL15	100.0 %	60.6	653	-11 700
HIGHS02	100.0 %	102.8	1107	-20 646
OFFIC03	37.4 %	47.2	508	-9488
OFFIC08	40.4 %	50.9	548	-9192
OFFIC16	22.2 %	28.0	302	-6675
RETAIL1	100.0 %	229.8	2474	-34 210
RSTRNT1	100.0 %	10.7	115	-4268
Total		**559.6**	**6024**	**-101 296**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

13.2.4 Life-Cycle Costs

Table 13-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 13-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Nebraska

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$6.51	$0.61
APART06	$5.43	$0.50
DORMI04	-$1.75	-$0.16
DORMI06	$2.69	$0.25
HOTEL15	$5.51	$0.51
HIGHS02	-$4.79	-$0.45
OFFIC03	-$17.09	-$1.59
OFFIC08	-$16.88	-$1.57
OFFIC16	$5.62	$0.52
RETAIL1	$5.03	$0.47
RSTRNT1	-$48.43	-$4.50

Table 13-11 applies the Table 13-10 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $857 290 in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Eight-story office buildings ($859 676) and 3-story office buildings ($806 793) realize the greatest reductions in life-cycle costs. Retail stores realize the greatest increase in life-cycle costs ($1.2 million). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $1.4 million over the 10-year study period.

Table 13-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Nebraska

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	13.2	143	\$86 268
APART06	55.1 %	16.2	175	\$88 078
HOTEL15	100.0 %	60.6	653	\$334 231
HIGHS02	100.0 %	102.8	1107	-\$492 735
OFFIC03	37.4 %	47.2	508	-\$806 793
OFFIC08	40.4 %	50.9	548	-\$859 676
OFFIC16	22.2 %	28.0	302	\$157 380
RETAIL1	100.0 %	229.8	2474	\$1 155 175
RSTRNT1	100.0 %	10.7	115	-\$519 218
Total		**559.6**	**6024**	**-\$857 290**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

13.3 State Summary

Nebraska has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions, and does so in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 170.8 GWh (583.0 GBtu), energy cost savings of \$11.1 million, and carbon emissions reductions of 166 606 metric tons while decreasing life-cycle costs of \$1.4 million for one year's worth of commercial building construction.

14 North Dakota

North Dakota is located in the West North Central Census Division and spans two climate zones (Zone 6 and Zone 7). The state does not have a commercial building energy code, and is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements. Table 14-1 provides an overview of North Dakota's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 96 kWh/m^2 to 129 kWh/m^2 (30 kBtu/ft^2 to 41 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 308 kWh/m^2 to 346 kWh/m^2 (104 kBtu/ft^2 to 110 kBtu/ft^2) annually.

Table 14-1 Average Annual Energy Use by Building Type and Standard Edition, North Dakota

Building Type	Standard Edition									
	1999		2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	219	69	218	69	211	67	200	63	180	57
APART06	216	68	215	68	207	66	197	63	179	57
DORMI04	177	56	175	55	173	55	160	51	138	44
DORMI06	238	75	237	75	228	72	216	69	198	63
HOTEL15	211	67	209	66	207	66	210	67	190	60
HIGHS02	346	110	345	109	343	109	329	104	308	98
OFFIC03	147	47	146	46	143	45	129	41	104	33
OFFIC08	129	41	127	40	122	39	115	37	96	30
OFFIC16	187	59	186	59	188	60	191	61	168	53
RETAIL1	184	58	183	58	176	56	155	49	125	40
RSTRNT1	255	81	252	80	248	79	203	64	149	47

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of increasingly stringent energy standard editions. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

14.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in more energy efficient designs for the state of North Dakota.

14.1.1 Energy Use

Table 14-2 shows minimal change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types realizing reductions in energy use of 1.7 % or less. There is a small decrease in energy use for 10 of 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from 0.4 % to -5.7 % with an average of -2.9 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from 2.2 % to -20.6 %, with an overall average of -8.9 %.

Table 14-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, North Dakota

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.3	-3.7	-8.5	-17.5
APART06	-0.4	-4.1	-8.5	-17.2
DORMI04	-1.0	-1.7	-9.3	-21.6
DORMI06	-0.4	-4.2	-9.0	-16.6
HOTEL15	-0.6	-1.7	-0.4	-10.0
HIGHS02	-0.4	-1.0	-4.9	-11.1
OFFIC03	-1.2	-3.1	-12.5	-29.5
OFFIC08	-1.7	-5.7	-10.7	-26.0
OFFIC16	-0.7	0.4	2.2	-9.9
RETAIL1	-0.7	-4.1	-15.7	-31.8
RSTRNT1	-1.3	-2.8	-20.6	-41.8
Average	**-0.8**	**-2.9**	**-8.9**	**-21.2**

The *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* designs realize an increase for the 16-story office building. The key driver is the consolidation of the 26 climate zones in *ASHRAE 90.1-2001* down to 8 climate zones in *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007*, which resulted in changes in building envelope requirements for some locations in the state, including relaxation of the maximum window U-factor requirement and insulation R-value minimum requirements. Given the cold climate in North Dakota, the relaxation of these requirements leads to increases in natural gas consumption.

For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC in Zone 6 and Zone 7 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007*, making the requirement less strict. The 100 % glazing amplifies the impact of this requirement relaxation enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

The LEC design realizes the greatest reductions in energy use, with the change in energy use relative to *ASHRAE 90.1-1999* ranging from -9.9 % to -41.8 % with an average of -21.2 %. Similar to the *ASHRAE 90.1-2007* design, the lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratio due to the less strict window SHGC requirement.

14.1.2 Energy Costs

Table 14-3 shows minimal change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.5 % to -2.0 %), which mirrors the energy use results described above. There is a significant variation in the percentage change in average energy costs for *ASHRAE 90.1-2004*, ranging from -5.1 % to -15.9 % depending on the building type, with an average of -11.7 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -1.8 % to -20.8 %, with an overall average of -14.6 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -13.5 % to -44.2 % with an average of -28.5 % overall.

Table 14-3 Average Percentage Change in Energy Costs, 10-Year, North Dakota

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.5	-15.6	-18.8	-30.8
APART06	-0.6	-15.9	-18.8	-30.5
DORMI04	-1.4	-15.8	-20.2	-33.7
DORMI06	-0.6	-15.3	-18.3	-28.8
HOTEL15	-0.9	-14.0	-10.9	-20.8
HIGHS02	-0.7	-5.1	-8.1	-18.9
OFFIC03	-1.6	-8.5	-12.9	-30.5
OFFIC08	-2.0	-10.4	-12.5	-28.1
OFFIC16	-1.0	-5.5	-1.8	-13.5
RETAIL1	-1.0	-11.5	-18.0	-33.4
RSTRNT1	-1.8	-10.7	-20.8	-44.2
Average	**-1.1**	**-11.7**	**-14.6**	**-28.5**

For all building designs, the reductions in energy costs are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. In the most extreme cases, electricity consumption is reduced while natural gas consumption is increased. The buildings use electricity for all energy consumption except for the heating component of the HVAC system, which uses natural gas. The energy efficiency measures adopted may lead to a decrease in energy use for both lighting and cooling the building while increasing heating loads. Since electricity is more expensive than natural gas on a per unit of energy basis, the shift in energy use from cooling to heating magnifies the decrease in energy costs for the building. Even the 16-story office building, which realizes a percentage increase in energy use, realizes a percentage reduction in energy costs due to a shift in energy use from electricity to natural gas.

14.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small changes (2.0 % or less) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 14-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -6.1 % to -18.5 % with an average of -13.3 %. The *ASHRAE 90.1-2007* design leads to slightly greater reductions than *ASHRAE 90.1-2004*, with the average change in carbon emissions ranging from -2.4 % to -20.9 % and an overall average of -15.7 %. The LEC design leads to the greatest average carbon emissions changes, ranging from -14.1 % to -44.6 % depending on the building type with an average of -29.9 % across all building types.

Table 14-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, North Dakota

Building Type	Standard Edition			
	2001	**2004**	**2007**	**LEC**
APART04	-0.6	-18.0	-20.9	-33.4
APART06	-0.6	-18.2	-20.8	-33.1
DORMI04	-1.5	-18.5	-22.2	-36.0
DORMI06	-0.6	-17.4	-20.2	-31.2
HOTEL15	-1.0	-16.3	-12.9	-22.8
HIGHS02	-0.7	-6.1	-8.9	-20.8
OFFIC03	-1.6	-9.3	-13.0	-30.6
OFFIC08	-2.0	-11.1	-12.8	-28.4
OFFIC16	-1.0	-6.5	-2.4	-14.1
RETAIL1	-1.0	-12.8	-18.4	-33.7
RSTRNT1	-1.9	-12.1	-20.9	-44.6
Average	**-1.2**	**-13.3**	**-15.7**	**-29.9**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage changes in carbon emissions are greater than the percentage changes in energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity further decreases carbon emissions because electricity has a higher carbon emissions rate per unit of energy than natural gas in North Dakota. The 16-story office building realizes reductions in carbon emissions from adopting the *ASHRAE 90.1-2004* and *-2007* designs even though it realizes a percentage increase in energy use due to a shift in energy use from electricity to natural gas.

14.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 14-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE*

90.1-1999 for 8 of 11 building types over a 10-year study period. *ASHRAE 90.1-1999* is the lowest cost building design for three building types while *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design are the lowest cost building design for one, five, and two building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* ranges from -2.1 % to 5.8 % depending on building type. The LEC design realizes a reduction in life-cycle costs for 6 of 11 building types, with the percentage change in life-cycle costs ranging from -1.6 % to 1.3 %. Based on the overall average percentage reduction in life-cycle costs of 0.2 %, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

Table 14-5 Average Percentage Change in Life-Cycle Costs, 10-Year, North Dakota

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.1	-1.1	**-1.6**	-1.0
APART06	0.0	-1.2	**-1.6**	-0.9
DORMI04	3.3	1.6	1.2	0.3
DORMI06	-0.0	-1.7	**-2.1**	-1.6
HOTEL15	-0.0	-1.8	**-1.6**	-1.1
HIGHS02	0.7	0.1	-0.4	**-0.9**
OFFIC03	5.0	3.1	2.4	0.8
OFFIC08	4.9	2.9	2.5	1.3
OFFIC16	-0.0	**-0.5**	-0.2	0.4
RETAIL1	2.8	0.5	**-0.3**	0.6
RSTRNT1	6.7	5.8	2.9	**-0.2**
Average	**2.1**	**0.7**	**0.1**	**-0.2**

14.1.5 City Comparisons

Simulations are run for three cities located in North Dakota: Bismarck in Climate Zone 6A, and Fargo and Minot in Climate Zone 7. The results may vary across cities within North Dakota for three reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

As can be seen in Table 14-6, the average reduction in energy use for all building types from adopting newer energy standard editions varies by standard edition and city. For *ASHRAE 90.1-2004* and *-2007*, the city located in the warmer climate zone (Zone 6A) realizes greater reductions in energy use than the cities in the colder climate zone (Zone 7). Meanwhile, the percentage reduction in energy use varies minimally for the *ASHRAE 90.1-2001* and LEC design.

Table 14-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, North Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Bismarck	6A	-0.8	-5.8	-10.0	-21.0
Fargo	7	-0.8	-1.5	-8.3	-21.1
Minot	7	-0.8	-1.4	-8.4	-21.4
Average		**-0.8**	**-2.9**	**-8.9**	**-21.2**

The variations in the percentage change in energy costs across cities are a result of two factors, the reduction in energy use and the fuel source of the reduction. Table 14-7 shows that the average reduction in energy costs for all building types is greater for the city in Zone 6A relative to cities in Zone 7 for the *ASHRAE 90.1-2004* and *-2007* designs. For the LEC design, there is minimal variation in the percentage change in energy costs across cities in different climate zones. The percentage change in energy costs is greater than the percentage change in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption.

Table 14-7 Average Percentage Change in Energy Costs by City, 10-Year, North Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Bismarck	6A	-1.1	-13.6	-15.5	-28.9
Fargo	7	-1.2	-10.6	-14.2	-28.0
Minot	7	-1.1	-10.7	-14.3	-28.4
Average		**-1.1**	**-11.7**	**-14.6**	**-28.5**

Table 14-8 reports changes in energy-related carbon emissions by city for North Dakota. For all cities, the more stringent standard editions result in greater reductions in carbon emissions. As with the energy use, the city in Zone 6A realizes a greater average change in emissions than the cities in Zone 7 for the *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* design while there is minimal difference for the *ASHRAE 90.1-2001* and LEC designs.

Table 14-8 Average Percentage Change in Carbon Emissions by City, 10-Year, North Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Bismarck	6A	-1.0	-14.5	-16.2	-30.4
Fargo	7	-1.1	-11.7	-15.0	-29.3
Minot	7	-1.0	-11.8	-15.1	-29.7
Average		**-1.1**	**-12.7**	**-15.4**	**-29.8**

The data reported in Table 14-9 show that, over a 10-year period, average life-cycle costs increase for all cities for *ASHRAE 90.1-2001* and *-2004* compared to *ASHRAE 90.1-1999*. For the *ASHRAE 90.1-2007* design, the city in Zone 6A (Bismarck) realizes a percentage reduction in life-cycle costs while the cities in Zone 7 realize a percentage increase in life-cycle costs. For the LEC design, Bismarck and Minot realize percentage reductions in life-cycle costs while Fargo realizes a slight percentage increase in life-cycle costs.

Table 14-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, North Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Bismarck	6A	2.1	0.3	-0.1	**-0.5**
Fargo	7	2.2	0.9	0.3	0.0
Minot	7	2.1	0.9	0.2	**-0.2**
Average		**2.1**	**0.7**	**0.1**	**-0.2**

14.2 Total Savings

How much can North Dakota save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

14.2.1 Energy Use

Table 14-10 reports the average per unit change in annual energy use by building type and building design in the state.[30] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 14-11 reports the

[30] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.

estimated average annual floor area of new construction and the total annual change in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[31]

Table 14-10 Average Per Unit Change in Annual Energy Use, North Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	-0.8	-0.2	-8.0	-2.5	-18.7	-5.9	-38.2	-12.1
APART06	-0.8	-0.3	-8.8	-2.8	-18.3	-5.8	-37.0	-11.7
DORMI04	-1.7	-0.5	-3.1	-1.0	-16.5	-5.2	-38.1	-12.1
DORMI06	-0.9	-0.3	-10.0	-3.2	-21.4	-6.8	-39.5	-12.5
HOTEL15	-1.3	-0.4	-3.6	-1.2	-0.9	-0.3	-21.1	-6.7
HIGHS02	-1.2	-0.4	-4.6	-1.5	-18.5	-5.9	-43.5	-13.8
OFFIC03	-1.8	-0.6	-3.6	-1.1	-17.0	-5.4	-38.6	-12.3
OFFIC08	-2.2	-0.7	-7.4	-2.4	-13.9	-4.4	-33.5	-10.6
OFFIC16	-1.4	-0.4	0.6	0.2	4.0	1.3	-18.6	-5.9
RETAIL1	-1.3	-0.4	-7.6	-2.4	-28.8	-9.1	-58.6	-18.6
RSTRNT1	-3.2	-1.0	-7.1	-2.3	-52.5	-16.6	-106.7	-33.8

The total annual reduction in energy use ranges widely across building designs, but the *ASHRAE 90.1-2001*, *-2004*, and *-2007*, and LEC designs all decrease overall energy use across the state. Adopting the *ASHRAE 90.1-2001*, *-2004*, and *-2007* designs result in an annual decrease of 213 MWh (726 MBtu), 853 MWh (2.9 GBtu), and 3.0 GWh (10.3 GBtu) annually, respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 5.6 GWh (19.3 GBtu) of total energy use annually for one year's worth of new construction for these building types. The *ASHRAE 90.1-2004* and *-2007* designs increase total energy use for the 16-story office building relative to *ASHRAE 90.1-1999* because of the changes in building envelope requirements as a result of the consolidation of climate zones.

[31] State-level subcategory data are not available.

Table 14-11 Statewide Change in Annual Energy Use for One Year of Construction, North Dakota

Building Type	Subcat. Weight.	m^2 (1000s)	ft^2 (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	0.7	7	-0	-2	-5	-17	-12	-40	-24	-83
APART06	55.1 %	0.7	8	-1	-2	-7	-23	-14	-49	-29	-98
HOTEL15	100.0 %	18.2	196	-24	-82	-66	-227	-16	-55	-385	-1315
HIGHS02	100.0 %	34.7	374	-43	-148	-125	-426	-591	-2019	-1343	-4587
OFFIC03	37.4 %	10.4	112	-19	-64	-47	-162	-192	-655	-451	-1538
OFFIC08	40.4 %	11.1	120	-24	-83	-83	-283	-155	-529	-374	-1279
OFFIC16	22.2 %	6.1	66	-9	-29	4	13	25	84	-114	-390
RETAIL1	100.0 %	66.2	713	-83	-284	-503	-1718	-1911	-6526	-3881	-13 251
RSTRNT1	100.0 %	2.9	31	-9	-32	-21	-70	-151	-516	-307	-1049
Total		**151.2**	**1628**	**-213**	**-726**	**-853**	**-2914**	**-3018**	**-10 305**	**-6909**	**-23 590**
Note: Dormitories are excluded because no such floor area category is reported in the construction data.											

