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Benefits and Costs of Energy Standard Adoption in New Commercial Buildings

Joshua Kneifel

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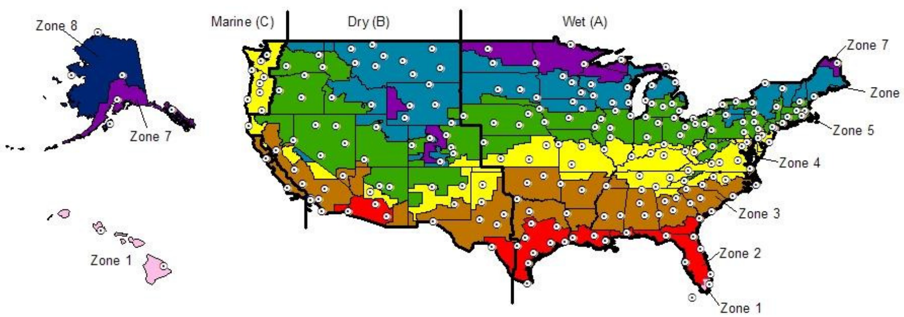
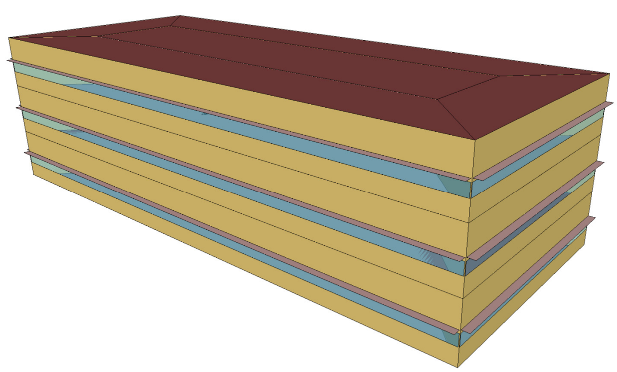


BIRDS
Building Industry
Reporting and
Design *for*
Sustainability



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Abstract

Energy efficiency requirements in current energy codes for commercial buildings vary across states, and many states have not yet adopted the newest energy standard edition. As of December 2011, states have adopted energy codes ranging across all editions of *American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE) 90.1* (*-1999, -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 a state 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. William Healy 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 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.

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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
CH4	Methane
CO2	Carbon Dioxide
CO2e	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
N2O	Nitrous Oxide
NERC	North American Electric Reliability Corporation
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

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

Executive Summary

Energy efficiency requirements in current energy codes for commercial buildings vary across states, and many states have not yet adopted the newest energy standard editions. As of December 2011, state energy code adoptions range across all editions of the *American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1-1999, -2001, -2004,* and *-2007*). Some states in the U.S. 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 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 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.

Results are analyzed in detail for the *ASHRAE 90.1-2007* and LEC designs in both 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 and regions of the United States. Results are aggregated at the state level for seven states to estimate the magnitude of total energy use savings, energy cost savings, and cradle-to-grave energy-related carbon emissions reductions that could be attained by adoption of a more energy efficient state energy code, and the life-cycle costs associated with those savings. The seven states chosen for this study to illustrate the detailed analysis possible with the BIRDS database are Alaska, Colorado, Florida, Maryland, Oregon, Tennessee, and Wisconsin.

Overall, adoption of *ASHRAE 90.1-2007* for the 19 states that have not yet adopted it as their state energy code leads to reductions in energy use, energy costs, and energy-related carbon emissions. The average state energy use reduction for new commercial buildings is 9.6 % while energy costs and carbon emissions realize average reductions of 12.2 % and 12.4 %, respectively for a 10-year study period. The reductions in energy use and carbon emissions are cost-effective, with average life-cycle costs decreasing by 0.7 %.

However, *ASHRAE 90.1-2007* does not lead to energy efficiency improvements over older editions of *ASHRAE 90.1* for all locations in the U.S. for two reasons. First, the simplification of the *ASHRAE* climate zones from 26 zones in *ASHRAE 90.1-2001* to 8 zones in *ASHRAE 90.1-2004* resulted in the relaxation of some building envelope requirements for some locations. Second, *ASHRAE 90.1-2007* has less stringent solar heat gain coefficient (SHGC) requirements relative to *ASHRAE 90.1-2004* for some climate zones. As a result, high-rise, 100 % glazed buildings realize smaller reductions, and occasionally increases, in energy use because the less stringent window requirements overwhelm the stricter requirements for other energy efficiency measures analyzed in this study.

Overall, adoption of the LEC design in all 50 states leads to nationwide reductions in energy use, energy costs, and carbon emissions greater than those realized by *ASHRAE 90.1-2007*. The average state energy use reduction is 17.8 % over current state energy codes while energy costs and carbon emissions realize average reductions of 22.6 % and 20.4 %, respectively. The reductions in energy use and carbon emissions are cost-effective, with life-cycle costs decreasing by 1.1 % on average for a 10-year study period.

States with current energy codes based on older editions of *ASHRAE 90.1* realize greater reductions in energy use, energy costs, and carbon emissions for the *ASHRAE 90.1-2007* design. For a small office building, the 13 states with reductions in energy use of at least 10 % have no state energy code or have adopted *ASHRAE 90.1-1999/2001*. For the LEC design, 14 of the 18 states that realize reductions in energy use greater than 25 % have no state energy code or have adopted *ASHRAE 90.1-1999/2001*, including all 13 states with reductions greater than 30 %. Similar trends hold for energy costs and energy-related carbon emissions.

Over all building types, states located in the warmest climates realize the greatest reductions in energy use from adopting the “Low Energy Case” (LEC) design because several of the energy efficiency improvements (e.g., overhangs and daylighting controls) are more beneficial for warmer climates. However, states in colder climates see greater percentage reductions in energy costs and carbon emissions per percentage reduction in energy use because the energy efficiency measures tend to shift some energy use from electricity to natural gas consumption. Electricity is more expensive per unit of energy and typically has greater CO_2e emissions factors per unit of energy relative to natural gas. Therefore the shift of energy consumption from electricity to natural gas can lead to greater reductions in energy costs and energy-related carbon emissions than reductions in total energy use. In an extreme case, cities located in Zone 8 realize a reduction in energy costs and carbon emissions while realizing an increase in total energy use.

The results for the *ASHRAE 90.1-2007* design have some similarities and some differences relative to the results for the LEC design. Similar to the LEC design, the current state energy codes are a key driver of variation in the results. The variation across climate zones diverges depending on the state energy code. For locations in states that have not adopted any state energy code or have adopted older editions of *ASHRAE 90.1* (*-1999* or *-2001*), warmer climate zones realize greater percentage reductions in energy use. For cities located in states that have adopted *ASHRAE 90.1-2004*, the percentage reductions in energy use do not follow the same trend. Instead the percentage changes are the greatest for cities in Zone 2 followed by Zone 7 and smallest for cities in Zone 1 and Zone 3.

Similar to the LEC design, many cities realize a shift in energy use from electricity to natural gas, which decreases energy costs and carbon emissions by a greater percentage than the percentage decrease in energy consumption. However, nearly all zones realize smaller percentage reductions in carbon emissions than the percentage reductions in energy use because adopting *ASHRAE 90.1-2007* decreases consumption of both electricity and natural gas for most cities.

The length of the study period impacts life-cycle cost-effectiveness to some degree. Assuming nationwide adoption of the LEC design, a 10-year study period realizes average life-cycle cost decreases of 1.1 % for all building types and locations. The percentage decrease in life-cycle costs is 1.4 % for a 20-year, and 1.8 % for a 30-year, and 1.9 % for a 40-year study period. As the study period length increases from 5 to 40 years, the life-cycle cost-effectiveness tends to increase for more energy efficient commercial building designs. This result is supported by the state-level aggregated impact estimates, with only one of the seven states in this study realizing an increase in total life-cycle costs from the adoption of the LEC design.

States with the most newly constructed commercial building floor area realize the greatest total energy use, energy cost, and energy-related carbon emissions reductions from adopting *ASHRAE 90.1-2007* or the LEC design even if those states do not realize the greatest percentage reductions. Maryland and Oregon, both of which have adopted *ASHRAE 90.1-2007*, realize reductions in energy use of 15 % for the LEC design. However, Maryland realizes total reductions in energy use of 622 GWh while Oregon realizes reductions of 261 GWh because Maryland has almost twice the amount of newly constructed floor area. Similarly, Florida, which ranks 1st in the country for new floor area, realizes greater aggregate reductions in energy costs and energy-related carbon emissions reductions than Maryland even though both states realize approximately the same percentage reductions in these two metrics.