Assuming that the buildings considered in this study, which represent 66.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from adopting the LEC design in new commercial buildings to be 10.5 GWh (35.7 GBtu) per year. These savings imply 104.5 GWh (356.9 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 4.6 GWh (15.6 GBtu) annually or 45.7 GWh (155.9 GBtu) over the 10-year study period.

The statewide change in energy use varies across building types within a building design. Building types that represent a greater amount of new floor area realize the largest changes in aggregate energy use. The greatest total reductions are realized by retail stores and high schools because they represent 43.8 % and 22.9 %, respectively, of the new construction in the state while all other building types represent 12.0 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- rank 2^{nd} and 10^{th} in percentage reduction, respectively, among the 11 building types, as reported in Table 14-2.

14.2.2 Energy Costs

Table 14-12 reports the average per unit change in energy costs by building type and building design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 14-12 Average Per Unit Change in Energy Costs, 10-Year, North Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$0.42	-$0.04	-$12.24	-$1.14	-$14.76	-$1.37	-$24.10	-$2.24
APART06	-$0.44	-$0.04	-$12.44	-$1.16	-$14.69	-$1.36	-$23.88	-$2.22
DORMI04	-$0.95	-$0.09	-$10.39	-$0.97	-$13.23	-$1.23	-$22.10	-$2.05
DORMI06	-$0.50	-$0.05	-$13.06	-$1.21	-$15.70	-$1.46	-$24.63	-$2.29
HOTEL15	-$0.73	-$0.07	-$10.95	-$1.02	-$8.56	-$0.80	-$16.31	-$1.52
HIGHS02	-$1.00	-$0.09	-$5.36	-$0.50	-$8.18	-$0.76	-$19.31	-$1.79
OFFIC03	-$0.69	-$0.06	-$5.33	-$0.50	-$8.49	-$0.79	-$19.85	-$1.84
OFFIC08	-$1.21	-$0.11	-$6.31	-$0.59	-$7.59	-$0.70	-$17.03	-$1.58
OFFIC16	-$0.77	-$0.07	-$4.32	-$0.40	-$1.41	-$0.13	-$10.61	-$0.99
RETAIL1	-$0.70	-$0.06	-$8.23	-$0.77	-$12.86	-$1.19	-$23.89	-$2.22
RSTRNT1	-$1.78	-$0.17	-$10.48	-$0.97	-$20.48	-$1.90	-$43.40	-$4.03

Table 14-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. The *ASHRAE 90.1-2001* design realizes small reductions in energy costs ($117 799). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize reductions in energy costs of $1.1 million, $1.6 million, and $3.2 million respectively. The 16-story office buildings that realize an increase in total energy use from the adoption of the *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* designs realize a decrease in total energy costs because of the shift in energy consumption from electricity to natural gas.

Assuming that the buildings considered in this study, which represent 66.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of $178 214, $1.7 million, $2.4 million, and $4.8 million over the 10-year study period, respectively.

Table 14-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, North Dakota

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	0.7	7	-$268	-$7771	-$9366	-$15 298
APART06	55.1 %	0.7	8	-$342	-$9673	-$11 417	-$18 565
HOTEL15	100 %	18.2	196	-$13 380	-$199 866	-$156 225	-$297 550
HIGHS02	100 %	34.7	374	-$24 005	-$185 385	-$295 274	-$689 980
OFFIC03	37.4 %	10.4	112	-$10 321	-$55 528	-$84 737	-$200 121
OFFIC08	40.4 %	11.1	120	-$13 499	-$70 561	-$84 797	-$190 346
OFFIC16	22.2 %	6.1	66	-$4743	-$26 537	-$8678	-$65 222
RETAIL1	100 %	66.2	713	-$46 114	-$545 753	-$852 105	-$1 583 528
RSTRNT1	100 %	2.9	31	-$5129	-$30 184	-$58 983	-$125 002
Total		**151.2**	**1628**	**-$117 799**	**-$1 131 258**	**-$1 561 583**	**-$3 185 613**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

14.2.3 Energy-related Carbon Emissions

Table 14-14 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type and building design. The carbon emissions estimation approach is defined in Section 5.3.

Table 14-14 Average Per Unit Change in Carbon Emissions, 10-Year, North Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-6.8	-1.4	-212.3	-43.5	-246.3	-50.4	-394.0	-80.7
APART06	-7.1	-1.5	-215.0	-44.0	-245.3	-50.2	-391.2	-80.1
DORMI04	-15.2	-3.1	-184.1	-37.7	-221.0	-45.3	-358.0	-73.3
DORMI06	-8.0	-1.6	-224.8	-46.1	-260.3	-53.3	-402.2	-82.4
HOTEL15	-11.8	-2.4	-193.7	-39.7	-153.5	-31.4	-271.6	-55.6
HIGHS02	-11.1	-2.3	-92.3	-18.9	-135.1	-27.7	-316.8	-64.9
OFFIC03	-16.0	-3.3	-91.8	-18.8	-127.8	-26.2	-302.0	-61.8
OFFIC08	-19.5	-4.0	-106.0	-21.7	-122.1	-25.0	-271.5	-55.6
OFFIC16	-12.4	-2.5	-78.5	-16.1	-29.7	-6.1	-171.5	-35.1
RETAIL1	-11.2	-2.3	-140.4	-28.8	-201.1	-41.2	-368.5	-75.5
RSTRNT1	-28.7	-5.9	-181.4	-37.2	-313.4	-64.2	-669.1	-137.0

Table 14-15 applies the Table 14-14 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs decrease carbon emissions overall. The adoption of *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in savings of 19 494 metric tons and 24 947 metric tons over a 10-year study period, respectively. The 16-story office buildings, which realize an increase in total energy use from adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007*, realize a decrease in carbon emissions because the emissions resulting from the increase in natural gas consumption are less than the decrease in emissions from electricity consumption. The adoption of LEC as the state's energy code decreases carbon emissions by 50 089 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate statewide reductions in carbon emissions of 2871 metric tons, 29 491 metric tons, 37 741 metric tons, and 75 777 metric tons over the 10-year study period, respectively.

Table 14-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, North Dakota – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	0.7	7	-4	-135	-156	-250
APART06	55.1 %	0.7	8	-6	-167	-191	-304
HOTEL15	100.0 %	18.2	196	-216	-3534	-2801	-4956
HIGHS02	100.0 %	34.7	374	-387	-3210	-4695	-11 012
OFFIC03	37.4 %	10.4	112	-166	-951	-1324	-3129
OFFIC08	40.4 %	11.1	120	-217	-1184	-1364	-3034
OFFIC16	22.2 %	6.1	66	-76	-483	-183	-1054
RETAIL1	100.0 %	66.2	713	-743	-9307	-13 331	-24 422
RSTRNT1	100.0 %	2.9	31	-83	-523	-903	-1927
Total		**151.2**	**1628**	**-1898**	**-19 494**	**-24 947**	**-50 089**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

14.2.4 Life-Cycle Costs

Table 14-16 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type and building design. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 14-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, North Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m^2$	$/ft^2$	$/m^2$	$/ft^2$	$/m^2$	$/ft^2$	$/m^2$	$/ft^2$
APART04	$0.62	$0.06	-$10.13	-$0.94	-$14.89	-$1.38	-$8.74	-$0.81
APART06	$0.13	$0.01	-$10.87	-$1.01	-$14.62	-$1.36	-$7.78	-$0.72
DORMI04	$27.83	$2.59	$13.76	$1.28	$10.24	$0.95	$2.32	$0.22
DORMI06	-$0.16	-$0.01	-$15.95	-$1.48	-$19.59	-$1.82	-$15.15	-$1.41
HOTEL15	-$0.45	-$0.04	-$16.42	-$1.53	-$14.09	-$1.31	-$9.57	-$0.89
HIGHS02	$5.33	$0.50	$0.72	$0.07	-$2.75	-$0.26	-$6.87	-$0.64
OFFIC03	$34.76	$3.23	$21.55	$2.00	$16.84	$1.56	$5.29	$0.49
OFFIC08	$35.26	$3.28	$20.69	$1.92	$17.75	$1.65	$9.45	$0.88
OFFIC16	-$0.11	-$0.01	-$3.74	-$0.35	-$1.27	-$0.12	$2.82	$0.26
RETAIL1	$16.16	$1.50	$3.03	$0.28	-$1.49	-$0.14	$3.66	$0.34
RSTRNT1	$75.17	$6.98	$65.25	$6.06	$33.06	$3.07	-$2.54	-$0.24

Table 14-17 applies the Table 14-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. Total reductions in life-cycle costs over the 10-year study period vary across building designs. Adoption of the *ASHRAE 90.1-2001* design results in an increase in life-cycle costs for 7 of 9 building types. The *ASHRAE 90.1-2004* and *-2007* designs result in a decrease in life-cycle costs for 4 and 6 building types with total life-cycle costs increasing by $531 099 and decreasing by $12 000, respectively. Adopting the LEC design decreases life-cycle costs for 5 of 9 building types, and decreases total life-cycle costs by $11 945. For a 10-year study period, it is cost-effective to adopt the *ASHRAE 90.1-2007* or LEC design. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide changes in life-cycle costs of $3.4 million, $803 478, -$18 154, and -$18 072 over the 10-year study period, respectively.

Table 14-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, North Dakota

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	0.7	7	$396	-$6429	-$9452	-$5547
APART06	55.1 %	0.7	8	$102	-$8452	-$11 364	-$6050
HOTEL15	100.0 %	18.2	196	-$8138	-$299 673	-$257 043	-$174 538
HIGHS02	100.0 %	34.7	374	$185 286	$25 185	-$95 654	-$238 926
OFFIC03	37.4 %	10.4	112	$360 243	$223 264	$174 491	$54 774
OFFIC08	40.4 %	11.1	120	$393 977	$231 167	$198 301	$105 556
OFFIC16	22.2 %	6.1	66	-$699	-$22 997	-$7793	$17 315
RETAIL1	100.0 %	66.2	713	$1 070 934	$201 113	-$98 693	$242 791
RSTRNT1	100.0 %	2.9	31	$216 479	$187 920	$95 207	-$7320
Total		**151.2**	**1628**	**$2 218 579**	**$531 099**	**-$12 000**	**-$11 945**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

14.3 State Summary

North Dakota is one of the states that has no state energy code for commercial buildings, and represents the coldest climates in the Midwest Census Region. On average, adopting the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, or LEC design leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions. However, only the *ASHRAE 90.1-2007* and LEC designs do so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 45.7 GWh (155.9 GBtu), energy cost savings of $2.4 million, and 37 741 metric tons of carbon emissions reductions while saving $18 154 in life-cycle costs for one year's worth of commercial building construction.

However, adopting the *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* designs increase energy use for the 16-story office buildings in North Dakota. *ASHRAE 90.1-2004* condenses the 26 climate zones defined in *ASHRAE 90.1-1999/2001* into 8 climate zones. As a result, some of the building envelope requirements (window U-factors and insulation R-values) are slightly less stringent for cities in North Dakota. Additionally, *ASHRAE 90.1-2007* relaxes the window SHGC requirement above that required in *ASHRAE 90.1-2004* for North Dakota's climate zones, leading to lower energy efficiency performance.

The adoption of the LEC design leads to savings in total energy use and energy-related carbon emissions in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design would lead to even greater impacts than adopting *ASHRAE 90.1-2007*, with savings of 104.5 GWh (356.9 GBtu), $4.8 million of energy costs, 75 777 metric tons of carbon emissions, and life-cycle costs of $18 072 for one year's worth of commercial building construction. The LEC design leads to about the same reductions in life-cycle costs while realizing much larger reductions in energy use and carbon emissions.

15 Ohio

Ohio has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the East North Central Census Division, and spans two climate zones (Zone 4A and Zone 5A). Table 15-1 provides an overview of Ohio's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 84 kWh/m^2 to 102 kWh/m^2 (27 kBtu/ft^2 to 32 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 231 kWh/m^2 to 245 kWh/m^2 (73 kBtu/ft^2 to 78 kBtu/ft^2) annually.

Table 15-1 Average Annual Energy Use by Building Type and Standard Edition, Ohio

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	164	52	148	47
APART06	162	52	145	46
DORMI04	128	41	114	36
DORMI06	179	57	160	51
HOTEL15	171	54	151	48
HIGHS02	245	78	231	73
OFFIC03	113	36	94	30
OFFIC08	102	32	84	27
OFFIC16	162	51	139	44
RETAIL1	125	40	109	35
RSTRNT1	171	54	132	42

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

15.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in the LEC design in the state of Ohio.

15.1.1 Statewide Building Comparison

Table 15-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*.

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -5.6 % to -23.3 % depending on the building type with an overall average of -13.2 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 15-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Ohio

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.6	-16.0	-17.1	0.5
APART06	-10.6	-18.5	-19.9	0.4
DORMI04	-11.2	-16.9	-17.8	-1.2
DORMI06	-10.3	-17.9	-19.2	0.1
HOTEL15	-11.8	-18.1	-19.2	0.4
HIGHS02	-5.6	-14.2	-15.8	-0.8
OFFIC03	-17.5	-22.1	-22.7	-2.5
OFFIC08	-17.9	-20.6	-20.9	-2.2
OFFIC16	-14.4	-19.5	-20.2	0.5
RETAIL1	-12.5	-16.1	-16.6	-0.5
RSTRNT1	-23.3	-31.4	-32.6	-3.4
Average	**-13.2**	**-19.2**	**-20.2**	**-0.8**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -14.2 % to -31.4 % depending on the building type with an average of -19.2 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 8 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 42.6 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over 2.5 times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.8 % to -32.6 % with an average of -20.2 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity

consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 8 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -3.4 % to 0.5 % for a 10-year study period. Only 6 of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -0.8 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

15.1.2 City Comparisons

Simulations are run for six cities located in Ohio, all of which are located in Zone 5A: Columbus, Akron, Cleveland, Mansfield, Toledo, and Youngstown. While the six cities are located in the same climate zone, the results may still vary for two reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality.

Table 15-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design do not vary significantly across cities, ranging from -12.5 % to -14.2 % with an overall average of -13.2 %.

Table 15-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Ohio

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Columbus	5A	-13.2	-19.3	-21.0	-0.8
Akron	5A	-13.4	-19.3	-20.5	-0.7
Cleveland	5A	-14.2	-19.9	-20.5	-0.9
Mansfield	5A	-13.2	-19.2	-20.4	-0.9
Toledo	5A	-12.5	-18.8	-20.0	-0.6
Youngstown	5A	-12.5	-18.7	-20.0	-0.8
Average		**-13.2**	**-19.2**	**-20.4**	**-0.8**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -18.7 % to -19.9 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -20.0 % to -21.0 %. Changes in life-cycle costs for all building types vary slightly across cities, with the percentage change in life-cycle costs ranging from -0.6 % to -0.9 %.

15.2 Total Savings

How much can Ohio save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

15.2.1 Energy Use

Table 15-4 reports the average per unit change in annual energy use by building type and building design in the state.[32] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 15-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[33]

[32] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.

[33] State-level subcategory data are not available.

Table 15-4 Average Per Unit Change in Annual Energy Use, Ohio

Building Type	Standard Edition	
	LEC	
	kWh/m^2	kBtu/ft^2
APART04	-15.7	-5.0
APART06	-17.2	-5.5
DORMI04	-14.4	-4.6
DORMI06	-18.4	-5.8
HOTEL15	-20.2	-6.4
HIGHS02	-19.8	-6.3
OFFIC03	-13.8	-4.4
OFFIC08	-18.4	-5.8
OFFIC16	-23.2	-7.4
RETAIL1	-15.6	-5.0
RSTRNT1	-39.9	-12.7

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 47.8 GWh (163.2 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 57.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 82.7 GWh (282.3 GBtu) per year. These savings imply 826.8 GWh (2823.2 GBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. The greatest total reductions are realized by retail stores and high schools because they represent 36.2 % and 31.4 %, respectively, of the new construction in the state while all other building types represent 7.6 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. For example, the building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 5th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 15-2.

Table 15-5 Statewide Change in Annual Energy Use for One Year of Construction, Ohio

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	57.1	614	-895 330	-3 057 042
APART06	55.1 %	69.9	752	-1 201 296	-4 101 743
HOTEL15	100.0 %	185.0	1992	-3 739 195	-12 767 220
HIGHS02	100.0 %	890.4	9584	-12 275 926	-41 915 289
OFFIC03	37.4 %	200.2	2154	-3 957 577	-13 512 868
OFFIC08	40.4 %	215.8	2323	-3 962 034	-13 528 088
OFFIC16	22.2 %	118.8	1278	-2 761 081	-9 427 519
RETAIL1	100.0 %	1026.5	11 049	-16 028 204	-54 727 181
RSTRNT1	100.0 %	74.4	801	-2 970 162	-10 141 412
Total		**2838.0**	**30 548**	**-47 790 806**	**-163 178 362**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

15.2.2 Energy Costs

Table 15-6 reports the average per unit change in energy costs by building type for the LEC design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 15-6 Average Per Unit Change in Energy Costs, 10-Year, Ohio

Building Type	Standard Edition LEC	
	\$/m^2	\$/ft^2
APART04	-\$13.23	-\$1.23
APART06	-\$15.33	-\$1.42
DORMI04	-\$11.15	-\$1.04
DORMI06	-\$16.27	-\$1.51
HOTEL15	-\$15.83	-\$1.47
HIGHS02	-\$16.43	-\$1.53
OFFIC03	-\$16.08	-\$1.49
OFFIC08	-\$14.89	-\$1.38
OFFIC16	-\$19.43	-\$1.80
RETAIL1	-\$12.23	-\$1.14
RSTRNT1	-\$32.31	-\$3.00

Table 15-7 reports the statewide changes in total energy costs by building type and building design, which account for one year’s worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $42.8 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 57.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $74.1 million over the 10-year study period.