In general, the states that realize the greatest reductions in energy use also realize the greatest reductions in energy costs and energy-related carbon emissions. However, states with higher electricity and natural gas rates will realize greater reductions in energy costs. For example, Tennessee realizes greater aggregate reductions in energy use than

Maryland (808 GWh versus 622 GWh), but less total energy cost savings ($58.7 million versus $62.4 million). Also, states that rely heavily on coal-fired electricity will realize greater emissions reductions per unit of energy reduced than those states using more alternative energy sources. For example, Colorado relies on coal for 72 % of electricity generation and decreases carbon emissions by over 1000 tons per GWh of electricity generation. Meanwhile, Oregon relies on coal for 7 % of electricity generation and only saves 560 tons per GWh.

For a 10-year study period, adopting either *ASHRAE 90.1-2007* or the LEC design reduces total life-cycle costs for the three states in this study that have adopted an older edition of *ASHRAE 90.1* or have not yet adopted a state energy code for commercial buildings: $815 858 for Alaska, $32.5 million for Colorado, and $4.4 million for Tennessee. Meanwhile, adopting the LEC design would decrease life-cycle costs for six of the seven states selected for this study, ranging from $2.3 million to $151.3 million. The variation is primarily driven by the amount of new construction in a state. The life-cycle cost savings realized by these six states makes the increase in life-cycle costs realized by Oregon insignificant.

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. Detailed analysis of the remaining 43 states 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 both a full range of life-cycle environmental impacts and building activities, such as construction, maintenance, repair, and replacement 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 retrofitting these same prototype buildings would greatly increase the scope of the database. The extensive BIRDS database can be used to answer many more questions than posed in this report, and should be made available to the public through a simple-to-use software tool that allows other researchers access to the database for their own research on building energy efficiency. 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 newest energy standard editions. As of December 2011, state energy code adoptions range across all editions of the *American Society of Heating, Refrigerating and Air-Conditioning Engineers Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1-1999, -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 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, energy-related carbon emissions, and building life-cycle costs. The results are analyzed for selected states and across all states to answer the following questions:

- State-By-State Analysis
    - How much, on a percentage basis, does each more stringent standard decrease building energy consumption, energy costs, and energy-related carbon emissions relative to the state's current energy code?
    - Is adopting a more stringent energy standard life-cycle cost-effective?
    - What causes variation across cities within a state for building energy consumption, energy costs, energy-related carbon emissions, and life-cycle costs reduction? Do these vary across states?
    - Based on new construction in each state, how much can a state save in total energy consumption, energy costs, energy-related carbon emissions, and life-cycle costs over time?
- Across-State Analysis
    - Are newer energy standard editions really more energy efficient? And if so, how much more efficient?
    - Which states would benefit the most from adopting newer energy standard editions?
    - What factors drive the relative energy savings across states?
    - How does the study period length impact the cost-effectiveness of energy efficiency investments?

Seven states that represent the full range of state energy codes are chosen for the detailed state-by-state analysis. The average changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for all states are used for cross-state comparative analysis.

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 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 the 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 reduction for 228 cities across the U.S. with at least one city in every climate zone 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 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.

1.3 Approach

This study uses the Building Industry Reporting and Design for Sustainability (BIRDS) database to analyze the benefits and costs of increasing building energy efficiency across the United States. 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 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 and regions of the United States. 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 through 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).This study analyzes whole building energy simulations, life-cycle costs, and life-cycle carbon emissions for 12 540 buildings covering 5 energy efficiency designs for 11 new commercial building types, 228 cities across 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. 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

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 location. For this study, the *ASHRAE 90.1 Standard*-equivalent design is used to meet current state energy

[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

codes and to define the alternative building designs. Additionally, a “Low Energy Case” design that goes beyond *ASHRAE 90.1-2007* requirements is included as a building design alternative, and for simplicity may be referred to as an “edition” of the energy standard throughout the remainder of this report.

Table 2-2 shows that commercial building energy codes as of December 2011 vary by state.[3] In a few instances, local jurisdictions have adopted energy standard editions that are more stringent than the state energy codes.[4] These cities are also included in Table 2-2.

Table 2-2 Energy Code by State and City Exception

Location	Energy Code	Location	Energy Code	Location	Energy Code
AK	**None**	**IN**	**2007**	**NV**	**2004**
AL	**None**	**KS**	**None**	**NY**	**2007**
Huntsville	2001	**KY**	**2007**	**OH**	**2007**
AR	**2001**	**LA**	**2007**	**OK**	**None**
AZ	**None**	**MA**	**2007**	**OR**	**2007**
Flagstaff	2004	**MD**	**2007**	**PA**	**2007**
Phoenix	2004	**ME**	**None**	**RI**	**2007**
Tucson	2004	**MI**	**2007**	**SC**	**2004**
CA	**2007**	**MN**	**2004**	**SD**	**None**
CO	**2001**	**MO**	**None**	Huron	2001
Grand Junction	2004	St Louis	2001	**TN**	**2004**
CT	**2007**	**MS**	**None**	**TX**	**2007**
DE	**2007**	**MT**	**2007**	**UT**	**2007**
FL	**2007**	**NC**	**2007**	**VA**	**2007**
GA	**2007**	**ND**	**None**	**VT**	**2007**
HI	**2004**	**NE**	**2007**	**WA**	**2007**
IA	**2007**	**NH**	**2007**	**WI**	**2007**
ID	**2007**	**NJ**	**2007**	**WV**	**2001**
IL	**2007**	**NM**	**2007**	**WY**	**None**

Note: Some city ordinances require energy codes that exceed state energy codes.
Note: State codes as of December 1, 2011.

State energy codes vary from *ASHRAE 90.1-1999* to *ASHRAE 90.1-2007* with some regional trends shown in Figure 2-1. The states in the central U.S. tend to wait longer to adopt newer *ASHRAE 90.1 Standard* editions. However, there are many cases in which energy codes of neighboring states vary drastically. For example, Missouri has no state energy code while of the 8 surrounding states, 2 have no state energy code, 1 has adopted

[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.
[4] Local and jurisdictional requirements are obtained from the Database of State Incentives for Renewables and Efficiency (DSIRE). State energy code requirements targeting only public buildings and green standards are ignored in this study.

ASHRAE 90.1-2001, 1 has adopted *ASHRAE 90.1-2004*, and 4 have adopted *ASHRAE 90.1-2007*.