Table 15-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Ohio

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	57.1	614	-$754 715
APART06	55.1 %	69.9	752	-$1 071 102
HOTEL15	100.0 %	185.0	1992	-$2 929 604
HIGHS02	100.0 %	890.4	9584	-$14 317 011
OFFIC03	37.4 %	200.2	2154	-$3 289 486
OFFIC08	40.4 %	215.8	2323	-$3 213 562
OFFIC16	22.2 %	118.8	1278	-$2 306 878
RETAIL1	100.0 %	1026.5	11 049	-$12 554 631
RSTRNT1	100.0 %	74.4	801	-$2 403 926
Total		**2838.0**	**30 548**	**-$42 840 916**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

15.2.3 Energy-related Carbon Emissions

Table 15-8 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

Table 15-8 Average Per Unit Change in Carbon Emissions, 10-Year, Ohio

Building Type	Standard Edition LEC	
	kg/m^2	lb/ft^2
APART04	-148.6	-30.4
APART06	-173.1	-35.5
DORMI04	-124.1	-25.4
DORMI06	-183.6	-37.6
HOTEL15	-176.5	-36.2
HIGHS02	-185.6	-38.0
OFFIC03	-184.4	-37.8
OFFIC08	-166.6	-34.1
OFFIC16	-218.0	-44.7
RETAIL1	-136.4	-27.9
RSTRNT1	-361.5	-74.0

Table 15-9 applies the Table 15-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 484 121 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 837 580 metric tons over the 10-year study period.

Table 15-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Ohio – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	57.1	614	-8479
APART06	55.1 %	69.9	752	-12 098
HOTEL15	100.0 %	185.0	1992	-32 667
HIGHS02	100.0 %	890.4	9584	-165 230
OFFIC03	37.4 %	200.2	2154	-36 904
OFFIC08	40.4 %	215.8	2323	-35 963
OFFIC16	22.2 %	118.8	1278	-25 894
RETAIL1	100.0 %	1026.5	11 049	-139 989
RSTRNT1	100.0 %	74.4	801	-26 897
Total		**2838.0**	**30 548**	**-484 121**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

15.2.4 Life-Cycle Costs

Table 15-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 15-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Ohio

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$5.23	$0.49
APART06	$4.19	$0.39
DORMI04	-$11.45	-$1.06
DORMI06	$1.11	$0.10
HOTEL15	$4.11	$0.38
HIGHS02	-$7.14	-$0.66
OFFIC03	-$20.98	-$1.95
OFFIC08	-$18.92	-$1.76
OFFIC16	$3.69	$0.34
RETAIL1	-$3.22	-$0.30
RSTRNT1	-$46.12	-$4.28

Table 15-11 applies the Table 6-10 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 5 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $19.6 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools, 3-story office buildings, and 8-story office buildings realize the greatest statewide decreases in life-cycle costs ($6.4 million, $4.2 million, and $4.1 million, respectively) while hotels and 16-story office buildings realize the greatest increases in life-cycle costs ($760 121 and $438 543, respectively). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a decrease in statewide life-cycle costs of $33.9 million over the 10-year study period.

Table 15-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Ohio

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	57.1	614	$298 431
APART06	55.1 %	69.9	752	$292 876
HOTEL15	100.0 %	185.0	1992	$760 121
HIGHS02	100.0 %	890.4	9584	-$6 355 737
OFFIC03	37.4 %	200.2	2154	-$4 199 547
OFFIC08	40.4 %	215.8	2323	-$4 083 527
OFFIC16	22.2 %	118.8	1278	$438 543
RETAIL1	100.0 %	1026.5	11 049	-$3 308 504
RSTRNT1	100.0 %	74.4	801	-$3 430 813
Total		**2838.0**	**30 548**	**-$19 588 158**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

15.3 State Summary

Ohio has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 826.8 GWh (2823.2 GBtu), energy cost savings of $74.1 million, and carbon emissions reductions of 837 580 metric tons while decreasing life-cycle costs by $33.9 million for one year's worth of commercial building construction.

16 South Dakota

South Dakota is located in the West North Central Census Division, and spans two climate zones (Zone 5 and Zone 6). The state does not have a commercial building energy code, and is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements. Table 16-1 provides an overview of South Dakota's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 95 kWh/m^2 to 130 kWh/m^2 (30 kBtu/ft^2 to 41 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 280 kWh/m^2 to 314 kWh/m^2 (89 kBtu/ft^2 to 100 kBtu/ft^2) annually.

Table 16-1 Average Annual Energy Use by Building Type and Standard Edition, South Dakota

Building Type	Standard Edition									
	1999		2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	215	68	214	68	197	63	188	60	170	54
APART06	212	67	211	67	194	62	186	59	168	53
DORMI04	174	55	172	54	161	51	150	48	132	42
DORMI06	230	73	229	73	211	67	208	66	190	60
HOTEL15	207	66	206	65	191	61	200	64	182	58
HIGHS02	314	100	313	99	308	98	298	95	280	89
OFFIC03	146	46	144	46	137	44	127	40	105	33
OFFIC08	130	41	128	41	120	38	114	36	95	30
OFFIC16	185	59	183	58	176	56	186	59	166	53
RETAIL1	175	56	173	55	164	52	146	46	122	39
RSTRNT1	248	79	244	77	231	73	198	63	151	48

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of increasingly stringent energy standard editions. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

16.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in more energy efficient designs for the state of South Dakota.

16.1.1 Energy Use

Table 16-2 shows minimal change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types having reductions in energy use of 1.3 % or less. There is a decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from -1.9 % to -8.3 % with an average of -6.5 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from 1.2 % to -19.9 %, with an overall average of -10.5 %.

Table 16-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, South Dakota

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.3	-8.2	-12.5	-21.2
APART06	-0.3	-8.3	-12.1	-20.6
DORMI04	-0.9	-7.3	-13.1	-24.0
DORMI06	-0.3	-8.2	-9.6	-17.3
HOTEL15	-0.5	-7.6	-3.0	-11.8
HIGHS02	-0.3	-1.9	-5.0	-10.9
OFFIC03	-1.0	-5.8	-12.6	-28.1
OFFIC08	-1.3	-7.7	-12.4	-26.8
OFFIC16	-0.5	-4.3	1.2	-10.1
RETAIL1	-0.7	-6.3	-16.1	-29.9
RSTRNT1	-1.1	-6.5	-19.9	-39.0
Average	**-0.7**	**-6.5**	**-10.5**	**-21.8**

The *ASHRAE 90.1-2007* design realizes an increase for the 16-story office building. The key driver is the consolidation of the 26 climate zones in *ASHRAE 90.1-2001* down to 8 climate zones in *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007*, which resulted in changes in building envelope requirements for some locations in the state, including relaxation of the maximum window U-factor requirement and insulation R-value minimum requirements. Given the cold climate in South Dakota, the relaxation of these requirements leads to increases in natural gas consumption.

For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007*. For the *ASHRAE 90.1-2007* design, the 16-story office building realizes a small percentage increase in energy use (1.2 %) while the hotel realizes a small decrease relative to *ASHRAE 90.1-1999*. The maximum window SHGC in Zone 5 and Zone 6 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007*, making the requirement less strict. The 100 % glazing amplifies the impact of this requirement relaxation enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

The LEC design realizes the greatest reductions in energy use, with the change in energy use relative to *ASHRAE 90.1-1999* ranging from -10.1 % to -39.0 % with an average of -21.8 %. Similar to the *ASHRAE 90.1-2007* design, the lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratio due to the less strict window SHGC requirement.

16.1.2 Energy Costs

Table 16-3 shows minimal change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.5 % to -1.6 %), which mirrors the energy use results described above. There is a significant variation in the percentage change in average energy costs for *ASHRAE 90.1-2004*, ranging from -6.4 % to -19.5 % depending on the building type, with an average of -14.2 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -1.5 % to -20.9 %, with an overall average of -15.7 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -13.2 % to -43.6 % with an average of -29.5 % overall.

Table 16-3 Average Percentage Change in Energy Costs, 10-Year, South Dakota

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.5	-19.2	-21.9	-34.1
APART06	-0.5	-19.2	-21.6	-33.5
DORMI04	-1.3	-19.5	-22.7	-35.7
DORMI06	-0.5	-19.0	-19.8	-30.6
HOTEL15	-0.7	-17.6	-12.1	-21.8
HIGHS02	-0.5	-6.4	-8.7	-20.0
OFFIC03	-1.3	-9.7	-12.8	-30.2
OFFIC08	-1.5	-11.0	-12.9	-28.4
OFFIC16	-0.7	-7.8	-1.5	-13.2
RETAIL1	-0.9	-12.8	-18.4	-33.5
RSTRNT1	-1.6	-13.5	-20.9	-43.6
Average	**-0.9**	**-14.2**	**-15.7**	**-29.5**

For all building designs, the reductions in energy costs are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. In the most extreme cases, electricity consumption is reduced while natural gas consumption is increased. The buildings use electricity for all energy consumption except for the heating component of the HVAC system, which uses natural gas. The energy efficiency measures adopted may lead to a decrease in energy use for both lighting and cooling the building while increasing heating loads. Since electricity is more expensive than natural gas on a per unit of energy basis, the shift in energy use from cooling to heating magnifies the decrease in energy costs for the building.

16.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small reductions (1.6 % or less) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 16-4 shows a significant change in energy-related carbon emissions for *ASHRAE 90.1-2004* across building types, ranging from -7.3 % to -21.3 % with an average of -15.2 %. The *ASHRAE 90.1-2007* design leads to slightly greater reductions than *ASHRAE 90.1-2004*, with the average change in carbon emissions ranging from -1.8 % to -24.0 % with an overall average of -16.5 %. The LEC design leads to the greatest average carbon emissions changes, ranging from -13.6 % to -44.2 % depending on the building type with an average of -30.6 % across all building types.

Table 16-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, South Dakota

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.5	-20.8	-23.3	-35.9
APART06	-0.5	-20.8	-22.9	-35.4
DORMI04	-1.3	-21.3	-24.0	-37.3
DORMI06	-0.5	-20.5	-21.3	-32.5
HOTEL15	-0.7	-19.0	-13.4	-23.2
HIGHS02	-0.5	-7.3	-9.4	-21.7
OFFIC03	-1.3	-10.2	-12.8	-30.4
OFFIC08	-1.5	-11.4	-12.9	-28.6
OFFIC16	-0.7	-8.2	-1.8	-13.6
RETAIL1	-1.0	-13.7	-18.7	-34.0
RSTRNT1	-1.6	-14.5	-21.0	-44.2
Average	**-0.9**	**-15.2**	**-16.5**	**-30.6**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage changes in carbon emissions are greater than the percentage changes in energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. This greater relative reduction in electricity consumption further decreases carbon emissions because electricity has a higher carbon emissions rate per unit of energy than natural gas in South Dakota.

16.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 16-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for all building types over a 10-year study period. *ASHRAE 90.1-1999* is never the lowest cost building design while *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building design for two and four building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -2.3 % to 2.4 % depending on building type. The LEC design realizes a reduction in life-cycle costs for 10 of 11 building types, with the percentage change in life-cycle costs ranging from -3.0 % to 0.2 %.

Table 16-5 Average Percentage Change in Life-Cycle Costs, 10-Year, South Dakota

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.0	-1.7	**-2.2**	-1.7
APART06	0.0	-1.8	**-2.1**	-1.5
DORMI04	2.3	-1.0	-1.2	**-1.4**
DORMI06	0.0	-2.2	**-2.3**	-2.0
HOTEL15	0.0	**-2.3**	-1.8	-1.3
HIGHS02	0.3	-0.5	-0.9	**-1.8**
OFFIC03	3.2	1.3	0.8	**-0.7**
OFFIC08	3.2	1.1	0.7	**-0.5**
OFFIC16	0.0	**-0.9**	-0.2	0.2
RETAIL1	2.0	-0.4	**-1.1**	-0.9
RSTRNT1	4.6	2.4	0.3	**-3.0**
Average	**1.4**	**-0.6**	**-0.9**	**-1.3**

16.1.5 City Comparisons

Simulations are run for three cities located in South Dakota, all of which are located in Zone 6: Huron, Pierre, and Sioux Falls. While the three cities are located in the same climate zone, the results may still vary across cities within the state for three reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality. Finally, Huron has adopted a stricter building energy code than the state.

As can be seen in Table 16-6, the average reduction in energy use for all building types from adopting newer energy standard editions is smallest for Huron followed by Sioux Falls and Pierre. The variation is small even though the Huron has adopted *ASHRAE 90.1-2001* as its local energy code for commercial buildings.

Table 16-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, South Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Huron	6A	0.0	-5.5	-9.6	-20.8
Pierre	6A	-1.0	-7.4	-11.1	-22.7
Sioux Falls	6A	-0.9	-6.7	-10.6	-21.9
Average		**-0.7**	**-6.5**	**-10.5**	**-21.8**

The variations in energy costs across cities are a result of three factors, the reduction in energy use, the fuel source of the reduction, and the city's local energy code. Table 16-7 shows that average reduction in energy costs for all building types is highly correlated with reductions in energy use. For all building designs, Huron realizes slightly lower reductions in energy costs. The percentage change in energy costs is greater than the percentage change in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption.

Table 16-7 Average Percentage Change in Energy Costs by City, 10-Year, South Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Huron	6A	0.0	-13.1	-14.8	-28.5
Pierre	6A	-1.4	-15.0	-16.4	-30.3
Sioux Falls	6A	-1.3	-14.4	-16.0	-29.7
Average		**-0.9**	**-14.2**	**-15.7**	**-29.5**

Table 16-8 reports changes in energy-related carbon emissions by city for South Dakota. For all three cities, the more stringent standard editions result in greater reductions in carbon emissions. As with the energy use, Huron realizes the smallest reductions in carbon emissions for all building designs.

Table 16-8 Average Percentage Change in Carbon Emissions by City, 10-Year, South Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Huron	6A	0.0	-13.6	-15.3	-29.6
Pierre	6A	-1.3	-15.3	-16.8	-31.3
Sioux Falls	6A	-1.2	-14.9	-16.5	-30.7
Average		**-0.8**	**-14.6**	**-16.2**	**-30.5**

The data reported in Table 16-9 show that, over a 10-year period, average life-cycle costs increase for Pierre and Sioux Falls from the adoption of the *ASHRAE 90.1-2001* and *-2004* designs. Huron realizes average percentage reductions in life-cycle costs for the *ASHRAE 90.1-2004*, *-2007*, and LEC designs. Adopting the *ASHRAE 90.1-2007* and LEC designs results in reductions in average life-cycle costs for Pierre and Sioux Falls. For all three cities, the LEC design is the most cost-effective building design alternative.

Table 16-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, South Dakota

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Huron	6A	0.0	-1.9	-2.3	**-2.7**
Pierre	6A	2.2	0.1	-0.3	**-0.7**
Sioux Falls	6A	2.1	0.1	-0.2	**-0.5**
Average		**1.4**	**-0.6**	**-0.9**	**-1.3**

16.2 Total Savings

How much can South Dakota save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

16.2.1 Energy Use

Table 16-10 reports the average per unit change in annual energy use by building type and building design in the state.[34] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 16-11 reports the estimated average annual floor area of new construction and the total annual change in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[35]

[34] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[35] State-level subcategory data are not available.

Table 16-10 Average Per Unit Change in Annual Energy Use, South Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-0.7	-0.2	-17.5	-5.6	-26.9	-8.5	-45.5	-14.4
APART06	-0.7	-0.2	-17.6	-5.6	-25.6	-8.1	-43.6	-13.8
DORMI04	-1.5	-0.5	-12.5	-4.0	-22.7	-7.2	-41.4	-13.1
DORMI06	-0.8	-0.2	-18.7	-5.9	-22.0	-7.0	-39.8	-12.6
HOTEL15	-0.9	-0.3	-15.6	-4.9	-6.1	-1.9	-24.3	-7.7
HIGHS02	-0.8	-0.3	-8.3	-2.6	-18.3	-5.8	-40.8	-12.9
OFFIC03	-1.4	-0.5	-5.8	-1.8	-15.5	-4.9	-34.2	-10.8
OFFIC08	-1.7	-0.5	-10.0	-3.2	-16.1	-5.1	-34.8	-11.0
OFFIC16	-0.9	-0.3	-7.9	-2.5	2.2	0.7	-18.5	-5.9
RETAIL1	-1.2	-0.4	-11.0	-3.5	-28.2	-8.9	-52.2	-16.6
RSTRNT1	-2.8	-0.9	-16.0	-5.1	-49.0	-15.5	-96.2	-30.5

The total annual reduction in energy use ranges widely across building designs, but *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC all decrease overall energy use across the state. Adopting *ASHRAE 90.1-2001* results in an annual decrease of 755.1 MWh (221 172 kBtu) while adopting *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* save 1.9 GWh (6.4 GBtu) and 3.7 GWh (12.7 GBtu) annually, respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 7.9 GWh (26.9 GBtu) of total energy use annually for one year's worth of new construction for these building types.

Table 16-11 Statewide Change in Annual Energy Use for One Year of Construction, South Dakota

Building Type	Subcat. Weight.	m² (1000s)	ft² (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	1.2	13	-1	-3	-21	-71	-32	-109	-54	-184
APART06	55.1 %	1.5	16	-1	-3	-26	-87	-37	-127	-63	-216
HOTEL15	100.0 %	17.1	184	-16	-54	-267	-912	-105	-358	-416	-1419
HIGHS02	100.0 %	53.6	577	-43	-148	-311	-1063	-829	-2832	-1830	-6249
OFFIC03	37.4 %	19.2	207	-28	-95	-161	-549	-351	-1200	-785	-2681
OFFIC08	40.4 %	20.8	223	-34	-118	-207	-705	-334	-1139	-722	-2464
OFFIC16	22.2 %	11.4	123	-11	-37	-90	-307	26	88	-211	-721
RETAIL1	100.0 %	68.2	734	-80	-273	-748	-2554	-1 920	-6556	-3560	-12 157
RSTRNT1	100.0 %	2.6	28	-7	-24	-41	-140	-126	-429	-247	-842
Total		195.5	2104	**-221**	**-755**	**-1871**	**-6389**	**-3 708**	**-12 661**	**-7888**	**-26 934**
Note: Dormitories are excluded because no such floor area category is reported in the construction data.											

Assuming that the buildings considered in this study, which represent 64.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from adopting the LEC design in new commercial buildings to be 12.2 GWh (41.8 GBtu) per year. These savings imply 122.3 GWh (417.6 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 5.7 GWh (19.6 GBtu) annually or 57.5 GWh (196.3 GBtu) over the 10-year study period.

The statewide change in energy use varies across building types within a building design. Building types that represent a greater amount of new floor area realize the largest changes in aggregate energy use. The greatest total reductions are realized by retail stores and high schools because they represent 34.9 % and 27.4 %, respectively, of the new construction in the state while all other building types represent less than 10.6 %. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- rank 2nd and 10th in percentage reduction, respectively, among the 11 building types, as reported in Table 16-2.

16.2.2 Energy Costs

Table 16-12 reports the average per unit change in energy costs by building type and building design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 16-12 Average Per Unit Change in Energy Costs, 10-Year, South Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$0.39	-$0.04	-$16.04	-$1.49	-$18.34	-$1.70	-$28.51	-$2.65
APART06	-$0.40	-$0.04	-$16.06	-$1.49	-$17.99	-$1.67	-$27.99	-$2.60
DORMI04	-$0.87	-$0.08	-$13.41	-$1.25	-$15.58	-$1.45	-$24.51	-$2.28
DORMI06	-$0.45	-$0.04	-$17.18	-$1.60	-$17.93	-$1.67	-$27.65	-$2.57
HOTEL15	-$0.54	-$0.05	-$14.18	-$1.32	-$9.72	-$0.90	-$17.57	-$1.63
HIGHS02	-$0.84	-$0.08	-$6.48	-$0.60	-$8.52	-$0.79	-$20.07	-$1.86
OFFIC03	-$0.47	-$0.04	-$6.61	-$0.61	-$8.93	-$0.83	-$20.58	-$1.91
OFFIC08	-$0.97	-$0.09	-$7.08	-$0.66	-$8.25	-$0.77	-$18.22	-$1.69
OFFIC16	-$0.55	-$0.05	-$6.30	-$0.59	-$1.18	-$0.11	-$10.65	-$0.99
RETAIL1	-$0.68	-$0.06	-$9.47	-$0.88	-$13.57	-$1.26	-$24.70	-$2.29
RSTRNT1	-$1.62	-$0.15	-$13.90	-$1.29	-$21.46	-$1.99	-$44.73	-$4.16

Table 16-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. The *ASHRAE 90.1-2001* design realizes small reductions in energy costs ($128 438). Adopting the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and

LEC designs decrease energy costs by $1.7 million, $2.0 million, and $4.2 million respectively. The 16-story office building, which realizes an increase in total energy use from the adoption of the *ASHRAE 90.1-2007* design, realizes a decrease in total energy costs because the increase in natural gas costs is less than the decrease in electricity costs.

Assuming that the buildings considered in this study, which represent 64.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of $199 129, $2.6 million, $3.1 million, and $6.5 million over the 10-year study period, respectively.

Table 16-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, South Dakota

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	1.2	13	-$467	-$19 021	-$21 746	-$33 808
APART06	55.1 %	1.5	16	-$587	-$23 325	-$26 137	-$40 656
HOTEL15	100 %	17.1	184	-$9226	-$242 858	-$166 498	-$300 995
HIGHS02	100 %	53.6	577	-$25 231	-$354 075	-$478 315	-$1 102 594
OFFIC03	37.4 %	19.2	207	-$16 139	-$124 616	-$163 979	-$386 210
OFFIC08	40.4 %	20.8	223	-$20 034	-$146 894	-$171 146	-$378 037
OFFIC16	22.2 %	11.4	123	-$6233	-$71 896	-$13 512	-$121 600
RETAIL1	100 %	68.2	734	-$46 367	-$645 146	-$925 080	-$1 683 293
RSTRNT1	100 %	2.6	28	-$4156	-$35 650	-$55 019	-$114 702
Total		**195.5**	**2104**	**-$128 438**	**-$1 663 481**	**-$2 021 431**	**-$4 161 896**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

16.2.3 Energy-related Carbon Emissions

Table 16-14 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type and building design. The carbon emissions estimation approach is defined in Section 5.3.

Table 16-14 Average Per Unit Change in Carbon Emissions, 10-Year, South Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kg/m²	lb/ft²	kg/m²	lb/ft²	kg/m²	lb/ft²	kg/m²	lb/ft²
APART04	-6.0	-1.2	-254.9	-52.2	-285.7	-58.5	-441.1	-90.3
APART06	-6.2	-1.3	-255.2	-52.3	-281.0	-57.6	-433.9	-88.9
DORMI04	-13.3	-2.7	-214.9	-44.0	-242.9	-49.8	-377.4	-77.3
DORMI06	-6.9	-1.4	-273.0	-55.9	-282.9	-58.0	-431.4	-88.4
HOTEL15	-8.3	-1.7	-225.2	-46.1	-158.2	-32.4	-275.0	-56.3
HIGHS02	-7.2	-1.5	-106.2	-21.7	-137.1	-28.1	-317.2	-65.0
OFFIC03	-12.9	-2.6	-101.8	-20.9	-128.0	-26.2	-303.2	-62.1
OFFIC08	-14.8	-3.0	-110.6	-22.7	-125.2	-25.6	-277.1	-56.8
OFFIC16	-8.4	-1.7	-99.2	-20.3	-21.8	-4.5	-163.5	-33.5
RETAIL1	-10.5	-2.1	-149.9	-30.7	-204.6	-41.9	-371.4	-76.1
RSTRNT1	-24.9	-5.1	-220.2	-45.1	-319.7	-65.5	-671.4	-137.5

Table 16-15 applies the Table 16-14 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs decrease carbon emissions overall. The adoption of *ASHRAE 90.1-2001*, *-2004*, and *-2007* result in savings of 1974 metric tons, 26 389 metric tons, and 30 873 metric tons over a 10-year study period, respectively. The 16-story office building, which realizes an increase in total energy use from adopting *ASHRAE 90.1-2007*, realizes a decrease in carbon emissions because the emissions resulting from the increase in natural gas consumption are less than the decrease in emissions from electricity consumption. The adoption of LEC as the state's energy code decreases carbon emissions by 63 352 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide reductions in carbon emissions of 3060 metric tons, 40 913 metric tons, 47 865 metric tons, and 98 221 metric tons over the 10-year study period, respectively.

Table 16-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, South Dakota – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	1.2	13	-7	-302	-339	-523
APART06	55.1 %	1.5	16	-9	-371	-408	-630
HOTEL15	100.0 %	17.1	184	-142	-3858	-2710	-4711
HIGHS02	100.0 %	53.6	577	-388	-5689	-7345	-17 000
OFFIC03	37.4 %	19.2	207	-248	-1960	-2462	-5,835
OFFIC08	40.4 %	20.8	223	-308	-2296	-2598	-5,750
OFFIC16	22.2 %	11.4	123	-96	-1133	-248	-1,867
RETAIL1	100.0 %	68.2	734	-712	-10 216	-13 943	-25 315
RSTRNT1	100.0 %	2.6	28	-64	-565	-820	-1722
Total		**195.5**	**2104**	**-1974**	**-26 389**	**-30 873**	**-63 352**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

16.2.4 Life-Cycle Costs

Table 16-16 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type and building design. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 16-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, South Dakota

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	$0.26	$0.02	-$15.33	-$1.42	-$19.41	-$1.80	-$14.80	-$1.37
APART06	-$0.05	$0.00	-$15.54	-$1.44	-$18.54	-$1.72	-$13.32	-$1.24
DORMI04	$18.97	$1.76	-$8.74	-$0.81	-$10.01	-$0.93	-$11.45	-$1.06
DORMI06	-$0.25	-$0.02	-$20.38	-$1.89	-$21.48	-$2.00	-$18.50	-$1.72
HOTEL15	-$0.34	-$0.03	-$20.05	-$1.86	-$15.39	-$1.43	-$11.51	-$1.07
HIGHS02	$2.05	$0.19	-$4.02	-$0.37	-$6.64	-$0.62	-$13.10	-$1.22
OFFIC03	$21.89	$2.03	$8.79	$0.82	$5.10	$0.47	-$5.41	-$0.50
OFFIC08	$22.64	$2.10	$7.41	$0.69	$5.00	$0.46	-$3.51	-$0.33
OFFIC16	-$0.11	-$0.01	-$5.98	-$0.56	-$1.52	-$0.14	$1.50	$0.14
RETAIL1	$11.15	$1.04	-$2.59	-$0.24	-$6.40	-$0.59	-$4.98	-$0.46
RSTRNT1	$51.16	$4.75	$25.74	$2.39	$2.26	$0.21	-$35.14	-$3.26

Table 16-17 applies the Table 16-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. The total change in life-cycle costs over the 10-year study period varies across building designs. Adoption of the *ASHRAE 90.1-2001* design results in an increase in life-cycle costs for 6 of 9 building types. The *ASHRAE 90.1-2004* and *-2007* designs result in a decrease in life-cycle costs for 6 of 9 building types, with total life-cycle costs decreasing by \$455 599 and \$915 667, respectively. The LEC design decreases life-cycle costs for 8 of 9 building types, and decreases total life-cycle costs by \$1.5 million. For a 10-year study period, it is cost-effective to adopt *ASHRAE 90.1-2004*, *-2007*, or the LEC design. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate statewide changes in life-cycle costs of \$2.9 million, -\$706 355, -\$1.4 million, and -\$2.4 million over the 10-year study period, respectively.

Table 16-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, South Dakota

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	1.2	13	\$310	-\$18 176	-\$23 024	-\$17 546
APART06	55.1 %	1.5	16	-\$76	-\$22 574	-\$26 937	-\$19 341
HOTEL15	100.0 %	17.1	184	-\$5 859	-\$343 398	-\$263 659	-\$197 170
HIGHS02	100.0 %	53.6	577	\$109 975	-\$215 562	-\$355 960	-\$701 783
OFFIC03	37.4 %	19.2	207	\$421 303	\$169 176	\$98 147	-\$104 021
OFFIC08	40.4 %	20.8	223	\$469 749	\$153 699	\$103 763	-\$72 774
OFFIC16	22.2 %	11.4	123	-\$1 260	-\$68 269	-\$17 370	\$17 182
RETAIL1	100.0 %	68.2	734	\$759 704	-\$176 484	-\$436 429	-\$339 655
RSTRNT1	100.0 %	2.6	28	\$131 177	\$65 989	\$5 801	-\$90 112
Total		**195.5**	**2104**	**\$1 885 024**	**-\$455 599**	**-\$915 667**	**-\$1 525 220**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

16.3 State Summary

South Dakota is one of the four states in the Midwest Census Region that have no state energy code for commercial buildings. On average, adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions at negative life-cycle costs. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 57.5 GWh (196.3 GBtu), energy cost savings of \$3.1 million, and 47 865 metric tons of carbon emissions reductions while saving \$1.4 million in life-cycle costs for one year's worth of commercial building construction.

However, adopting the *ASHRAE 90.1-2007* design increases energy use for 16-story office buildings in South Dakota. *ASHRAE 90.1-2004* condenses the 26 climate zones defined in *ASHRAE 90.1-1999/2001* into 8 climate zones. As a result, some of the building envelope requirements (window U-factors and insulation R-values) are slightly less stringent for cities in Zone 6. Additionally, *ASHRAE 90.1-2007* relaxes the window SHGC above that required in *ASHRAE 90.1-2004* for South Dakota.

The adoption of the LEC design leads to savings in total energy use and energy-related carbon emissions in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design would lead to even greater impacts than adopting *ASHRAE 90.1-2007*, with savings of 122.3 GWh (417.6 GBtu), $6.5 million of energy costs, 98 221 metric tons of carbon emissions, and $2.4 million in life-cycle costs for one year's worth of commercial building construction.

17 Wisconsin

Wisconsin has adopted ASHRAE 90.1-2007 as its state energy code for commercial buildings, is located in the East North Central Census Region, and spans two climate zones (Zone 6A and Zone 7). Table 17-1 provides an overview of Wisconsin's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 93 kWh/m^2 to 111 kWh/m^2 (29 kBtu/ ft^2 to 35 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 282 kWh/m^2 to 300 kWh/m^2 (90 kBtu/ft^2 to 95 kBtu/ft^2) annually.

Table 17-1 Average Annual Energy Use by Building Type and Standard Edition, Wisconsin

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	189	60	171	54
APART06	187	59	170	54
DORMI04	150	48	132	42
DORMI06	209	66	192	61
HOTEL15	201	64	183	58
HIGHS02	300	95	282	90
OFFIC03	124	39	102	32
OFFIC08	111	35	93	29
OFFIC16	183	58	163	52
RETAIL1	143	45	120	38
RSTRNT1	191	61	146	46

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

17.1 Percentage Savings

Changes in percentage terms allow for direct comparisons across building types and locations within a state. This section discusses the average percentage changes from investing in the LEC design in the state of Wisconsin.

17.1.1 Statewide Building Comparison

Table 17-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*.

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -5.9 % to -23.6 % depending on the building type with an overall average of -12.6 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

Table 17-2 Average Percentage Change from Adoption of the LEC design, 10-Year, Wisconsin

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.5	-15.9	-16.4	0.4
APART06	-9.3	-15.5	-16.0	0.5
DORMI04	-12.0	-17.0	-17.4	-0.8
DORMI06	-8.2	-13.7	-14.2	0.2
HOTEL15	-8.9	-11.2	-11.4	0.4
HIGHS02	-5.9	-12.7	-13.4	-1.1
OFFIC03	-17.5	-20.1	-20.2	-1.7
OFFIC08	-16.4	-18.0	-18.1	-1.2
OFFIC16	-10.9	-11.9	-12.0	0.3
RETAIL1	-15.9	-18.0	-18.1	-1.1
RSTRNT1	-23.6	-28.7	-29.1	-3.3
Average	**-12.6**	**-16.6**	**-16.9**	**-0.7**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -11.2 % to -28.7 % depending on the building type with an average of -16.6 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For the high school, adopting the LEC design increases natural gas consumption while decreasing electricity consumption. The increase in natural gas consumption offsets 13.2 % of the reduction in electricity consumption, and results in the percentage reduction in energy costs to be over twice the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -11.4 % to -29.1 % with an average of -16.9 %. For the LEC design, the percentage reduction in carbon emissions is slightly greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity consumption further decreases carbon emissions because natural gas has a lower average carbon emissions rate than electricity.

The percentage change in life-cycle costs varies across building types, ranging from -3.3 % to 0.5 % for a 10-year study period with 6 of the 11 building types realizing reductions in life-cycle costs. Based on the overall average percentage change of -0.7 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

17.1.2 City Comparisons

Simulations are run for five cities located in Wisconsin, all located in Zone 6A: Eau Claire, Green Bay, La Crosse, Madison, and Milwaukee. While the selected cities are located in the same climate zone, the results may still vary for two reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality.

Table 17-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design do not vary significantly across cities, ranging from -12.1 % to -12.8 % with an overall average of -12.6 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 17-3 Average Percentage Change in Energy Use from Adoption of the LEC Design by City, Wisconsin

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Eau Claire	6A	-12.1	-16.1	-16.7	-0.7
Green Bay	6A	-12.4	-16.5	-17.1	-0.8
La Crosse	6A	-12.7	-16.6	-17.2	-0.5
Madison	6A	-12.8	-16.8	-17.3	-0.7
Milwaukee	6A	-12.8	-16.7	-17.3	-0.6
Average		**-12.6**	**-16.6**	**-17.1**	**-0.7**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -16.1 % to -16.8 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -16.7 %

to -17.3 %. Reductions in life-cycle costs for all building types vary minimally across cities, with the percentage change ranging from -0.5 % to -0.8 %.