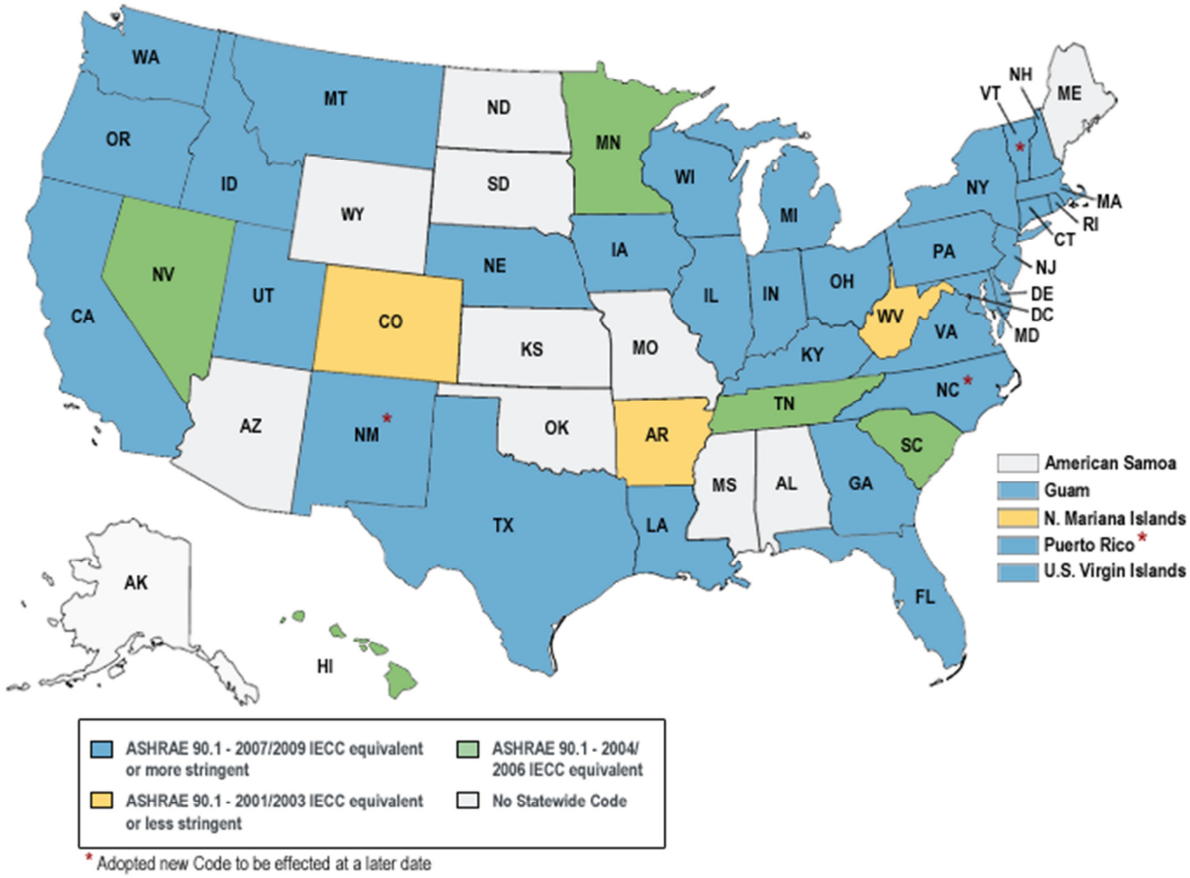

Figure 2-1 State Commercial Energy Codes[5]

The 228 cities and *ASHRAE* climate zones for the U.S. are seen in Figure 2-2. These cities are selected for three reasons. First, the cities are spread out to represent the entire United States, and represent as many climate zones in each state as possible. Second, the locations include all the major population centers in the country. Third, multiple locations for a climate zone within a state are included to allow building costs to vary for each building design.

[5] Figure was obtained from the DOE Building Technologies Program in December 2011.

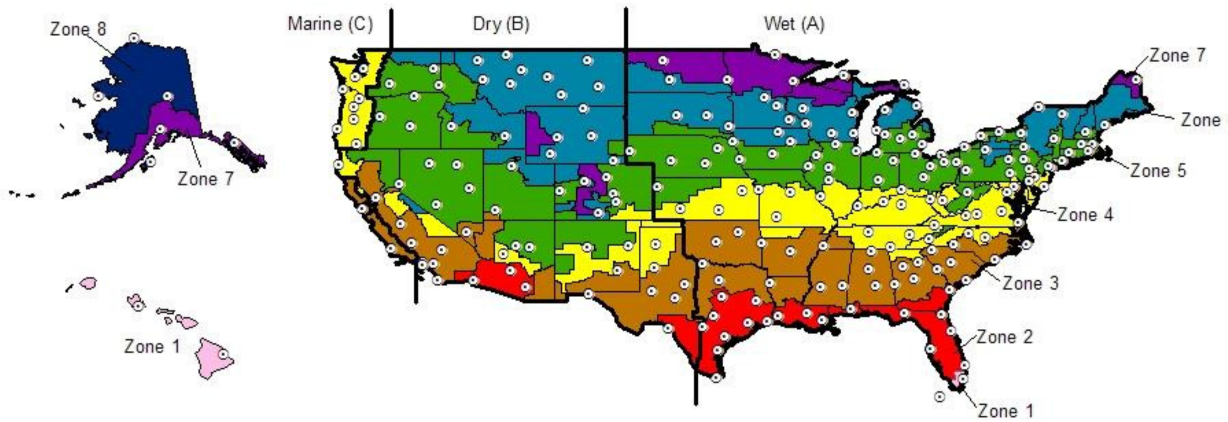

Figure 2-2 Cities and *ASHRAE* Climate Zones

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 cross section of potential 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 representative of a developer that intends to sell a property soon after it is constructed. A 5-year to 15-year study period best 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. The 10-year study period length is the focus of this study.

3 Cost Data

The cost data collected to estimate life-cycle costs originates from multiple sources, including RSMeans databases, Whitestone (2008), and the U.S. Energy Information Administration (EIA). 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. [6]

3.1 First Costs

Building construction costs are obtained from the RS Means *CostWorks* online databases. 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.

[6] 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)	1.7-4.4 (10.0-25.0)	1.7-4.4 (10.0-25.0)	2.6-3.5 (15.0-20.0)	2.6-3.5 (15.0-20.0)	4.4-6.2 (25.0-35.0)
Wall Insulation	R-Value	m^2*K/W (ft^2·°F·h/Btu)	0.0-3.8 (0.0-21.6)	0.0-3.8 (0.0-21.6)	0.0-2.7 (0.0-15.2)	0.0-2.7 (0.0-15.2)	0.7-5.5 (3.8-31.3)
Windows	U-Factor	W/(m2·K) (Btu/(h·ft^2·°F))	1.42-7.21 (0.25-1.27)	1.42-7.21 (0.25-1.27)	1.99-6.47 (0.35-1.14)	2.50-6.47 (0.44-1.14)	1.97-6.42 (0.35-1.13)
	SHGC	Fraction	0.14-NR†	0.14-NR†	0.17-NR†	0.25-NR	0.25-0.47
Lighting	Power Density	W/m^2 (W/ft^2)	14.0-20.5 (1.3-1.9)	14.0-20.5 (1.3-1.9)	10.8-16.1 (1.0-1.5)	10.8-16.1 (1.0-1.5)	8.6-16.1 (0.8-1.5)
Overhangs			None	None	None	None	Zones 1-5
Daylighting			None	None	None	None	Zones 1-8

†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. By definition, 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.[7] 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.[8]

Table 3-2 summarizes the HVAC efficiency requirements for each building design option across the different types of HVAC equipment.[9] Note that the LEC design assumes the same efficiency 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 multiple *ASHRAE 90.1 Standard* editions.

[7] 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).
[8] Overhang cost source is Winiarski et al. (2003)
[9] 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	8.2-9.0	9.0-9.9	9.2-10.1	9.5-13.0	9.5-13.0
	Air-Cooled Chiller	COP	2.5-2.7	2.8	2.8	2.8	2.8
	Water-Cooled Chiller	COP	3.80-5.20	4.45-5.50	4.45-5.50	4.45-5.50	4.45-5.50
	Split System with Condensing Unit	EER	8.7-9.9	9.9-10.1	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 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 and 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 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 last 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. 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.

Maintenance, repair, and replacement 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 and Natural Gas Navigator, 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).[10] 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.

[10] 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 Commercial 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 includes 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 46.4 % of nationwide new commercial building stock square footage for 2003 through 2007. 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 56.8 % of the new commercial building stock.

Table 4-1 New Commercial Building Construction (U.S., 2003 through 2007)

Category	Subcategory	Conditioned Floor Area 1000 m^2 (1000 ft^2)	Percentage in Category	Percentage of Total
Office	**Large**	**20 451 (220 134)**	**22.2 %**	**2.6 %**
Office	**Medium**	**37 170 (400 091)**	**40.4 %**	**4.8 %**
Office	**Small**	**34 468 (371 009)**	**37.4 %**	**4.5 %**
Retail		**93 762 (1 009 246)**		**12.2 %**
Strip Mall		34 847 (375 093)		4.5 %
School	Primary	30 697 (330 418)		4.0 %
School	**Secondary**	**63 686 (685 508)**		**8.3 %**
Hospital		21 194 (228 131)		2.8 %
Other Health Care		26 865 (289 171)		3.5 %
Restaurant	**Sit Down**	**4055 (43 650)**		**0.5 %**
Restaurant	Fast Food	3605 (38 809)		0.5 %
Hotel	**Large**	**30 432 (327 562)**		**0.4 %**
Hotel/Motel	Small	10 576 (113 837)		1.4 %
Warehouse		102 746 (1 105 951)		13.4 %
Apartment	**High-rise**	**55 114 (593 241)**	**55.1 %**	**7.2 %**
Apartment	**Mid-rise**	**44 997 (484 343)**	**44.9 %**	**5.9 %**
No Prototype		153 270 (1 649 785)		20.0 %
Total (2003 to 2007)		767 934 (8 265 977)		100.0 %

The types and floor area of buildings being constructed vary across states**.** Table A-2, Table A-3, and Table A-4 in Appendix A report new building construction for 2003 through 2007 by building type and state, in total square meters, total square feet, and percentage terms, 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 status quo 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 the standard 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 savings resulting from adopting the alternative 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 reasonable given the maintenance, repair, and replacement costs included in the analysis to ensure the building and its equipment perform 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.[11] 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.