17.2 Total Savings

How much can Wisconsin save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

17.2.1 Energy Use

Table 17-4 reports the average per unit change in annual energy use by building type and building design in the state.[36] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 17-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[37]

Table 17-4 Average Per Unit Change in Annual Energy Use, Wisconsin

Building Type	Standard Edition	
	LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-17.9	-5.7
APART06	-17.4	-5.5
DORMI04	-178.0	-5.7
DORMI06	-17.2	-5.5
HOTEL15	-17.8	-5.6
HIGHS02	-21.8	-6.9
OFFIC03	-17.6	-5.6
OFFIC08	-18.2	-5.8
OFFIC16	-20.0	-6.3
RETAIL1	-22.7	-7.2
RSTRNT1	-44.9	-14.3

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 28.0 GWh (95.6 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that

[36] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[37] State-level subcategory data are not available.

the buildings considered in this study, which represent 57.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 49.1 GWh (167.6 GBtu) per year. These savings imply 491.0 GWh (1676.3 GWh) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. The greatest total reductions are realized by retail stores and high schools because they represent 36.6 % and 16.6 %, respectively, of the new construction in the state while all other building types represent 9.3 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 17-2.

Table 17-5 Statewide Change in Annual Energy Use for One Year of Construction, Wisconsin

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	81	877	-1 460 482	-4 986 715
APART06	55.1 %	100	1074	-1 733 043	-5 917 355
HOTEL15	100.0 %	117	1255	-2 069 204	-7 065 153
HIGHS02	100.0 %	226	2430	-3 977 568	-13 581 126
OFFIC03	37.4 %	117	1254	-2 534 616	-8 654 268
OFFIC08	40.4 %	126	1352	-2 279 698	-7 783 868
OFFIC16	22.2 %	69	744	-1 382 125	-4 719 170
RETAIL1	100.0 %	498	5359	-11 317 290	-38 642 095
RSTRNT1	100.0 %	27	295	-1 230 620	-4 201 865
Total		**1360**	**14 639**	**-27 984 646**	**-95 551 615**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

17.2.2 Energy Costs

Table 17-6 reports the average per unit change in energy costs by building type for the LEC design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

Table 17-6 Average Per Unit Change in Energy Costs, 10-Year, Wisconsin

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$13.26	-$1.23
APART06	-$12.99	-$1.21
DORMI04	-$11.46	-$1.06
DORMI06	-$12.68	-$1.18
HOTEL15	-$10.13	-$0.94
HIGHS02	-$15.17	-$1.41
OFFIC03	-$14.99	-$1.39
OFFIC08	-$13.00	-$1.21
OFFIC16	-$12.09	-$1.12
RETAIL1	-$13.91	-$1.29
RSTRNT1	-$29.49	-$2.74

Table 17-7 reports the statewide changes in total energy costs by building type for the LEC design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with statewide reductions in energy costs of $18.9 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 57.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $33.2 million over the 10-year study period.

Table 17-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Wisconsin

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	81	877	-$1 079 803
APART06	55.1 %	100	1074	-$1 296 271
HOTEL15	100.0 %	117	1255	-$1 180 194
HIGHS02	100.0 %	226	2430	-$3 425 643
OFFIC03	37.4 %	117	1254	-$1 745 771
OFFIC08	40.4 %	126	1352	-$1 633 430
OFFIC16	22.2 %	69	744	-$835 570
RETAIL1	100.0 %	498	5359	-$6 923 358
RSTRNT1	100.0 %	27	295	-$807 577
Total		**1360**	**14 639**	**-$18 927 617**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

17.2.3 Energy-related Carbon Emissions

Table 17-8 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

Table 17-8 Average Per Unit Change in Carbon Emissions, 10-Year, Wisconsin

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-153.9	-31.5
APART06	-150.9	-30.9
DORMI04	-131.9	-27.0
DORMI06	-147.2	-30.2
HOTEL15	-115.8	-23.7
HIGHS02	-177.4	-36.3
OFFIC03	-173.3	-35.5
OFFIC08	-150.7	-30.9
OFFIC16	-138.8	-28.4
RETAIL1	-159.7	-32.7
RSTRNT1	-340.1	-69.7

Table 17-9 applies the Table 17-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 218 699 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 383 682 metric tons over the 10-year study period.

Table 17-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Wisconsin – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	81	877	-12 536
APART06	55.1 %	100	1074	-15 055
HOTEL15	100.0 %	117	1255	-13 501
HIGHS02	100.0 %	226	2430	-40 043
OFFIC03	37.4 %	117	1254	-20 191
OFFIC08	40.4 %	126	1352	-18 927
OFFIC16	22.2 %	69	744	-9591
RETAIL1	100.0 %	498	5359	-79 534
RSTRNT1	100.0 %	27	295	-9321
Total		**1360**	**14 639**	**-218 699**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

17.2.4 Life-Cycle Costs

Table 17-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 17-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Wisconsin

Building Type	Standard Edition LEC $/$m^2$	Standard Edition LEC $/$ft^2$
APART04	$4.42	$0.41
APART06	$5.20	$0.48
DORMI04	-$8.05	-$0.75
DORMI06	$2.48	$0.23
HOTEL15	$3.87	$0.36
HIGHS02	-$9.40	-$0.87
OFFIC03	-$13.92	-$1.29
OFFIC08	-$10.53	-$0.98
OFFIC16	$2.76	$0.26
RETAIL1	-$7.40	-$0.69
RSTRNT1	-$45.18	-$4.20

Table 17-11 applies the Table 17-10 results to one year's worth of new building construction in the state to estimate statewide life-cycle cost changes from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 5 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $8.5 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. The 6-story apartment buildings and hotels realize the greatest statewide increases in life-cycle costs ($518 369 and $450 877, respectively) while retail stores realize the greatest decrease in life-cycle costs ($3.7 million). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide life-cycle cost decrease of $14.9 million over the 10-year study period.

Table 17-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Wisconsin

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	81	877	$359 919
APART06	55.1 %	100	1074	$518 369
HOTEL15	100.0 %	117	1255	$450 877
HIGHS02	100.0 %	226	2430	-$2 122 267
OFFIC03	37.4 %	117	1254	-$1 621 064
OFFIC08	40.4 %	126	1352	-$1 322 856
OFFIC16	22.2 %	69	744	$191 013
RETAIL1	100.0 %	498	5359	-$3 684 303
RSTRNT1	100.0 %	27	295	-$1 237 360
Total		**1360**	**14 639**	**-$8 467 672**

Note: Dormitories are excluded because no such floor area category is reported in the construction data.

17.3 State Summary

Wisconsin has adopted *ASHRAE 90.1-2007* as its state commercial building energy code. On average, adopting the LEC design reduces energy use, energy costs and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 491.0 GWh (1676.3 GWh), energy cost savings of $33.2 million, and carbon emissions reductions of 383 682 metric tons while decreasing life-cycle costs by $14.9 million for one year's worth of commercial building construction.

18 State Comparisons for the Adoption of the Low Energy Case Design

One purpose of this study is to determine which states could benefit the most from adopting a more stringent state energy code. This chapter analyzes benefits from the region-wide adoption of the LEC design relative to the current collection of state energy codes. The aggregate benefits and costs are compared for each of the states in the Midwest Census Region. Benefits and costs on a percentage basis are also evaluated across several dimensions: geography (state and climate zone), time, and building type. As in the state-by-state analysis for analyzing benefits from adopting the LEC design, it is necessary to assume a particular study period length because energy costs and life-cycle costs fluctuate on an annual basis. A 10-year study period is used as the baseline because it is the most realistic investor time frame of the nine study period length options in BIRDS. The significance of the study period length will be tested below.

It would be expected that the four states with no state energy code would realize greater benefits from adopting the LEC design relative to the other eight states in the Midwest Census Region that have adopted the more energy efficient *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007*.

18.1 Total Savings Comparison

By comparing the aggregate results from the detailed state-by-state analysis, some interesting trends emerge. Table 18-1 shows the total savings in energy use, energy costs, carbon emissions, and life-cycle costs from adopting the LEC design as the commercial building energy code for each of the states in the Midwest Census Region for a 10-year study period. In general, there is a strong correlation between energy use with both energy costs and carbon emissions. However, there are a number of factors that lead to significant variation in relative savings, including current state energy code requirements, newly constructed building stock mix and size, climate zone, electricity costs, and electricity production fuel mix.

Table 18-1 Total Reductions by State for Adoption of the LEC Design, 10-Year

State	Code	Average Annual New Floor Area 1000 m^2 (1000 ft^2)	Energy Use (GWh)	Energy Costs ($million)	Carbon (1000 tCO_2e)	LCC ($million)
IA	2007	1447 (15 573)	283.7	17.6	256.4	4.0
IL	2007	6929 (74 579)	1212.7	124.4	1343.5	31.4
IN	2007	3663 (39 425)	656.9	49.8	652.7	13.3
KS	None	1077 (11 590)	438.6	28.6	436.0	2.3
MI	2007	2964 (31 905)	511.9	40.4	490.9	17.0
MN	2004	2329 (25 068)	816.7	33.5	443.8	12.4
MO	None	2358 (25 383)	984.7	56.9	1000.6	2.7
ND	None	229 (2464)	104.5	4.8	75.8	0.0
NE	2007	920 (9900)	170.8	11.1	166.6	1.4
OH	2007	4907 (52 814)	826.8	74.1	837.6	33.9
SD	None	303 (3262)	122.3	6.5	98.2	2.4
WI	2007	2386 (25 679)	491.0	33.2	383.7	14.8
Total		**29 510 (317 641)**	**6620.6**	**458.5**	**6218.8**	**135.6**

Total energy use savings varies across states for a number of reasons. First, states with more newly constructed commercial floor area realize greater reductions in energy use. Second, states located in warmer climate zones realize greater reductions in energy use than the states located in colder climate zones because the buildings in warmer climates benefit more from the overhangs and daylighting installed in the LEC design. Third, a state's current state energy code for commercial buildings drives variation in energy use.

Consider the reductions in energy use for three states with nearly identical amounts of new floor area, Minnesota, Missouri, and Wisconsin. Of these three states, Missouri realizes the greatest total reduction in energy use (984.7 GWh) followed by Minnesota (816.7 GWh) and Wisconsin (491.0 GWh). Even though Wisconsin has slightly more new floor area construction than the other two states, both realize greater total reductions because both have not yet adopted *ASHRAE 90.1-2007* while Wisconsin has already done so.

Table 18-2 shows the reduction in energy use per unit of newly constructed floor area by state. The reduction in energy use per unit of floor area is driven by the state's adopted energy code for commercial buildings. The greatest reduction in energy use per unit of floor area resulting from adoption of the LEC design is realized by the four states that have no state energy code, ranging from 404 kWh/m^2 (128 kBtu/ft^2) to 456 kWh/m^2 (145 kBtu/ft^2), followed by the state that has adopted *ASHRAE 90.1-2004* and realizes reductions of 351 kWh/m^2 (111 kBtu/ft^2). The states that have adopted *ASHRAE 90.1-2007* realize reductions ranging from 168 kWh/m^2 (53 kBtu/ft^2) to 206 kWh/m^2 (65 kBtu/ft^2).

Table 18-2 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC Design by State, 10-Year

State	Code	Floor Area Ranking	Average Annual New Floor Area 1000 m² (1000 ft²)	Energy Use Reduction		
				GWh	kWh/m²	kBtu/ft²
ND	None	49	229 (2464)	104.5	456	145
MO	None	23	2358 (25 383)	984.7	418	133
KS	None	35	1077 (11 590)	438.6	407	129
SD	None	45	303 (3262)	122.3	404	128
MN	2004	24	2329 (25 068)	816.7	351	111
WI	2007	22	2386 (25 679)	491.0	206	65
IA	2007	31	1447 (15 573)	283.7	196	62
NE	2007	36	920 (9900)	170.8	186	59
IN	2007	13	3663 (39 425)	656.9	179	57
IL	2007	5	6929 (74 579)	1212.7	175	56
MI	2007	19	2964 (31 905)	511.9	173	55
OH	2007	7	4907 (52 814)	826.8	168	53

In general, the states that realize the greatest reductions in energy use also realize the greatest reductions in energy costs. However, reductions in energy costs are also impacted by the per unit energy costs of electricity and natural gas and the fuel mix of the reductions in energy use for the twelve states in the study. Table 18-3 shows each state's reduction in energy costs per unit of reduction in energy use, natural gas rate, electricity rate, and the weighted average fraction of reductions in electricity consumption offset by a change in natural gas consumption.[38] States with the highest electricity rates tend to realize the greatest reductions in energy costs per unit of reduction in energy use. Relative to electricity prices, natural gas prices are fairly constant across states ($0.03/kWh or $0.04/kWh) and are always cheaper per unit of energy.

There is some fluctuation in the results due to the fuel source of the reductions in energy use. For example, Ohio (9.7¢/kWh) and Wisconsin (9.6¢/kWh) have similar electricity rates. However, Ohio realizes a greater average energy cost savings per unit of energy use savings ($0.09) than Wisconsin ($0.07) because Ohio realizes a shift in fuel consumption from electricity to natural gas, leading to additional savings. Meanwhile, Wisconsin realizes a reduction in both electricity and natural gas consumption, which dampens its savings per unit of reduction in energy use.

[38] The fraction of electricity offset by natural gas consumption is greater (less) than 100 % (-100 %) when natural gas consumption increases (decreases) by a greater amount than electricity consumption decreases.

Table 18-3 Energy Cost Reduction per kWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year

State	Code	Offset* (%)	Electricity Rate (¢/kWh)	Natural Gas Rate (¢/kWh)	Energy Cost Reduction ($/kWh)
IL	2007	11.6	11.3	2.5	0.10
OH	2007	15.3	9.7	3.1	0.09
MI	2007	3.7	9.2	2.7	0.08
IN	2007	-13.6	8.3	2.7	0.08
WI	2007	-25.9	9.6	2.6	0.07
KS	None	2.6	7.9	2.9	0.07
IA	2007	-1.0	7.6	2.3	0.06
NE	2007	9.6	7.3	2.2	0.06
MO	None	3.0	7.0	3.2	0.06
SD	None	-14.6	7.1	2.2	0.05
ND	None	-33.0	6.8	2.2	0.05
MN	2004	-121.2	7.9	2.3	0.04

*Percentage of the reduction in electricity consumption offset by change in natural gas consumption.

Table 18-4 shows the weighted average fraction of reductions in electricity consumption offset by a change in natural gas consumption, the average CO_2e emission rate for electricity and natural gas, and the reduction in cradle-to-grave energy-related carbon emissions per unit of reduction in energy use. There is a direct correlation between the CO_2e emissions rate for electricity generation in a state and the reduction in carbon emissions per unit of reduction in energy use. However, the correlation is not perfect. For example, five states have the same average emissions rate for electricity generation. The states with a greater offset in the reduction of electricity due to a change in natural gas realize a greater average reduction in carbon emissions. Additionally, Nebraska realizes greater average reductions in carbon emissions than Wisconsin even though its emissions rate for electricity is smaller, because Nebraska's offset reflects an increase in natural gas consumption while Wisconsin's reflects a decrease.

Table 18-4 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year

State	Code	Offset* (%)	CO_2e Emissions Rate for Electricity (t/GWh)	CO_2e Emissions Rate for Natural Gas (t/GWh)	CO_2e Reduction (t/GWh)
IL	2007	11.6	993	241	1108
MO	None	3.0	984	241	1016
OH	2007	15.3	875	241	1013
KS	None	2.6	971	241	994
IN	2007	13.6	875	241	994
NE	2007	9.6	892	241	975
MI	2007	3.7	909	241	959
IA	2007	-1.0	892	241	904
SD	None	-14.6	892	241	803
WI	2007	-25.9	905	241	781
ND	None	-33.0	892	241	725
MN	2004	-121.2	892	241	543

*Percentage of the reduction in electricity consumption offset by change in natural gas consumption.

The relative change in life-cycle costs per unit of new floor area is shown in Table 18-5. There is no correlation between the energy cost savings (Table 18-3) and the life-cycle cost-effectiveness of adopting the LEC design because additional construction costs are required in order to obtain energy cost savings. All Midwest states realize an average decrease in life-cycle costs from adoption of the LEC design, with savings ranging from \$0.08/m^2 (\$0.01/ft^2) to \$7.92/m^2 (\$0.74/ft^2). There is no correlation between the state energy code and the total statewide reduction in life-cycle costs.

Table 18-5 Life-Cycle Cost Reductions per Unit of New Floor Area for Adoption of the LEC Design by State, 10-Year

State	Code	Floor Area Ranking	kWh/m^2	LCC Reduction		
				$million	$/m^2	$/ft^2
SD	None	45	404	$2.4	$7.92	$0.74
OH	2007	7	168	$33.9	$6.91	$0.64
WI	2007	22	206	$14.8	$6.20	$0.58
MI	2007	19	173	$17.0	$5.74	$0.53
MN	2004	24	351	$12.4	$5.32	$0.49
IL	2007	5	175	$31.4	$4.53	$0.42
IN	2007	13	179	$13.3	$3.63	$0.34
IA	2007	31	196	$4.0	$2.76	$0.26
KS	None	35	407	$2.3	$2.14	$0.20
NE	2007	36	186	$1.4	$1.52	$0.14
MO	None	23	418	$2.7	$1.15	$0.11
ND	None	49	456	$0.0	$0.08	$0.01

18.2 Percentage Savings Comparison

State comparisons are made based on the simple average changes for the cities analyzed in each state by building type.[39] One building type is chosen to illustrate the detailed analysis possible with the powerful BIRDS database compiled for this study. Energy use, energy costs, energy-related carbon emissions, and life-cycle costs are analyzed for the most common existing building type, small office buildings. Summary results for the other 10 building types are reported in Table B-1 through Table B-10 in Appendix B.

18.2.1 3-Story Office Building

Table 18-6 summaries the percentage changes in energy use, energy costs, carbon emissions, and life-cycle costs from region-wide adoption of the LEC design for the 3-story office building for a 10-year study period. On average, adoption of the LEC design for a 3-story office building decreases energy use, energy costs, and energy-related carbon emissions by more than 20 % each while reducing life-cycle costs by 1.5 %.

[39] City-level data is not available to weight by amount of building construction in each city.

Table 18-6 Average Percentage Change by State from Region-wide Adoption of the LEC design, 3-Story Office Building, 10-Year

State	Percentage Change			
	Energy Use	Energy Cost	Carbon Emissions	LCC
IA	-17.7	-21.4	-21.9	-1.7
IL	-17.5	-23.0	-23.0	-2.4
IN	-18.3	-22.4	-23.0	-2.1
KS	-31.9	-34.3	-35.1	0.7
MI	-16.4	-21.0	-21.5	-2.6
MN	-26.1	-23.7	-23.4	-1.8
MO	-31.6	-33.4	-34.4	1.4
ND	-29.5	-30.5	-30.6	0.8
NE	-18.2	-23.0	-23.5	-2.3
OH	-17.5	-22.1	-22.7	-2.5
SD	-28.1	-30.2	-30.4	-0.7
WI	-17.5	-20.1	-20.2	-1.7
Avg.	**-21.4**	**-24.5**	**-24.9**	**-1.5**

These detailed results can be readily analyzed in mappings of the Midwest Census Region. Figure 18-1, Figure 18-2, Figure 18-3, and Figure 18-4 display the average percentage energy use savings, energy cost savings, carbon emissions reduction, and life-cycle cost savings by state, respectively. The states with no state energy code are shown with cross hatching and a bolded state border. Figure 18-1 shows that the states that have not yet adopted *ASHRAE 90.1-2007* realize the greatest reductions in energy use. Kansas and Missouri realize energy use savings greater than 30 % by adopting the LEC design. Neither state currently has an energy code. North Dakota, South Dakota, and Minnesota realize reductions of 25 % to 30 %. None of the seven Midwestern states that have adopted *ASHRAE 90.1-2007* realize energy use savings of greater than 20 %.

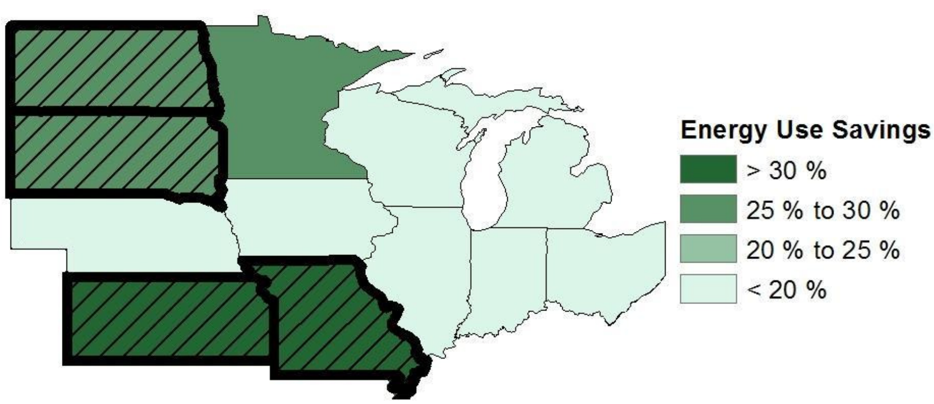


Figure 18-1 Average Energy Use Savings by State, 3-Story Office Building, 10-Year

Figure 18-2 shows the average energy cost savings over 10 years by state from adopting the LEC design. Every state reduces energy costs by at least 20 %. All four states that have no state energy code realize energy cost savings of greater than 30 %. None of the other eight states have cost savings greater than 25 %.

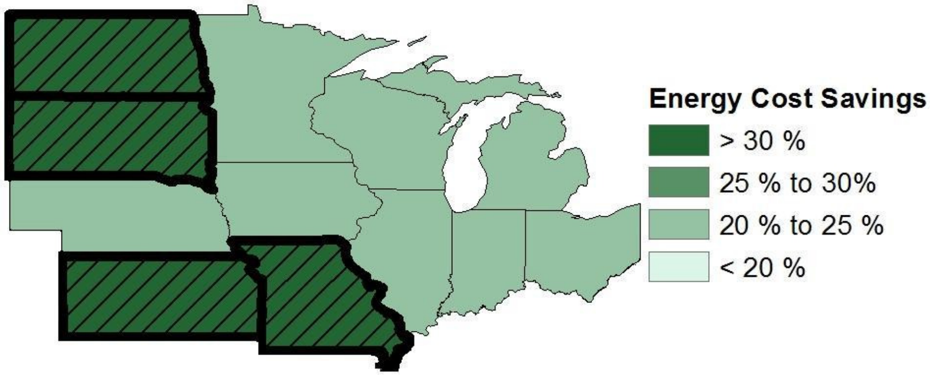


Figure 18-2 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year

Figure 18-3 shows the average reductions in energy-related carbon emissions by state from adopting the LEC design. Similar to energy cost savings, the four states that have no state energy code realize reductions in carbon emissions of greater than 30 %. The other eight states realize reductions between 20 % and 25 %.

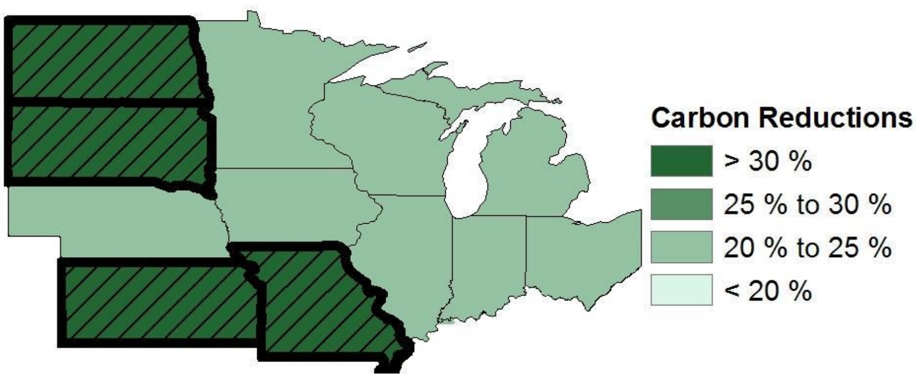


Figure 18-3 Average Energy-related Carbon Emissions Reduction by State, 3-Story Office Building, 10-Year

Figure 18-4 shows the average life-cycle cost savings over 10 years by state from adopting the LEC design. Three of the four states that have not adopted a state energy code realize increases in life-cycle costs while the fourth (South Dakota) realizes a small reduction in life-cycle costs (0.7 %). Of the states that have adopted *ASHRAE 90.1-2004* and *-2007*, three states realize reductions in life-cycle costs of less than 2 % while the other five states realize reductions in life-cycle costs between 2 % and 4 %.

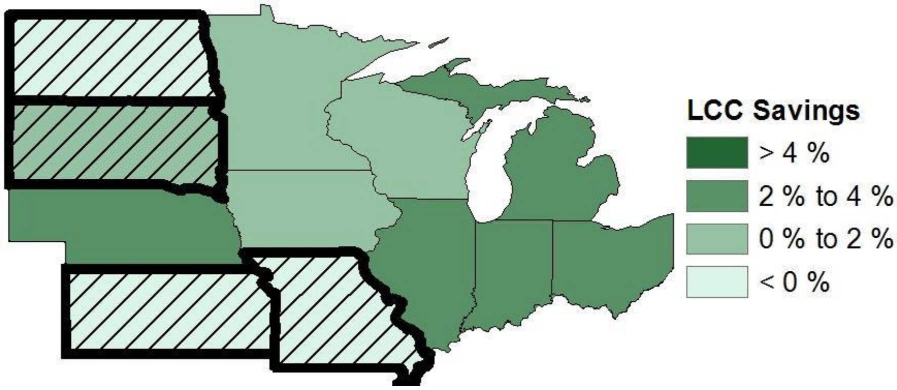


Figure 18-4 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year

For a 3-story office building, as expected, the states that have no state energy code have the most to gain in percentage terms in energy use, energy cost, and carbon emissions savings from adopting the LEC design. Additionally, holding state energy codes constant, states in warmer climates would realize greater savings than states with colder climates. However, the benefits realized by states with no state energy code tend to not be life-cycle cost-effective. Of the four states with no state energy code, only South Dakota realizes a small percentage reduction in life-cycle costs. The other eight states would realize significant benefits from the adoption of the LEC design for 3-story office buildings, and do so in a cost-effective manner.

18.2.2 Region-wide Results by Study Period Length

The percentage change comparisons up to this point have focused on 3-story office buildings over a 10-year study period. It is important to consider how the study period length -- representing the time horizon of the investor -- impacts energy use, energy costs, energy-related carbon emissions, and life-cycle costs. Nine study period lengths are analyzed: 1 year, 5 years, 10 years, 15 years, 20 years, 25 years, 30 years, 35 years, and 40 years. All building types are included in this analysis.

Average reductions in energy use from adoption of the LEC design are constant over all study period lengths because energy efficiency is assumed to be constant over time. The regional reduction in average energy use across all 58 cities in the study ranges from 7.6 % to 28.7 %, depending on the building type, with an overall regional average of 16.1 %. Table 18-7 shows these results.

Table 18-7 Midwest Region Average Percentage Change in Energy Use by Building Type

Building Type	Percentage Change
APART04	-13.0
APART06	-13.5
DORMI04	-15.4
DORMI06	-12.8
HOTEL15	-11.9
HIGHS02	-7.6
OFFIC03	-21.4
OFFIC08	-20.8
OFFIC16	-13.1
RETAIL1	-18.8
RSTRNT1	-28.7
Average	**-16.1**

As shown in Table 18-8, savings in energy costs vary slightly, in percentage terms, over increasing study period lengths. The regional average reduction in energy costs across all location-building type combinations ranges from 21.8 % for a 1-year study period to 21.3 % for a 40-year study period. The minor variation within a building type is a result of some negative differential escalation rates used to adjust future energy prices, causing the percentage change in energy costs to decrease in magnitude as the study period lengthens. The regional average reduction ranges from 15.2 % to 34.9 %, depending on the building type, over all study periods.

Table 18-8 Midwest Region Average Percentage Change in Energy Costs by Building Type and Study Period Length

Building Type	Study Period Length								
	1	5	10	15	20	25	30	35	40
APART04	-20.5	-20.4	-20.4	-20.3	-20.2	-20.1	-20.0	-19.9	-19.9
APART06	-22.0	-21.9	-21.8	-21.8	-21.7	-21.6	-21.5	-21.4	-21.3
DORMI04	-21.9	-21.8	-21.7	-21.7	-21.6	-21.5	-21.5	-21.4	-21.3
DORMI06	-20.9	-20.8	-20.7	-20.7	-20.6	-20.5	-20.4	-20.3	-20.2
HOTEL15	-17.9	-17.8	-17.8	-17.7	-17.7	-17.6	-17.5	-17.5	-17.4
HIGHS02	-16.0	-15.8	-15.8	-15.7	-15.6	-15.5	-15.4	-15.3	-15.2
OFFIC03	-24.5	-24.5	-24.5	-24.5	-24.4	-24.4	-24.4	-24.3	-24.3
OFFIC08	-22.6	-22.6	-22.6	-22.6	-22.6	-22.6	-22.6	-22.6	-22.5
OFFIC16	-16.8	-16.8	-16.8	-16.8	-16.7	-16.7	-16.6	-16.6	-16.6
RETAIL1	-21.5	-21.4	-21.4	-21.4	-21.4	-21.4	-21.3	-21.3	-21.3
RSTRNT1	-34.9	-34.8	-34.8	-34.7	-34.7	-34.6	-34.5	-34.5	-34.4
Average	**-21.8**	**-21.7**	**-21.7**	**-21.6**	**-21.6**	**-21.5**	**-21.4**	**-21.4**	**-21.3**

Since the regional average reduction in energy use is constant over all study periods, the average energy-related carbon emissions reductions are also constant at 22.7 %. The regional average reduction in carbon emissions ranges from 17.4 % to 35.7 % depending on the building type, as shown in Table 18-9.

Table 18-9 Midwest Region Average Percentage Change in Carbon Emissions by Building Type

Building Type	Percentage Change
APART04	-21.9
APART06	-23.5
DORMI04	-23.0
DORMI06	-22.3
HOTEL15	-19.0
HIGHS02	-17.6
OFFIC03	-24.9
OFFIC08	-22.8
OFFIC16	-17.4
RETAIL1	-21.8
RSTRNT1	-35.7
Average	**-22.7**

Table 18-10 shows that the percentage changes in life-cycle costs vary significantly over increasing study period lengths, but on average decrease for all study period lengths. Seven of the 11 building types realize reductions in life-cycle costs for all study periods.

Table 18-10 Midwest Region Average Percentage Change in Life-Cycle Costs by Building Type and Study Period Length

Building Type	Study Period Length								
	1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
APART04	-1.7	0.0	0.0	-0.3	-0.1	-0.3	-0.4	-0.6	-0.5
APART06	0.1	0.3	-0.0	-0.4	-0.3	-0.5	-0.6	-0.8	-0.7
DORMI04	-5.7	-0.8	-0.6	-0.8	-0.6	-0.7	-0.8	-0.9	-0.8
DORMI06	0.7	-0.1	-0.4	-0.8	-0.7	-0.9	-1.0	-1.2	-1.2
HOTEL15	1.4	0.4	0.0	-0.4	-0.4	-0.7	-0.9	-1.1	-1.1
HIGHS02	-1.1	-0.9	-1.0	-1.3	-1.3	-1.4	-1.6	-1.8	-1.7
OFFIC03	-8.9	-1.8	-1.5	-1.7	-1.4	-1.5	-1.6	-1.7	-1.7
OFFIC08	-3.3	-1.3	-1.3	-1.6	-1.3	-1.5	-1.6	-1.7	-1.7
OFFIC16	2.0	1.0	0.5	-0.1	-0.0	-0.3	-0.5	-0.8	-0.7
RETAIL1	-8.3	0.1	0.0	-0.4	0.0	-0.2	-0.4	-0.6	-0.5
RSTRNT1	-10.0	-4.0	-3.4	-3.9	-3.5	-3.6	-3.8	-4.0	-4.1
Average	**-3.2**	**-0.6**	**-0.7**	**-1.1**	**-0.9**	**-1.0**	**-1.2**	**-1.4**	**-1.3**

Figure 18-5 shows that four building types – the 6-story apartment building, 6-story dormitory, hotel, and 16-story office building – are not cost-effective for a 5-year study period, with an average change in life-cycle costs ranging from 0.0 % to 1.0 %. By a 15-year study period, these four building types become cost-effective. The retail store is the only building type that is not cost-effective for all study periods longer than 10 years, realizing a 0.003 % increase in life-cycle costs for a 20-year study period.

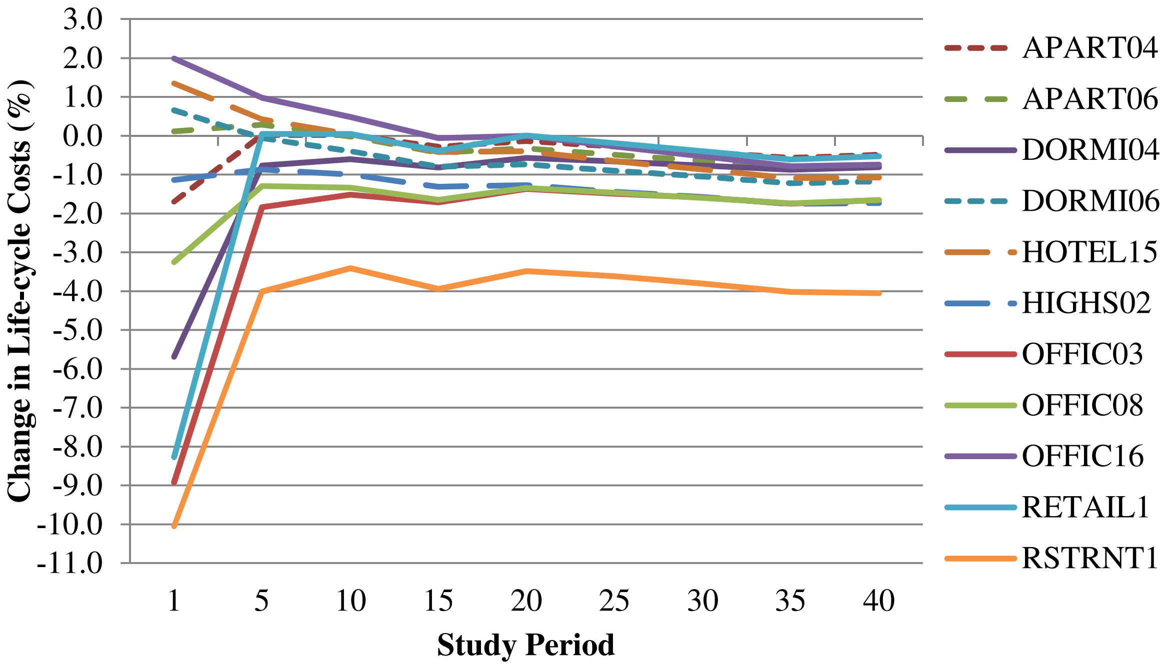


Figure 18-5 Average Change in Life-Cycle Costs by Building Type and Study Period Length

18.2.3 Region-wide Results by Building Type

For a 10-year study period length, Table 18-11 shows the simple average changes across all 58 cities in the Midwest Census Region, in percentage terms, from adopting the LEC design. The building type that realizes the smallest percentage reductions in energy use, energy costs, and energy-related carbon emissions is the high school followed by the hotel and 16-story office building, while the greatest reductions are realized by the restaurant followed by the 3- and 8-story office buildings.