[11] 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.[12] 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 US LCI database. 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).[13] Table A-5 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.[14]

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

[12] For states located in more than one NERC sub-region, a weighted average of emissions rates for the multiple sub-regions is implemented.
[13] Emissions rates are held constant over all study periods.
[14] 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 versions 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, life-cycle cost savings, and energy-related carbon emissions reductions 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 that 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.

5.5 States Selected for Detailed Analysis

Detailed analysis of all 50 states is beyond the scope of this study. Certain states are chosen to illustrate the detailed analysis possible with the powerful BIRDS database compiled for this study. A number of criteria are used to choose the selected states. First, it was of interest to select states from across the country. The states chosen represent the West Coast, East Coast, Midwest, South, Central U.S., and Alaska. Second, each edition of *ASHRAE 90.1* should be represented by the selected states. Third, states should represent a range of state rankings in terms of volume of new construction for 2003 through 2007. Fourth, at least 2 states must have adopted the same edition of *ASHRAE 90.1* to illustrate a comparison across states. Finally, it was important to limit the number of states for detailed analysis. Based on these criteria, the 7 states in Table 5-2 were selected for this study: Alaska, Colorado, Florida, Maryland, Oregon, Tennessee, and Wisconsin. The results for each of these 7 states are analyzed in the following chapters.

Table 5-2 Selection Criteria Values for States Analyzed in Detail (2003 to 2007)

State	Standard Edition	New Floor Area 1000 m^2 (1000 f^2)	Floor Area Ranking
FL	2007	82 712 (890 306)	1
MD	2007	16 924 (182 163)	16
CO	2001	16 461 (177 186)	17
TN	2004	16 360 (176 095)	18
WI	2007	11 928 (128 395)	22
OR	2007	8727 (93 941)	27
AK	None	1448 (15 581)	46

It is necessary to assume a particular study period length to generate results. Although the annual energy use savings and energy-related carbon emissions reductions, both in percentage and total value terms, are the same across study period lengths, the energy costs and life-cycle costs vary with the study period length because costs vary year-over-year. A 10-year study period is used for the majority of this analysis because it is the most realistic investor time frame of the 9 study period length options.

6 Alaska

Alaska is selected for this study for two reasons. First, Alaska represents the states that have not yet adopted a state energy code for commercial buildings. Second, the state represents the two coldest climate zones in the United States. Third, Alaska represents the bottom 10 states in terms of new construction volume. For this study, Alaska is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements.

Table 6-1 provides an overview of Alaska'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 113 kWh/m^2 to 140 kWh/m^2 (36 kBtu/ft^2 to 44 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 448 kWh/m^2 to 480 kWh/m^2 (142 kBtu/ft^2 to 152 kBtu/ft^2) annually.

Table 6-1 Average Annual Energy Use by Building Type and Energy Code, Alaska

Building Type	Energy Code									
	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	270	86	270	86	269	85	258	82	239	76
APART06	265	84	265	84	264	84	253	80	236	75
DORMI04	228	72	228	72	231	73	218	69	192	61
DORMI06	286	91	286	91	288	91	275	87	258	82
HOTEL15	263	84	263	83	263	84	276	87	250	79
HIGHS02	480	152	480	152	481	153	473	150	448	142
OFFIC03	171	54	171	54	172	55	162	51	131	42
OFFIC08	140	44	139	44	137	44	134	43	113	36
OFFIC16	223	71	222	70	223	71	236	75	209	66
RETAIL1	219	70	219	69	221	70	207	66	166	53
RSTRNT1	286	91	285	90	291	92	257	82	197	63

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.

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 more energy efficient designs for the state of Alaska.

6.1.1 Energy Use

Table 6-2 shows the percentage changes in energy use for Alaska. There is 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 0.7 % or less. There is a small decrease in energy use for 9 of 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from 0.6 % to -3.4 % with an average of -0.8 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from 4.0 % to -12.4 %, with an overall average of -4.8 %.

Table 6-2 Average Percentage Change in Energy Use from Adoption of Newer Codes, Alaska

Building Type	Energy Code			
	2001	2004	2007	LEC
APART04	-0.1	-1.2	-5.6	-12.7
APART06	-0.1	-1.3	-5.5	-12.2
DORMI04	-0.2	0.2	-6.5	-18.1
DORMI06	-0.1	-0.2	-5.1	-11.1
HOTEL15	-0.2	-1.0	2.7	-6.9
HIGHS02	0.0	-0.2	-2.4	-7.7
OFFIC03	-0.4	-1.0	-8.0	-25.5
OFFIC08	-0.7	-3.4	-6.0	-21.3
OFFIC16	-0.3	-0.7	4.0	-8.1
RETAIL1	-0.1	-0.5	-8.4	-26.3
RSTRNT1	-0.3	0.6	-12.4	-33.4
Average	-0.2	-0.8	-4.8	-16.7

The *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* designs realize an increase for some building types. 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 Alaska, 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 7 and Zone 8 is decreased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007*, making the requirement stricter. Buildings in colder climates benefit from additional solar heat gains. The 100 % glazing amplifies the lost heat gain from the lower SHGC, which increases natural gas consumption enough to overwhelm the energy efficiency gains obtained from other measures that decrease energy consumption, such as increased roof 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 -6.9 % to -33.4 % with an average of -16.7 %. 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 stricter window SHGC requirement.

6.1.2 Energy Costs

Table 6-3 shows minimal change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.1 % to -1.0 %), 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 -5.6 % to -18.0 % depending on the building type, with an average of -12.7 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -3.2 % to -21.1 %, with an overall average of -14.3 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -14.9 % to -40.1 % with an average of -27.6 % overall.

Table 6-3 Average Percentage Change in Energy Costs, 10-Year, Alaska

Building Type	Energy Code			
	2001	2004	2007	LEC
APART04	-0.1	-17.8	-20.2	-31.2
APART06	-0.1	-18.0	-20.3	-31.1
DORMI04	-0.4	-17.8	-21.1	-34.8
DORMI06	-0.2	-17.1	-19.9	-30.0
HOTEL15	-0.4	-16.2	-12.9	-23.5
HIGHS02	-0.1	-5.6	-7.1	-17.8
OFFIC03	-0.6	-8.1	-10.6	-27.6
OFFIC08	-1.0	-9.9	-10.8	-25.8
OFFIC16	-0.6	-6.9	-3.2	-14.9
RETAIL1	-0.2	-10.8	-13.9	-27.3
RSTRNT1	-0.6	-11.1	-17.0	-40.1
Average	**-0.4**	**-12.7**	**-14.3**	**-27.6**

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 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.

6.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small changes (less than 1 %) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 6-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -3.6 % to -12.5 % with an average of -8.9 %. 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 -1.0 % to -16.3 % with an overall average of -11.1 %. The LEC design leads to the greatest average carbon emissions changes, ranging from -12.9 % to -37.9 % depending on the building type with an average of -24.0 % across all building types.

Table 6-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Alaska

Building Type	Energy Code			
	2001	2004	2007	LEC
APART04	-0.1	-12.2	-15.3	-25.0
APART06	-0.1	-12.5	-15.4	-24.8
DORMI04	-0.3	-12.0	-16.3	-29.3
DORMI06	-0.1	-11.4	-14.9	-23.7
HOTEL15	-0.3	-11.2	-7.7	-18.0
HIGHS02	-0.1	-3.6	-5.3	-14.0
OFFIC03	-0.5	-6.0	-9.7	-26.9
OFFIC08	-0.9	-8.2	-9.5	-24.6
OFFIC16	-0.5	-5.1	-1.0	-12.9
RETAIL1	-0.1	-7.7	-12.1	-26.8
RSTRNT1	-0.5	-7.5	-15.4	-37.9
Average	**-0.3**	**-8.9**	**-11.1**	**-24.0**

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 consumption further decreases carbon emissions because electricity has a higher carbon emissions rate per unit of energy than natural gas in Alaska.

6.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 6-5. 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 the lowest cost building design for one building type 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 -2.6 % to 2.7 % 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 -2.4 % to 1.0 %.