The occupant activity is the primary driver of the results for the high school, which is heavily occupied during the school year and lightly occupied during the summer months. Some of the energy efficiency measures decrease heat gains, which lead to lower cooling loads during warmer months and greater heating loads during the colder months. A significant portion of the reductions in electricity consumption during these colder months is offset by increases in natural gas consumption required to meet the increased heating loads. Thus, a greater portion of the high school’s energy use occurs during the colder months relative to other building types. The combination of more energy use occurring during the colder months and the offsetting increase in natural gas consumption during those months leads to a smaller overall percentage reduction in energy use for high schools.

One of the reasons that the restaurant realizes the greatest reductions in energy use is that the restaurant has the smallest plug and process loads in terms of watts per unit of floor area. Since the plug and process load is the only electricity use not impacted by the energy efficiency measures adopted in this study, a greater fraction of energy use can be decreased for restaurants relative to the other building types.

For all building types, the percentage changes in energy costs and carbon emissions are greater than the percentage changes in energy use. This result is most significant for the high school, for which the percentage reduction in energy costs is over twice the percentage reduction in energy use. Seven of 11 building types realize reductions in life-cycle costs. The restaurant, 3-story office building, and 8-story office building realize the greatest percentage reduction in life-cycle costs. The 16-story office building realizes the greatest increase in life-cycle costs.

Table 18-11 Midwest Region Percentage Change for LEC by Building Type, 10-Year

Building Type	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-13.0	-20.4	-21.9	0.0
APART06	-13.5	-21.8	-23.5	-0.0
DORMI04	-15.4	-21.7	-23.0	-0.6
DORMI06	-12.8	-20.7	-22.3	-0.4
HOTEL15	-11.9	-17.8	-19.0	0.0
HIGHS02	-7.6	-15.8	-17.6	-1.0
OFFIC03	-21.4	-24.5	-24.9	-1.5
OFFIC08	-20.8	-22.6	-22.8	-1.3
OFFIC16	-13.1	-16.8	-17.4	0.5
RETAIL1	-18.8	-21.4	-21.8	0.0
RSTRNT1	-28.7	-34.8	-35.7	-3.4
Average	**-16.1**	**-21.7**	**-22.7**	**-0.7**

18.2.4 Region-wide Results by Climate Zone

Table 18-12 shows the region-wide average percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs by *ASHRAE* climate zone. These changes are for the adoption of the LEC design relative to current state energy codes for all building types combined. However, it is necessary to control for state energy codes to properly analyze these results.

Table 18-12 Average Percentage Change for LEC by Climate Zone

Climate Zone	Energy Use	Energy Cost	Carbon Emissions	LCC
4A	-25.1	-31.1	-33.9	-0.5
5A	-13.5	-20.0	-21.0	-0.7
6A	-15.5	-20.0	-20.7	-0.8
7	-17.5	-21.6	-22.5	-0.6
Average	**-16.1**	**-21.7**	**-22.9**	**-0.7**

Table 18-13 shows the average percentage reduction in energy use from adopting the LEC design for all cities located in a climate zone while controlling for state energy codes. The region-wide average reduction in energy use is 16.1 % with Zone 4A realizing the greatest reduction (25.1 %) and Zone 5A the smallest (13.5 %). Controlling for state energy codes, the warmer the climate the greater the reduction in energy use, which is a result of the energy efficiency improvement options considered in the LEC design. Cities located in Zone 4A and Zone 5A have an additional option (adding overhangs) that is not beneficial in the colder climates because solar heat gains are beneficial in cold climates and harmful in warm climates.

Table 18-13 Average Percentage Change in Energy Use for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	**2001**	**2004**	**2007**	**All**
4A	-26.7	-25.1		-15.5	-25.1
5A	-25.2			-13.1	-13.5
6A	-21.9	-20.8	-16.1	-12.6	-15.5
7	-21.3		-20.1	-11.1	-17.5
Grand Total	**-24.5**	**-22.9**	**-17.7**	**-12.9**	**-16.1**

Table 18-14 shows the average percentage reduction in energy costs for all cities located in a climate zone while controlling for state energy codes. The region-wide average reduction in energy costs is 21.7 % with Zone 4A realizing the greatest average reduction in energy costs (31.1 %) and Zone 5A and Zone 6A realizing the smallest reduction (20.0 %). Similar to energy use, controlling for state energy codes, cities located in warmer climates tend to realize greater reductions in energy costs.

Table 18-14 Average Percentage Change in Energy Costs for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	2001	2004	2007	All
4A	-32.9	-30.6		-20.4	-31.1
5A	-33.3			-19.5	-20.0
6A	-29.6	-28.5	-17.7	-16.6	-20.0
7	-28.2		-19.7	-16.8	-21.6
Grand Total	**-31.4**	**-29.5**	**-18.5**	**-18.7**	**-21.7**

Table 18-15 shows the average percentage reduction in energy-related carbon emissions for all cities located in a climate zone. Similar to energy use and energy costs, while controlling for state energy codes, cities located in warmer climates tend to realize greater reductions in the carbon emissions. However, there is some additional variation that is driven by a state's average emissions rate.

Table 18-15 Average Percentage Change in Carbon Emissions for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	2001	2004	2007	All
4A	-35.9	-34.3		-21.4	-33.9
5A	-36.2			-20.5	-21.0
6A	-30.8	-29.6	-18.4	-17.2	-20.7
7	-29.5		-20.1	-17.8	-22.5
Grand Total	**-33.6**	**-32.0**	**-19.1**	**-19.6**	**-22.9**

Table 18-16 shows the average percentage change in life-cycle costs for all cities located in a climate zone while controlling for state energy codes. There are no distinct trends in the percentage change in life-cycle costs across climate zones.

Table 18-16 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	2001	2004	2007	All
4A	-0.3	-2.0		-0.7	-0.5
5A	-1.0			-0.7	-0.7
6A	-0.6	-2.7	-0.8	-0.7	-0.8
7	-0.1		-0.8	-0.9	-0.6
Grand Total	**-0.4**	**-2.4**	**-0.8**	**-0.7**	**-0.7**

State Comparisons for the Adoption of the Low Energy Case Design

19 Discussion

This study analyzes the impacts of adopting new, more stringent state energy codes for 58 cities located across the Midwest Census Region. Results are summarized at the regional level as well as the state level for all twelve Midwestern states. This section will discuss the key findings, limitations of the research, and recommended directions for future research.

19.1 Key Findings

Four states in the Midwest Census Region have not yet adopted a state energy code for commercial buildings: Kansas, Missouri, North Dakota, and South Dakota. For these states, adoption of *ASHRAE 90.1-2001* and *-2004* lead to reductions in energy use, energy costs, and energy-related carbon emissions. However, adoption of *ASHRAE 90.1-2001* is not life-cycle cost-effective in any of the four states because the additional costs from implementing the energy efficiency measures overwhelm the future energy cost savings. *ASHRAE 90.1-2004* is not life-cycle cost-effective to adopt in three of the four states, with only South Dakota realizing a reduction in life-cycle costs. Adopting *ASHRAE 90.1-2007* leads to greater reductions in energy use, energy costs, and carbon emissions than *ASHRAE 90.1-2001* or *-2004*, and is life-cycle cost-effective to adopt in three of the four states (Kansas is the exception).

Minnesota is the only state in the Midwest Census Region that has adopted *ASHRAE 90.1-2004* as its state energy code for commercial buildings. Minnesota would realize reductions in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adopting *ASHRAE 90.1-2007*.

The adoption of the LEC design is analyzed for all twelve states. The LEC design goes beyond *ASHRAE 90.1-2007* by setting stricter building envelope requirements, lower lighting densities, and requiring daylighting controls as well as requiring overhangs for warmer climate zones. There are several factors that impact the percentage savings from adopting the LEC design for all states in the Midwest Census Region, including the current state energy code, selected study period length, building type, and climate zone of the location.

The region-wide adoption of the LEC design as the commercial building energy code for all building types significantly decreases energy use (16.1 %), energy costs (21.7 %), and carbon emissions (22.7 %), on average, while reducing life-cycle costs (0.7 %), on average, for a 10-year study period. Although the LEC design leads to reductions for all states, the magnitude of the reductions varies according to each state’s adopted energy code. The four states with no energy code realize the greatest percentage savings in energy use, energy costs, and carbon emissions. However, three of the four states realize percentage increases in life-cycle costs and the fourth state realizes a minimal percentage decrease. Meanwhile, the states that have already adopted *ASHRAE 90.1-2007* realize reductions in life-cycle costs.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 5 years to 20 years, the number of building types that are cost-effective increases from 7 to all 11. The retail store is the only building type that is not cost-effective for all study periods longer than 10 years, and is cost-effective for all study period lengths of 20 years or greater. Study period length is an important determinant of cost-effectiveness and size of the percentage changes in life-cycle costs.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, and carbon emissions. After controlling for each state's energy code, cities located in warmer climates tend to realize greater average percentage reductions in these measures. There are no distinct trends in life-cycle costs associated with climate zones.

Different building types realize different regional average percentage reductions in energy use, energy costs, and carbon emissions for a 10-year study period. High schools realize the smallest reductions while restaurants and 3- and 8-story office buildings realize the greatest reductions in energy use and energy costs. The reduction in carbon emissions is not perfectly correlated with reductions in energy use because along with the reduction in energy use, there is a change in the fuel source mix. The greatest percentage reductions in life-cycle costs are realized by restaurants and 3- and 8-story office buildings while the smallest percentage reductions are realized by 16-story office buildings.

The magnitude of a building type's average percentage change is not necessarily correlated with its changes in total energy use, energy costs, and energy-related carbon emissions relative to other building types. For example, high schools tend to realize some of the smallest percentage reductions, but some of the greatest total reductions in energy use, energy costs, and energy-related carbon emissions. Total reductions are driven largely by total new floor area constructed for the building type in a state. The adoption of the LEC design would lead to greater aggregate reductions in energy use in Illinois than in Iowa the amount of newly constructed floor area for 2003 to 2007 was almost five times greater in Illinois.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy rates, and emissions rates. The greatest 10-year reduction in energy use per unit of floor area resulting from adoption of the LEC design is realized by the four states that have no state energy code, ranging from 404 kWh/m^2 (128 kBtu/ft^2) to 456 kWh/m^2 (145 kBtu/ft^2), followed by the state that has adopted *ASHRAE 90.1-2004* and realizes reductions of 351 kWh/m^2 (111 kBtu/ft^2). The states that have adopted *ASHRAE 90.1-2007* realize reductions ranging from 168 kWh/m^2

(53 kBtu/ft^2) to 206 kWh/m^2 (65 kBtu/ft^2). States with the highest electricity rates tend to realize the largest reductions in energy costs per unit of energy consumption reduced. Similarly, states with higher emission rates per unit of electricity generated tend to realize greater reductions in emissions per unit of energy consumption reduced. The greater the fraction of the total reduction in energy use that is from electricity consumption, the greater the reduction in both energy costs and carbon emissions per unit of energy consumption reduced.

19.2 Limitations and Future Research

The use of building prototypes in this study is meant to reveal general trends in the benefits and costs of energy standard adoption at the city, state, and regional levels. The study is not appropriate for analysis of individual buildings because each building has specific characteristics that may differ from the prototype. The analysis in this study is limited in scope and would be strengthened by analyzing more states, including sensitivity analysis, expanding the BIRDS database and metrics, and enabling public access to all the results.

This study only analyzes 12 of the 50 states in detail, and cannot be extrapolated to estimate the magnitude of nationwide savings. Combining the results in this study with detailed analysis of the remaining 38 states will allow for estimation of nationwide impacts. Also, analysis across census regions may show some additional variation in results revealing insights not captured in this study.

Sensitivity analysis is needed for at least two assumptions in the analysis. First, consider the assumed discount rate used in life-cycle costing. Although 3 % is a reasonable discount rate, in real terms, for federal government investment decisions, it may be too low of a value for an expected real return on an alternative investment in the private sector. A higher discount rate would decrease the value of future energy cost savings, which could impact the cost-effectiveness of adopting more energy efficient building designs. Sensitivity analysis on the assumed discount rate is needed to determine the robustness of the cost results. Second, the current analysis assumes that the cooling load is met by equipment running on electricity while heating loads are met with equipment running on natural gas, which is not the typical fuel mix for some areas of the nation. The database should be expanded to include alternative fuel sources for heating.

Additional data are needed to refine and expand the BIRDS database. First, the study uses simple statewide averages of constructed floor area to summarize energy use, energy cost, carbon emissions, and life-cycle cost changes. However, the amount of total floor area constructed will vary significantly from city to city. Future research could develop a weighted average of savings in a state based on the fraction of newly constructed floor area by city. Second, the 11 prototypical buildings analyzed in this study are likely not representative of the entire building stock for each building type. For example, all high-rise buildings are not 100 % glazed, as assumed here. For this reason, the results should be considered as general magnitudes instead of hard numbers. Future research should include additional prototypes, such as the DOE Benchmark Buildings (NREL, 2011), in the database. Additionally, since existing buildings account for nearly the entire building stock, prototypes for retrofitting buildings should be incorporated into the BIRDS database as well. Another addition to expand the database is the inclusion of building designs to meet the newest edition of *ASHRAE 90.1* (*-2010*) as well as *ASHRAE*'s green building standard (*ASHRAE 189.1-2011*). The state average energy cost rates and energy-related carbon emissions rates do not control for local variation in energy tariffs or electricity fuel mixes. By using utility-level energy cost and emissions rate data, the accuracy of the estimates in BIRDS could be improved. Additionally, the fuel mix used for electricity generation across the United States will change over time as economic and regulatory conditions change. A range of potential emissions rates could be included to allow for potential changes in emissions rates in the future.

The analysis in this study ignores the impacts that plug and process loads have on the reductions in energy use. Buildings with greater plug and process loads will realize smaller percentage changes in energy use because the energy efficiency measures considered in this study focus on the building envelope and HVAC equipment, holding constant the energy use from other equipment used in the building. As building energy efficiency improves, the plug and process loads become a larger fraction of the overall energy load. Future research should consider the impact changes in plug and process loads have on the overall energy use savings realized by energy efficiency improvements to buildings.

This study only compares the current state energy code to newer, more stringent standard editions for states in the Midwest Census Region. The BIRDS database is much more expansive, allowing researchers to compare any of the editions of *ASHRAE 90.1* with any other edition of *ASHRAE 90.1* or the LEC design for any state in the country. The BIRDS database should be made available to the public through a simple-to-use software tool that allows other researchers to use the database for their own research on building energy efficiency.

Finally, a more comprehensive sustainability assessment of the benefits and costs of building energy efficiency would strengthen the impact of this work. This study applies environmental life cycle assessment methods to evaluate the global warming potentials attributable to building energy efficiency improvements. In a parallel effort, the BIRDS database is being expanded to include a full range of 11 life-cycle environmental impacts covering human health effects, ecological health effects, and resource depletion. The sustainability assessment is also being expanded beyond building energy efficiency to cover the materials used in construction, MRR, and waste management. The BIRDS software tool in development will provide the results of this more comprehensive sustainability assessment alongside the results summarized in this report.

References

ANSI/ASHRAE/USGBC/IES Standard 189.1-2011, Standard for the Design of High-Performance Green Buildings, 2011, ASHRAE, Inc. and U.S. Green Building Council.

ArcMap 10.1 software, ArcGIS desktop package, ESRI, Redlands, CA, http://www.esri.com/.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-1999 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 1999, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2001 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2001, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2004 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2004, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2007 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2007, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2010 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2010, ASHRAE, Inc.

ASTM International, ASTM Standards of Building Economics: 7th Edition, 2012.

D.B. Belzer, K.A. Cort, D.W. Winiarski, E.E. Richman, Analysis of Potential Benefits and Costs of Adopting a Commercial Building Energy Standard in South Dakota, March 2005, Pacific Northwest National Laboratory, PNNL-15101.

Commercial Buildings Energy Consumption Survey (CBECS) database, 2003, accessed June-July 2009, http://www.eia.doe.gov/emeu/cbecs/.

Database of State Incentives for Renewables and Efficiency, Rules, Regulations, and Policies for Energy Efficiency database, building energy codes, accessed summer 2010, www.dsireusa.org/.

Department of Energy, 2009a, Building Technologies Program, EnergyPlus energy simulation software, http://apps1.eere.energy.gov/buildings/energyplus/.

Department of Energy, 2009b, Building Technologies Program, State energy codes at-a-glance, http://www.energycodes.gov/states/maps/commercialStatus.stm.

EnergyPlus Example File Generator, Building Energy Simulation Web Interface for EnergyPlus, accessed Feb. 2009, U.S. Department of Energy National Renewable Energy Laboratory, http://apps1.eere.energy.gov/buildings/energyplus/.

Environmental Protection Agency, 2007 Emissions and Generation Integrated Database.

S. Fuller, S. Petersen, Life-Cycle Costing Manual for the Federal Energy Management Program, 1996, NIST Handbook 135, 1995 Edition, U.S. Department of Commerce, Technology Administration and NIST.