Table 6-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Alaska

Building Type	Energy Code			
	2001	**2004**	**2007**	**LEC**
APART04	0.1	-1.8	**-2.3**	-1.7
APART06	0.0	-1.8	**-2.2**	-1.5
DORMI04	2.2	-1.1	-1.8	**-2.4**
DORMI06	0.0	-2.2	**-2.6**	-2.2
HOTEL15	0.0	**-2.5**	-2.1	-1.8
HIGHS02	0.4	-0.4	-0.7	**-1.6**
OFFIC03	3.6	1.6	0.9	**-0.5**
OFFIC08	3.7	1.5	1.1	**-0.0**
OFFIC16	0.0	**-0.9**	-0.4	-0.2
RETAIL1	1.7	0.0	**-0.7**	-0.2
RSTRNT1	4.5	2.7	2.4	1.0
Average	**1.5**	**-0.5**	**-0.8**	**-1.0**

6.1.5 City Comparisons

Simulations are run for 6 cities located in Alaska: Anchorage, Juneau, and Kodiak in Climate Zone 7 and Barrow, Fairbanks, and Nome in Climate Zone 8. The results vary across cities within Alaska 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.

As can be seen in Table 6-6, average reduction in energy use for all building types from adopting newer energy standard editions is greater for the cities located in Zone 7. For the LEC design, Zone 7 realizes a change in average energy use of -23.1 % compared to -10.2 % for Zone 8. The extreme case is Barrow, which realizes an energy use increase of over 10 % for both *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-1999*.

Table 6-6 Average Percentage Change in Energy Use from Adoption of Newer Codes by City, Alaska

Cities	Zone	Energy Code			
		2001	2004	2007	LEC
Anchorage	7	-0.3	-3.0	-10.5	-22.0
Juneau	7	-0.2	-3.6	-11.7	-23.1
Kodiak	7	-0.3	-4.4	-12.0	-24.2
Barrow	8	-0.1	10.8	10.6	-1.6
Fairbanks	8	-0.3	-2.5	-3.1	-14.6
Nome	8	-0.2	-2.1	-2.4	-14.4
Average		**-0.2**	**-0.8**	**-4.8**	**-16.7**

The variations in energy costs across cities are a result of two factors, the reductions in energy use and the fuel source of the reduction. Table 6-7 shows that the average reduction in energy costs for all building types is lower for cities in Zone 8 relative to cities in Zone 7. For the LEC design, Zone 7 realizes an average change in energy costs of -31.9 % compared to -23.4 % for Zone 8.

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. In some cases, electricity consumption is decreased while natural gas consumption is increased. Nowhere is this more apparent than in Barrow, Alaska. Even though Barrow has an increase in total energy use of 11 %, it realizes a decrease in energy costs of over 4 % for both *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-1999*. The lower cost of natural gas use relative to electricity use is significant enough to overwhelm the increase in total energy use.

Table 6-7 Average Percentage Change in Energy Costs by City, 10-Year, Alaska

Cities	Zone	Energy Code			
		2001	2004	2007	LEC
Anchorage	7	-0.5	-15.0	-17.9	-31.4
Juneau	7	-0.4	-15.4	-18.4	-31.6
Kodiak	7	-0.4	-16.3	-18.7	-32.8
Barrow	8	-0.1	-4.4	-4.8	-17.6
Fairbanks	8	-0.6	-12.2	-12.8	-26.0
Nome	8	-0.3	-12.6	-12.9	-26.4
Average		**-0.4**	**-12.7**	**-14.3**	**-27.6**

Table 6-8 reports changes in energy-related carbon emissions by city for Alaska. For 5 of the 6 cities, the more stringent standard editions result in greater reductions in carbon emissions. As with energy use, the cities in Zone 7 realize a greater average change in emissions than the cities in Zone 8, -29.0 % versus -18.5 % for the LEC design, on average. For both Zone 7 and Zone 8, adopting *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* would decrease energy-related carbon emissions overall. Barrow realizes an increase in average carbon emissions for *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007*, which is driven by the increase in energy use.

Table 6-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Alaska

Cities	Zone	Energy Code			
		2001	2004	2007	LEC
Anchorage	7	-0.4	-10.9	-15.2	-28.2
Juneau	7	-0.3	-11.4	-16.0	-28.8
Kodiak	7	-0.4	-12.4	-16.4	-30.0
Barrow	8	-0.1	1.2	0.8	-11.7
Fairbanks	8	-0.4	-8.5	-9.2	-21.8
Nome	8	-0.3	-8.7	-9.1	-22.1
Average		**-0.3**	**-8.9**	**-11.1**	**-23.8**

The data reported in Table 6-9 show that, over a 10-year period, average life-cycle costs increase for all cities for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999*. The *ASHRAE 90.1-2007* and LEC designs result in the lowest average life-cycle costs of all building design alternative for one city and 4 cities, respectively. For the *ASHRAE 90.1-2001*, *-2004*, *-2007* and LEC designs, the cities located in Zone 7 realize smaller increases and/or greater decreases in their average percentage changes in life-cycle costs than cities in Zone 8. The adoption of any of the newer standard editions increases life-cycle costs for the city of Barrow.

Table 6-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Alaska

Cities	Zone	Energy Code			
		2001	2004	2007	LEC
Anchorage	7	1.5	-0.8	-1.3	**-1.5**
Juneau	7	1.5	-0.8	**-1.4**	-1.4
Kodiak	7	1.4	-0.9	-1.1	**-1.3**
Barrow	8	1.4	0.4	0.3	0.0
Fairbanks	8	1.5	-0.2	-0.4	**-1.0**
Nome	8	1.4	-0.5	-0.5	**-0.9**
Average		**1.5**	**-0.5**	**-0.8**	**-1.0**

6.2 Total Savings

How much can Alaska 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 first necessary to estimate savings per unit of floor area for each building type in the state.

6.2.1 Energy Use

Table 6-10 reports the average per unit change in annual energy use by building type and building design in the state.[15] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type. Table 6-11 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.[16]

Table 6-10 Average Per Unit Change in Annual Energy Use, Alaska

Building Type	Energy Code							
	2001		2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-0.1	-0.0	-1.4	-0.5	-12.6	-4.0	-31.7	-10.0
APART06	-0.2	-0.0	-1.6	-0.5	-12.0	-3.8	-29.6	-9.4
DORMI04	-0.4	-0.1	3.4	1.1	-10.6	-3.4	-36.5	-11.6
DORMI06	-0.2	-0.1	1.7	0.5	-10.9	-3.5	-27.7	-8.8
HOTEL15	-0.5	-0.2	-0.2	-0.1	12.1	3.8	-13.0	-4.1
HIGHS02	-0.1	-0.0	0.7	0.2	-10.0	-3.2	-40.2	-12.7
OFFIC03	-0.6	-0.2	1.3	0.4	-6.8	-2.1	-31.8	-10.1
OFFIC08	-1.0	-0.3	-3.0	-1.0	-6.1	-1.9	-27.5	-8.7
OFFIC16	-0.7	-0.2	0.4	0.1	13.1	4.2	-13.9	-4.4
RETAIL1	-0.2	-0.1	2.0	0.6	-12.5	-4.0	-52.7	-16.7
RSTRNT1	-0.9	-0.3	5.0	1.6	-28.4	-9.0	-88.2	-28.0

The total annual reduction in energy use ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2007*, and LEC designs all decrease overall energy use across the state. Adopting *ASHRAE 90.1-2001* results in an annual decrease of 65.0 MWh (221.9 MBtu) while adopting *ASHRAE 90.1-2007* saves 793.1 MWh (2.7 GBtu) annually. 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

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

for one year's worth of new construction for these building types. The adoption of the *ASHRAE 90.1-2004* design increases total annual energy use by 106 821 kWh (365 MBtu) even though the overall average percentage change in energy use is negative for this building design. This emphasizes the importance of estimating aggregate impacts instead of relying solely on simple average percentage changes.

Table 6-11 Statewide Change in Annual Energy Use for One Year of Construction, Alaska

Building Type	Subcat. Weight.	m^2 (1000s)	ft^2 (1000s)	Energy Code							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	1.7	18	-0	-1	-2	-8	-21	-72	-53	-182
APART06	55.1 %	2.0	22	-0	-1	-3	-11	-25	-84	-61	-208
HOTEL15	100.0 %	25.2	271	-13	-43	-5	-16	304	1038	-328	-1120
HIGHS02	100.0 %	46.2	497	-6	-20	59	203	-312	-1065	-1467	-5010
OFFIC03	37.4 %	16.9	182	-11	-36	12	42	-168	-575	-678	-2315
OFFIC08	40.4 %	18.2	196	-18	-62	-55	-187	-111	-379	-501	-1712
OFFIC16	22.2 %	10.0	108	-7	-24	4	15	131	448	-139	-476
RETAIL1	100.0 %	41.6	448	-8	-27	83	285	-519	-1771	-2194	-7491
RSTRNT1	100.0 %	2.5	27	-2	-8	13	44	-72	-247	-225	-767
Total		**164.3**	**1769**	**-65**	**-222**	**107**	**365**	**-793**	**-2708**	**-5646**	**-19 279**

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

Assuming that the buildings considered in this study, which represent 56.8 % 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 the total statewide savings from LEC adoption in new commercial buildings to be 9.9 GWh (33.9 GBtu) per year. These savings imply 99.4 GWh (339 GBtu) in energy savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 1.4 GWh (4.8 GBtu) annually or 14.0 GWh (47.7 GBtu) over the 10-year study period.

The relative reduction in energy use across the 9 building types with reported floor area data varies by building design. The greatest reductions for *ASHRAE 90.1-2004* are found in mid-sized office buildings while for the *ASHRAE 90.1-2007* and LEC designs, the greatest reductions are realized by retail stores and high schools. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in an increase in energy use for 5 and 2 building types, respectively. The *ASHRAE 90.1-2004* design increases total energy use for the low-rise and high-rise office buildings, high schools, retail stores, and restaurants relative to *ASHRAE 90.1-1999* because of the changes in building envelope requirements for cities in Zone 8 as a result of the condensing of climate zones. Interestingly, four of these building types realized small average percentage decreases in energy use (see Table 6-2), which emphasizes the importance of estimating the total energy use impacts. For the *ASHRAE 90.1-2007* design, the two high-rise buildings with 100 % window glazing realize increases in statewide energy use because of the relaxation of window U-factors and stricter window SHGC requirements for cities in Zone 8. The adoption of *ASHRAE 90.1-2007* leads to an increase in natural gas consumption that overwhelms any reduction in electricity consumption.

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 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 2nd and 10th in percentage reduction, respectively, among the 11 building types, as reported in Table 6-2.

6.2.2 Energy Costs

Table 6-12 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 6-12 Average Per Unit Change in Energy Costs, 10-Year, Alaska

Building Type	Energy Code							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	-$0.16	-$0.01	-$23.51	-$2.18	-$26.75	-$2.48	-$41.65	-$3.87
APART06	-$0.18	-$0.02	-$23.74	-$2.21	-$26.81	-$2.49	-$41.31	-$3.84
DORMI04	-$0.46	-$0.04	-$21.19	-$1.97	-$25.09	-$2.33	-$41.88	-$3.89
DORMI06	-$0.23	-$0.02	-$24.34	-$2.26	-$28.29	-$2.63	-$43.04	-$4.00
HOTEL15	-$0.57	-$0.05	-$22.32	-$2.07	-$17.41	-$1.62	-$32.41	-$3.01
HIGHS02	-$0.14	-$0.01	-$10.57	-$0.98	-$13.23	-$1.23	-$34.63	-$3.22
OFFIC03	-$0.72	-$0.07	-$9.31	-$0.87	-$12.26	-$1.14	-$32.47	-$3.02
OFFIC08	-$1.15	-$0.11	-$11.08	-$1.03	-$12.07	-$1.12	-$29.13	-$2.71
OFFIC16	-$0.80	-$0.07	-$9.78	-$0.91	-$4.16	-$0.39	-$21.37	-$1.99
RETAIL1	-$0.22	-$0.02	-$14.11	-$1.31	-$17.99	-$1.67	-$36.17	-$3.36
RSTRNT1	-$1.03	-$0.10	-$18.87	-$1.75	-$28.78	-$2.67	-$68.99	-$6.41

Table 6-13 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 ($74 323). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $2.2 million, $2.4 million, and $5.5 million respectively. All the building types that realize an increase in total energy use from the adoption of the *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* designs realize 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 56.8 % 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 *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 $130 850, $3.9 million, $4.3 million, and $9.8 million over the 10-year study period, respectively.

Table 6-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Alaska

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code			
				2001	2004	2007	LEC
APART04	44.9 %	1.7	18	-$265	-$39 458	-$44 896	-$69 920
APART06	55.1 %	2.0	22	-$365	-$48 803	-$55 121	-$84 935
HOTEL15	100 %	25.2	271	-$14 307	-$562 750	-$438 938	-$817 228
HIGHS02	100 %	46.2	497	-$6672	-$488 114	-$611 097	-$1 599 031
OFFIC03	37.4 %	16.9	182	-$12 104	-$157 269	-$207 099	-$548 262
OFFIC08	40.4 %	18.2	196	-$20 863	-$201 693	-$219 820	-$530 469
OFFIC16	22.2 %	10.0	108	-$8054	-$97 980	-$41 692	-$214 100
RETAIL1	100 %	41.6	448	-$9068	-$587 353	-$748 800	-$1 505 613
RSTRNT1	100 %	2.5	27	-$2624	-$48 044	-$73 271	-$175 609
Total		**164.3**	**1769**	**-$74 323**	**-$2 231 464**	**-$2 440 734**	**-$5 545 167**

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

6.2.3 Energy-related Carbon Emissions

Table 6-14 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 6-14 Average Per Unit Change in Carbon Emissions, 10-Year, Alaska

Building Type	Energy Code							
	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	-0.9	-0.2	-112.5	-23.0	-141.7	-29.0	-235.8	-48.3
APART06	-1.0	-0.2	-113.8	-23.3	-141.3	-28.9	-231.5	-47.4
DORMI04	-2.6	-0.5	-95.6	-19.6	-131.4	-26.9	-242.9	-49.7
DORMI06	-1.3	-0.3	-112.6	-23.1	-146.8	-30.1	-237.3	-48.6
HOTEL15	-3.3	-0.7	-105.3	-21.6	-66.9	-13.7	-168.9	-34.6
HIGHS02	-0.8	-0.2	-48.2	-9.9	-70.8	-14.5	-202.9	-41.5
OFFIC03	-4.2	-0.9	-43.0	-8.8	-70.2	-14.4	-203.1	-41.6
OFFIC08	-6.6	-1.4	-55.9	-11.5	-64.5	-13.2	-171.6	-35.2
OFFIC16	-4.7	-1.0	-45.5	-9.3	-3.2	-0.7	-118.0	-24.2
RETAIL1	-1.3	-0.3	-64.0	-13.1	-100.3	-20.5	-236.3	-48.4
RSTRNT1	-6.0	-1.2	-82.6	-16.9	-171.1	-35.0	-435.3	-89.1

Table 6-15 applies the Table 6-14 results to one year's worth of new building construction in the state to estimate 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 10 375 metric tons and 12 486 metric tons over a 10-year study period, respectively. All building types that realized 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 the reduction in electricity consumption. The adoption of LEC as the state's energy code decreases carbon emissions by 33 177 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 18 265 tons, 21 983 tons, and 58 411 tons over the 10-year study period, respectively.