M.A. Halverson, K. Gowri, E.E. Richman, Analysis of Energy Savings Impacts of New Commercial Energy Codes for the Gulf Coast, December 2006, Pacific Northwest National Laboratory, PNNL-16282.

J. Kneifel, Life-cycle Carbon and Cost Analysis of Energy Efficiency Measures in New Commercial Buildings, Energy and Buildings 42 (3) (2010) 333-340.

J. Kneifel, 2011a, Beyond the Code: Energy, Carbon, and Cost Savings using Conventional Technologies, Energy and Buildings 43 (2011) 951-959.

J. Kneifel, 2011b, Prototype Commercial Buildings for Energy and Sustainability Assessment: Whole Building Energy Simulation Design, September 2011, NIST, Technical Note 1716.

J. Kneifel, 2012, Prototype Commercial Buildings for Energy and Sustainability Assessment: Design Specification, Life-Cycle Costing and Carbon Assessment, January 2012, NIST, Technical Note 1732.

J. Kneifel, 2013, Benefits and Costs of Energy Standard Adoption in New Commercial Buildings, February 2013, NIST, Special Publication 1147.

B. Lippiatt, Greig, A., Lavappa, P., Building for Environmental and Economic Sustainability (BEES) Online software, February 2011, NIST, http://ws680.nist.gov/bees/.

National Oceanic and Atmospheric Administration, map of census regions, accessed Dec. 2010, http://marineeconomics.noaa.gov/.

National Renewable Energy Laboratory, 2011, U.S. Department of Energy Commercial Reference Building Models of the National Building Stock, TP-5500-46861.

Pacific Northwest National Laboratory, 2009, Impacts of Standard 90.1-2007 for Commercial Buildings at State Level, United States Department of Energy Building Energy Codes Program.

RS Means CostWorks databases, accessed 2009, http://www.meanscostworks.com/.

A. Rushing, B. Lippiatt, Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-April 2008, May 2008, NIST, NISTIR 85-3273-23.

M. Towers, R. Dotz, L. Romani, The Whitestone Building Maintenance and Repair Cost Reference 2008-2009, 13th Annual Edition, 2008, Whitestone Research.

U.S. Energy Information Administration, 2010a, Electric power annual state data tables, Accessed 2010, http://www.eia.doe.gov/fuelelectric.html.

U.S. Energy Information Administration, 2010b, Natural Gas Navigator, accessed 2010, http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html.

U.S. Life-Cycle Inventory Database, 2012, http://www.nrel.gov/lci/.

D. Winiarski, S. Shankle, J. Hail, B. Liu, A. Walker, The Business Case for Sustainable Design in Federal Facilities: Appendix B: Energy and Construction Cost Estimates, August 2003, Pacific Northwest National Laboratory and National Renewable Energy Laboratory.

A Building and Energy Characteristics

Table A-1 CBECS Categories and Subcategories

Category	Subcategory
Education	elementary or middle school high school college or university preschool or daycare adult education career or vocational training religious education
Food Sales	grocery store or food market gas station with a convenience store; convenience store
Food Service	fast food restaurant or cafeteria
Health Care Inpatient	hospital inpatient rehabilitation
Health Care Outpatient	medical office (see previous column) clinic or other outpatient health care outpatient rehabilitation veterinarian
Lodging	motel or inn hotel dormitory, fraternity, or sorority retirement home nursing home, assisted living, etc. convent or monastery shelter, orphanage, halfway house
Mercantile Non-Mall	retail store beer, wine, or liquor store rental center dealership or showroom for vehicles or boats studio/gallery
Mercantile Malls	enclosed mall strip shopping center
Office	administrative or professional office government office mixed-use office bank or other financial institution medical office (see previous column) sales office contractor's office non-profit or social services research and development city hall or city center religious office call center
Public Assembly	social or meeting recreation entertainment or culture library funeral home student activities center armory exhibition hall broadcasting studio transportation terminal
Public Order and Safety	police station fire station jail, reformatory, or penitentiary courthouse or probation office
Religious Worship	None
Service	vehicle service or vehicle repair shop vehicle storage/ maintenance (car barn) repair shop dry cleaner or laundromat post office or postal center car wash gas station photo processing shop beauty parlor or barber shop tanning salon copy center or printing shop kennel
Warehouse and Storage	refrigerated warehouse non-refrigerated warehouse distribution or shipping center
Other	airplane hangar crematorium laboratory telephone switching agricultural with some retail space manufacturing or industrial with some retail space data center or server farm
Vacant	None

Table A-2 New Commercial Building Construction Floor Area for 2003 through 2007 by State and Building Type

	Building Construction Floor Area in 1000 m^2 (1,000 ft^2)										
State	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total
IA	143 (1542)	639 (6875)	427 (4598)	999 (10 749)	657 (7069)	74 (796)	1350 (14 534)	1262 (13 586)	621 (6688)	1062 (11 426)	7234 (77 863)
IL	7303 (78 609)	1765 (18 998)	1304 (14 037)	2930 (31 542)	1714 (18 451)	232 (2497)	5660 (60 928)	3083 (33 180)	6473 (69 674)	4179 (44 977)	34 643 (372 893)
IN	360 (3875)	1728 (18 600)	856 (9210)	1746 (18 791)	1323 (14 242)	255 (2747)	3302 (35 539)	2558 (27 535)	3771 (40 591)	2415 (25 992)	18 313 (197 123)
KS	98 (1057)	533 (5734)	353 (3795)	877 (9442)	295 (3178)	97 (1039)	1122 (12 076)	826 (8892)	513 (5521)	670 (7216)	5384 (57 950)
MI	446 (4800)	1797 (19 346)	713 (7671)	1696 (18 251)	1359 (14 629)	200 (2153)	3245 (34 934)	2058 (22 151)	864 (9305)	2442 (26 283)	14 820 (159 523)
MN	1437 (15 465)	1018 (10 954)	473 (5093)	1633 (17 575)	527 (5673)	102 (1098)	2135 (22 985)	1175 (12643)	803 (8643)	2342 (25 212)	11 645 (125 342)
MO	875 (9420)	940 (10 121)	881 (9483)	1226 (13 197)	780 (8395)	158 (1705)	2513 (27 054)	1626 (17 497)	819 (8818)	1972 (21 226)	11 791 (126 915)
ND	7 (76)	118 (1265)	91 (982)	138 (1490)	113 (1221)	14 (155)	331 (3567)	174 (1871)	57 (617)	100 (1077)	1145 (12 320)
NE	147 (1586)	453 (4880)	303 (3263)	631 (6790)	331 (3562)	54 (577)	1149 (12 369)	514 (5533)	340 (3660)	676 (7279)	4599 (49 498)
OH	635 (6832)	2452 (26 393)	925 (9959)	2674 (28 780)	1266 (13 630)	372 (4004)	5132 (55 245)	4452 (47 919)	3382 (36 400)	3243 (34 909)	24 533 (264 071)
SD	13 (142)	119 (1285)	86 (922)	257 (2767)	126 (1354)	13 (138)	341 (3668)	268 (2884)	88 (950)	205 (2202)	1515 (16 312)
WI	906 (9754)	1519 (16 350)	583 (6273)	1556 (16 751)	746 (8030)	137 (1474)	2489 (26 793)	1129 (12 148)	882 (9497)	1981 (21 325)	11 928 (128 395)
Total	12 371 (133 158)	13 081 (140 801)	6994 (75 286)	16 363 (176 125)	9238 (99 434)	1708 (18 383)	28 771 (309 692)	19 123 (205 839)	18 614 (200 364)	21 286 (229 124)	147 549 (1 588 205)

Table A-3 New Commercial Building Construction Share by State and Building Type

State	Percentage of Building Construction Floor Area											
	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total	Rep. by Study
IA	2.0 %	8.8 %	5.9 %	13.8 %	9.1 %	1.0 %	18.7 %	17.4 %	8.6 %	14.7 %	100.0 %	58.8 %
IL	21.1 %	5.1 %	3.8 %	8.5 %	4.9 %	0.7 %	16.3 %	8.9 %	18.7 %	12.1 %	100.0 %	59.2 %
IN	2.0 %	9.4 %	4.7 %	9.5 %	7.2 %	1.4 %	18.0 %	14.0 %	20.6 %	13.2 %	100.0 %	49.6 %
KS	1.8 %	9.9 %	6.5 %	16.3 %	5.5 %	1.8 %	20.8 %	15.3 %	9.5 %	12.5 %	100.0 %	62.6 %
MI	3.0 %	12.1 %	4.8 %	11.4 %	9.2 %	1.3 %	21.9 %	13.9 %	5.8 %	16.5 %	100.0 %	56.4 %
MN	12.3 %	8.7 %	4.1 %	14.0 %	4.5 %	0.9 %	18.3 %	10.1 %	6.9 %	20.1 %	100.0 %	59.7 %
MO	7.4 %	8.0 %	7.5 %	10.4 %	6.6 %	1.3 %	21.3 %	13.8 %	6.9 %	16.7 %	100.0 %	61.7 %
ND	0.6 %	10.3 %	8.0 %	12.1 %	9.9 %	1.3 %	29.0 %	15.2 %	5.0 %	8.7 %	100.0 %	66.1 %
NE	3.2 %	9.9 %	6.6 %	13.7 %	7.2 %	1.2 %	25.0 %	11.2 %	7.4 %	14.7 %	100.0 %	60.8 %
OH	2.6 %	10.0 %	3.8 %	10.9 %	5.2 %	1.5 %	20.9 %	18.1 %	13.8 %	13.2 %	100.0 %	57.8 %
SD	0.9 %	7.9 %	5.7 %	17.0 %	8.3 %	0.8 %	22.5 %	17.7 %	5.8 %	13.5 %	100.0 %	64.5 %
WI	7.6 %	12.7 %	4.9 %	13.0 %	6.3 %	1.1 %	20.9 %	9.5 %	7.4 %	16.6 %	100.0 %	57.0 %

Table A-4 Electricity Generation CO_2, CH_4, and N_2O Emissions Rates by State

State	CO_2 (t/GWh)	CH4 (t/GWh)	N2O (t/GWh)
IA	851.1	40.4	0.2
IL	948.3	44.4	0.2
IN	835.7	38.9	0.2
KS	926.0	44.8	0.3
MI	861.4	46.8	0.6
MN	851.1	40.4	0.2
MO	939.4	44.6	0.2
ND	851.1	40.4	0.2
NE	851.1	40.4	0.2
OH	835.7	38.9	0.2
SD	851.1	40.4	0.2
WI	860.7	44.1	0.4

B Additional BIRDS Database Results

Table B-1 4-Story Apartment Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-9.8	-15.8	-16.8	0.5
IL	-9.4	-17.1	-17.1	0.3
IN	-10.1	-16.0	-17.1	0.6
KS	-24.9	-35.3	-39.1	-1.6
MI	-8.5	-15.2	-16.3	0.4
MN	-13.8	-18.0	-18.6	0.2
MO	-25.4	-33.3	-38.6	-1.0
ND	-17.5	-30.8	-33.4	-1.0
NE	-9.8	-16.3	-17.2	0.7
OH	-9.6	-16.0	-17.1	0.5
SD	-21.2	-34.1	-35.9	-1.7
WI	-9.5	-15.9	-16.4	0.4

Table B-2 6-Story Apartment Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-10.6	-17.6	-18.7	0.5
IL	-10.5	-20.0	-20.1	0.1
IN	-11.3	-18.7	-20.1	0.5
KS	-25.9	-37.4	-41.4	-1.8
MI	-8.9	-16.7	-17.9	0.3
MN	-13.0	-17.3	-17.9	0.4
MO	-26.5	-35.2	-40.9	-1.1
ND	-17.2	-30.5	-33.1	-0.9
NE	-11.2	-19.5	-20.5	0.6
OH	-10.6	-18.5	-19.9	0.4
SD	-20.6	-33.5	-35.4	-1.5
WI	-9.3	-15.5	-16.0	0.5

Table B-3 4-Story Dormitory Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-11.7	-16.7	-17.5	-0.2
IL	-11.1	-17.8	-17.8	-0.3
IN	-11.8	-16.9	-17.9	-0.4
KS	-27.6	-37.1	-40.4	0.3
MI	-10.7	-16.5	-17.4	-1.2
MN	-19.0	-20.7	-20.9	-1.5
MO	-27.4	-35.0	-39.8	0.2
ND	-21.6	-33.7	-36.0	0.3
NE	-11.7	-17.2	-17.9	-0.2
OH	-11.2	-16.9	-17.8	-1.2
SD	-24.0	-35.7	-37.3	-1.4
WI	-12.0	-17.0	-17.4	-0.8

Table B-4 6-Story Dormitory Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-10.0	-16.4	-17.4	0.2
IL	-10.3	-19.4	-19.4	-0.2
IN	-11.0	-18.1	-19.4	0.2
KS	-24.8	-36.3	-40.4	-2.6
MI	-8.5	-15.9	-17.1	0.1
MN	-11.3	-15.2	-15.7	0.2
MO	-26.0	-34.9	-40.6	-1.9
ND	-16.6	-28.8	-31.2	-1.6
NE	-10.9	-18.8	-19.8	0.3
OH	-10.3	-17.9	-19.2	0.1
SD	-17.3	-30.6	-32.5	-2.0
WI	-8.2	-13.7	-14.2	0.2

Table B-5 15-Story Hotel Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-11.0	-15.3	-16.0	0.5
IL	-11.8	-19.2	-19.2	0.2
IN	-12.3	-18.1	-19.2	0.5
KS	-19.7	-29.4	-32.9	-1.5
MI	-10.1	-15.5	-16.4	0.2
MN	-6.8	-6.8	-6.8	0.9
MO	-19.8	-27.5	-32.6	-0.9
ND	-10.0	-20.8	-22.8	-1.1
NE	-12.7	-18.9	-19.7	0.6
OH	-11.8	-18.1	-19.2	0.4
SD	-11.8	-21.8	-23.2	-1.3
WI	-8.9	-11.2	-11.4	0.4

Table B-6 2-Story High School Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-6.1	-13.8	-15.2	-0.8
IL	-5.6	-16.4	-16.5	-1.1
IN	-6.4	-14.8	-16.6	-0.8
KS	-13.7	-23.4	-27.7	-1.5
MI	-4.6	-12.7	-14.2	-0.8
MN	-9.2	-14.1	-14.9	-1.1
MO	-14.3	-21.7	-27.7	-1.4
ND	-11.1	-18.9	-20.8	-0.9
NE	-5.8	-15.0	-16.4	-0.6
OH	-5.6	-14.2	-15.8	-0.8
SD	-10.9	-20.0	-21.7	-1.8
WI	-5.9	-12.7	-13.4	-1.1

Table B-7 8-Story Office Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-17.3	-19.6	-19.8	-1.5
IL	-17.8	-21.0	-21.0	-2.2
IN	-18.5	-20.8	-21.1	-2.0
KS	-32.5	-33.1	-33.3	0.3
MI	-16.7	-19.6	-19.8	-2.2
MN	-21.4	-19.8	-19.6	-1.3
MO	-32.3	-32.5	-32.6	0.4
ND	-26.0	-28.1	-28.4	1.3
NE	-18.5	-21.2	-21.5	-2.2
OH	-17.9	-20.6	-20.9	-2.2
SD	-26.8	-28.4	-28.6	-0.5
WI	-16.4	-18.0	-18.1	-1.2

Table B-8 16-Story Office Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-13.0	-16.2	-16.6	0.6
IL	-13.9	-19.8	-19.8	0.2
IN	-15.0	-19.7	-20.4	0.6
KS	-17.1	-21.6	-23.1	0.3
MI	-12.6	-16.9	-17.5	0.2
MN	-8.7	-7.8	-7.7	1.0
MO	-16.3	-20.0	-22.2	0.9
ND	-9.9	-13.5	-14.1	0.4
NE	-15.2	-20.2	-20.7	0.8
OH	-14.4	-19.5	-20.2	0.5
SD	-10.1	-13.2	-13.6	0.2
WI	-10.9	-11.9	-12.0	0.3

Table B-9 1-Story Retail Store Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-14.3	-17.2	-17.6	0.6
IL	-12.5	-16.9	-16.9	-0.4
IN	-13.5	-16.8	-17.4	0.5
KS	-30.6	-33.9	-35.1	1.0
MI	-12.6	-16.0	-16.4	-0.3
MN	-27.3	-23.9	-23.5	-0.8
MO	-31.3	-33.5	-34.8	1.7
ND	-31.8	-33.4	-33.7	0.6
NE	-12.5	-16.8	-17.2	0.8
OH	-12.5	-16.1	-16.6	-0.5
SD	-29.9	-33.5	-34.0	-0.9
WI	-15.9	-18.0	-18.1	-1.1

Table B-10 1-Story Restaurant Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
IA	-23.7	-30.3	-31.2	-4.4
IL	-23.3	-32.6	-32.6	-4.5
IN	-24.8	-31.9	-33.1	-4.3
KS	-40.8	-46.4	-48.3	-1.2
MI	-22.1	-30.3	-31.4	-3.0
MN	-37.9	-36.3	-36.1	-5.0
MO	-39.1	-43.9	-46.8	-3.3
ND	-41.8	-44.2	-44.6	-0.2
NE	-24.2	-32.6	-33.5	-3.9
OH	-23.3	-31.4	-32.6	-3.4
SD	-39.0	-43.6	-44.2	-3.0
WI	-23.6	-28.7	-29.1	-3.3