Table 6-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Alaska – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code			
				2001	2004	2007	LEC
APART04	44.9 %	1.7	18	-2	-189	-238	-396
APART06	55.1 %	2.0	22	-2	-234	-291	-476
HOTEL15	100.0 %	25.2	271	-83	-2656	-1687	-4259
HIGHS02	100.0 %	46.2	497	-39	-2224	-3268	-9366
OFFIC03	37.4 %	16.9	182	-70	-725	-1186	-3430
OFFIC08	40.4 %	18.2	196	-121	-1018	-1174	-3125
OFFIC16	22.2 %	10.0	108	-47	-456	-32	-1183
RETAIL1	100.0 %	41.6	448	-53	-2662	-4175	-9835
RSTRNT1	100.0 %	2.5	27	-15	-210	-436	-1108
Total		**164.3**	**1769**	**-431**	**-10 375**	**-12 486**	**-33 177**

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

6.2.4 Life-Cycle Costs

Table 6-16 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 6-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Alaska

Building Type	Energy Code							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	$1.00	$0.09	-$22.37	-$2.08	-$28.29	-$2.63	-$21.31	-$1.98
APART06	$0.50	$0.05	-$22.72	-$2.11	-$27.73	-$2.58	-$18.79	-$1.75
DORMI04	$25.64	$2.38	-$12.22	-$1.14	-$20.47	-$1.90	-$27.80	-$2.58
DORMI06	$0.23	$0.02	-$29.21	-$2.71	-$34.13	-$3.17	-$28.95	-$2.69
HOTEL15	-$0.24	-$0.02	-$31.41	-$2.92	-$26.03	-$2.42	-$22.59	-$2.10
HIGHS02	$4.92	$0.46	-$4.31	-$0.40	-$7.27	-$0.68	-$18.12	-$1.68
OFFIC03	$35.01	$3.25	$15.85	$1.47	$8.74	$0.81	-$4.79	-$0.44
OFFIC08	$37.12	$3.45	$15.27	$1.42	$10.66	$0.99	-$0.44	-$0.04
OFFIC16	-$0.13	-$0.01	-$9.25	-$0.86	-$4.13	-$0.38	-$1.42	-$0.13
RETAIL1	$13.89	$1.29	-$0.24	-$0.02	-$5.29	-$0.49	-$1.58	-$0.15
RSTRNT1	$68.46	$6.36	$40.66	$3.78	$35.97	$3.34	$15.27	$1.42

Table 6-17 applies the Table 6-16 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 6 of 9 building types, with total life-cycle costs decreasing by $463 949 and $815 858, respectively. The LEC design decreases life-cycle costs for 8 of 9 building types, and decreases total life-cycle costs by $1.3 million. The building types that realize a decrease in life-cycle costs far outweigh in terms of construction volume the building types that realize increases in life-cycle costs for the LEC design. For a 10-year study period, it is cost-effective to adopt newer editions of the *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 $3.8 million, -$816 812, -$1.4 million, and -$2.4 million over the 10-year study period, respectively.

Table 6-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Alaska

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code			
				2001	2004	2007	LEC
APART04	44.9 %	1.7	18	$1679	-$37 552	-$47 483	-$35 770
APART06	55.1 %	2.0	22	$1030	-$46 717	-$57 020	-$38 625
HOTEL15	100.0 %	25.2	271	-$5984	-$792 009	-$656 255	-$569 600
HIGHS02	100.0 %	46.2	497	$153 108	-$134 211	-$226 537	-$564 232
OFFIC03	37.4 %	16.9	182	$591 248	$267 717	$147 535	-$80 821
OFFIC08	40.4 %	18.2	196	$675 971	$278 128	$194 045	-$8033
OFFIC16	22.2 %	10.0	108	-$1324	-$92 661	-$41 419	-$14 218
RETAIL1	100.0 %	41.6	448	$578 191	-$10 138	-$220 286	-$65 841
RSTRNT1	100.0 %	2.5	27	$174 273	$103 494	$91 562	$38 862
Total		**164.3**	**1769**	**$2 168 193**	**-$463 949**	**-$815 858**	**-$1 338 279**

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

6.3 State Summary

Alaska is one of the states that has no state energy code for commercial buildings, and represents the coldest climates in the United States. 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 savings of 14.0 GWh (47.7 GBtu), energy cost savings of $4.3 million, and 21 983 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 90.1-2004* or *ASHRAE 90.1-2007* design increases energy use for some location-building type combinations in Alaska. *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 8. Additionally, *ASHRAE 90.1-2007* restricts the window SHGC below that required in *ASHRAE 90.1-2004* for Alaska's climate zones, leading to losses in beneficial heat gain through fenestration.

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 be even more beneficial for the state than adopting *ASHRAE 90.1-2007*, with savings of 99.4 GWh (339.4 GBtu), $9.8 million of energy costs, 58 411 metric tons of carbon emissions, and $2.4 million of life-cycle costs for one year's worth of commercial building construction.

7 Colorado

Colorado was selected for this study for four reasons. First, Colorado is one of the three states with a current state energy code based on *ASHRAE 90.1-2001* requirements. Second, the state is comparable in new construction volume to several other states selected for this study, which allows for comparisons across states. Third, the state represents the Rocky Mountain region of the U.S. and a variety of climate zones. Finally, Colorado has as least one jurisdiction that has adopted an energy standard edition that is more stringent than has been adopted by the state.

Table 7-1 provides an overview of Colorado'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 80 kWh/m^2 to 113 kWh/m^2 (25 kBtu/ft^2 to 36 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 203 kWh/m^2 to 228 kWh/m^2 (65 kBtu/ft^2 to 72 kBtu/ ft^2) annually.

Table 7-1 Average Annual Energy Use by Building Type and Energy Code, Colorado

Building Type	Energy Code							
	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	163	52	145	46	139	44	124	39
APART06	160	51	141	45	136	43	121	38
DORMI04	128	41	114	36	108	34	93	30
DORMI06	175	56	156	50	153	49	136	43
HOTEL15	158	50	142	45	149	47	130	41
HIGHS02	228	72	224	71	216	69	203	65
OFFIC03	120	38	112	35	105	33	84	27
OFFIC08	113	36	103	33	99	31	80	25
OFFIC16	149	47	139	44	148	47	124	39
RETAIL1	145	46	134	42	119	38	102	32
RSTRNT1	201	64	185	59	161	51	118	37

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.

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 more energy efficient designs for the state of Colorado.

7.1.1 Energy Use

Table 7-2 shows that the average percentage changes in energy use from adopting the *ASHRAE 90.1-2004* design relative to *ASHRAE 90.1-2001* range from -1.4 % to -9.1 % depending on the building type, with an overall average of -6.9 %. The average percentage change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from 0.3 % to -18.6 %, with an overall average of -10.4 %.

Table 7-2 Average Percentage Change in Energy Use from Adoption of Newer Codes, Colorado

Building Type	Energy Code		
	2004	2007	LEC
APART04	-8.8	-12.7	-21.9
APART06	-9.1	-12.4	-22.5
DORMI04	-8.3	-13.4	-24.9
DORMI06	-9.0	-10.6	-20.7
HOTEL15	-8.3	-3.4	-16.0
HIGHS02	-1.4	-5.0	-10.6
OFFIC03	-5.6	-11.3	-29.3
OFFIC08	-7.5	-10.7	-28.3
OFFIC16	-5.3	0.3	-15.7
RETAIL1	-6.5	-17.1	-28.4
RSTRNT1	-6.4	-18.6	-40.2
Average	**-6.9**	**-10.4**	**-23.5**

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 allowable window SHGC in Zone 5 and Zone 6 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007* for buildings with fenestration accounting for greater than 40 % of total wall surface area. 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 percentage change in energy use relative to *ASHRAE 90.1-2001*, with a range of -10.6 % to -40.2 % and an overall average of -23.5 %. Similar to the *ASHRAE 90.1-2007* design, smaller reductions in energy use for the LEC design occur in the buildings with the greatest window-to-wall ratios. The smallest percentage reduction is realized by the high school because of its occupancy pattern. Schools are used primarily during the school year with minimal use during the summer. Since some of the additional energy efficiency measures (daylighting and overhangs) adopted in the LEC design reduce solar heat gains, cooling loads are decreased while heating loads are increased. The increase in heating loads is greater than the reduction in cooling loads because the building has a low occupancy during the warmest months of the year and the Colorado climate requires significant heating during the coldest months.

7.1.2 Energy Costs

Table 7-3 shows a significant variation in the average change in energy costs over 10 years of operation from adopting the *ASHRAE 90.1-2004* design relative to *ASHRAE 90.1-2001*, ranging from -6.3 % to -19.8 % depending on the building type, with an overall average of -14.1 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -2.4 % to -22.0 %, with an overall average of -15.2 %. As with energy use savings, adopting *ASHRAE 90.1-2004* results in greater reductions in energy costs than adopting *ASHRAE 90.1-2007* for the two high rise buildings (16-story office building and 15-story hotel) because of the 100 % glazing in the buildings and the relaxed window SHGC requirements.

Table 7-3 Average Percentage Change in Energy Costs, 10-Year, Colorado

Building Type	Energy Code		
	2004	2007	LEC
APART04	-19.6	-22.0	-36.2
APART06	-19.8	-21.7	-37.7
DORMI04	-19.5	-21.8	-36.6
DORMI06	-19.7	-20.6	-36.0
HOTEL15	-18.4	-12.8	-28.8
HIGHS02	-6.3	-8.8	-23.1
OFFIC03	-8.8	-10.9	-32.1
OFFIC08	-9.7	-10.6	-29.7
OFFIC16	-9.1	-2.4	-21.2
RETAIL1	-11.7	-17.3	-32.0
RSTRNT1	-12.5	-18.8	-46.3
Average	**-14.1**	**-15.2**	**-32.7**

The LEC design realizes the greatest percentage changes in energy costs, with the average reduction by building type ranging from -23.1 % to -46.3 % and an overall average of -32.7 %. The reductions in energy costs are greater than the reductions in energy use because the adopted energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity consumption further decreases energy costs because natural gas is cheaper per unit of energy than electricity in Colorado.

7.1.3 Energy-related Carbon Emissions

Table 7-4 shows significant changes in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -7.0 % to -21.1 % with an overall average of -15.0 %. The average change in carbon emissions from constructing buildings using *ASHRAE 90.1-2007* requirements is -15.8 % overall with the average change in carbon emissions varying across building types from -2.7 % to -23.1 %. The LEC design leads to the greatest average percentage changes in carbon emissions, ranging from -21.7 % to -47.0 % depending on the building type with an overall average of -33.8 % across all building types.

Table 7-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Colorado

Building Type	Energy Code		
	2004	2007	LEC
APART04	-21.0	-23.1	-37.9
APART06	-21.1	-22.8	-39.5
DORMI04	-20.8	-22.8	-37.9
DORMI06	-21.0	-21.8	-37.9
HOTEL15	-19.6	-13.9	-30.3
HIGHS02	-7.0	-9.3	-25.0
OFFIC03	-9.2	-10.9	-32.4
OFFIC08	-9.9	-10.6	-29.9
OFFIC16	-9.5	-2.7	-21.7
RETAIL1	-12.3	-17.3	-32.4
RSTRNT1	-13.2	-18.8	-47.0
Average	**-15.0**	**-15.8**	**-33.8**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. However, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Since electricity production in Colorado generates greater emissions per unit of energy consumed than natural gas, the greater relative reduction in electricity leads to a greater reduction in carbon emissions.

7.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 7-5. The *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs realize the lowest life-cycle costs for one, five, and five building types, respectively. Both *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* realize lower life-cycle costs than *ASHRAE 90.1-2001* for all 11 building types. The LEC design results in significant reductions in life-cycle costs for 10 of 11 building types. The change in life-cycle costs for the LEC design ranges from -7.4 % to 0.1 %. Based on the overall average change of -2.8 % in life-cycle costs, the LEC design is likely to be cost-effective for the state to adopt as its state energy code for commercial buildings.

Table 7-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Colorado

Building Type	Energy Code		
	2004	2007	LEC
APART04	-1.6	**-1.9**	-1.2
APART06	-1.5	**-1.8**	-1.2
DORMI04	-2.4	-2.9	**-4.2**
DORMI06	-2.0	**-2.1**	-1.8
HOTEL15	**-2.1**	-1.6	-1.1
HIGHS02	-0.8	-1.1	**-1.9**
OFFIC03	-2.3	-2.6	**-5.5**
OFFIC08	-2.3	-2.6	**-5.1**
OFFIC16	-1.0	**-0.3**	0.1
RETAIL1	-2.1	**-2.9**	-2.0
RSTRNT1	-2.5	-4.5	**-7.4**
Average	**-1.9**	**-2.2**	**-2.8**

7.1.5 City Comparisons

Simulations are run for 6 cities located in Colorado: Boulder, Colorado Springs, Grand Junction, and Pueblo in Climate Zone 5 and Alamosa and Eagle in Climate Zone 6. The results vary across cities within the state for several reasons. There are no significant population centers in Zone 4 or Zone 7 in the state of Colorado. First, the cities selected for the state cover 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. Finally, Grand Junction has adopted a stricter building energy code than has the state.

As can be seen in Table 7-6, the average percentage reduction in energy use for all building types from adopting newer energy standard editions is generally greater for the cities located in Zone 5. For the LEC design, Zone 5 excluding Grand Junction realizes an average change in energy use of -25.8 % compared to -22.5 % for Zone 6. Grand Junction realizes much lower reductions in energy use for the *ASHRAE 90.1-2007* and LEC designs because it has already adopted *ASHRAE 90.1-2004* as its jurisdictional energy code.

Table 7-6 Average Percentage Change in Energy Use from Adoption of Newer Codes by City, Colorado

Cities	Zone	Energy Code		
		2004	2007	LEC
Boulder	5B	-9.4	-12.5	-25.5
Colorado Springs	5B	-9.2	-12.4	-24.9
Grand Junction	5B	0.0	-3.2	-17.9
Pueblo	5B	-10.5	-13.2	-27.3
Alamosa	6B	-6.6	-11.0	-23.1
Eagle	6B	-5.9	-10.3	-22.2
Average		**-6.9**	**-10.4**	**-23.5**

The variations in energy cost changes across cities are a result of two factors, the size of the reductions in energy use and the fuel source of the reduction. Table 7-7 shows that the average reduction in energy costs for all building types is similar across both Zone 5 and Zone 6 for both *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* when Grand Junction is excluded from the analysis. The LEC design realizes nearly twice the percentage reduction in energy costs than *ASHRAE 90.1-2007*, with Zone 5 cities excluding Grand Junction realizing an average change in energy costs of -35.7 % compared to -33.2 % for Zone 6. The reductions in energy costs are significantly greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Since Grand Junction has already adopted *ASHRAE 90.1-2004*, it realizes much smaller changes in energy costs for the *ASHRAE 90.1-2007* and LEC designs.

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

Cities	Zone	Energy Code		
		2004	2007	LEC
Boulder	5B	-16.8	-17.6	-35.6
Colorado Springs	5B	-16.9	-17.8	-35.4
Grand Junction	5B	0.0	-1.1	-22.6
Pueblo	5B	-16.9	-17.7	-36.1
Alamosa	6B	-17.3	-18.9	-33.5
Eagle	6B	-16.7	-18.3	-32.9
Average		**-14.1**	**-15.2**	**-32.7**

Table 7-8 reports changes in energy-related carbon emissions by city for the state. For all cities, the more energy efficient building designs result in greater reductions in carbon emissions. As with energy use, the cities in Zone 6 realize slightly lower average emission reductions than the cities in Zone 5 (excluding Grand Junction) for all building designs. For both climate zones, adopting the *ASHRAE 90.1-2007* and *ASHRAE 90.1-2004* designs would decrease energy-related carbon emissions on average. The LEC design realizes the greatest percentage reductions in carbon emissions, with the average percentage reduction ranging from -23.8 % to -37.1 % depending on the location.

Table 7-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Colorado

Cities	Zone	Energy Code		
		2004	2007	LEC
Boulder	5B	-17.0	-18.0	-36.7
Colorado Springs	5B	-17.1	-18.1	-36.6
Grand Junction	5B	0.0	-1.3	-23.8
Pueblo	5B	-16.9	-17.9	-37.1
Alamosa	6B	-17.9	-19.5	-34.7
Eagle	6B	-17.3	-19.0	-34.2
Average		**-15.0**	**-15.8**	**-33.8**

The data reported in Table 7-9 show that, over a 10-year period, the LEC design results in the lowest average life-cycle costs for all cities in both Zone 5 and Zone 6. Reductions in life-cycle costs are similar across all cities in the state except for Grand Junction, which realizes much smaller cost reductions because the city has adopted *ASHRAE 90.1-2004*. Life-cycle costs are reduced by adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2001* for all cities, on average.

Table 7-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Colorado

Cities	Zone	Energy Code		
		2004	2007	LEC
Boulder	5B	-2.1	-2.4	**-2.9**
Colorado Springs	5B	-2.1	-2.4	**-2.9**
Grand Junction	5B	0.0	-0.4	**-1.7**
Pueblo	5B	-2.2	-2.6	**-3.6**
Alamosa	6B	-2.5	-2.8	**-3.1**
Eagle	6B	-2.4	-2.7	**-2.9**
Average		**-1.9**	**-2.2**	**-2.8**

7.2 Total Savings

How much can Colorado 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 first necessary to estimate savings per unit of floor area for each building type in the state.

7.2.1 Energy Use

Table 7-10 reports the average per unit change in annual energy use by building type and building design in the state.[17] The reduction per m^2 (ft^2) is multiplied by the estimated annual m^2 (ft^2) of new construction of each building type. Table 7-11 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.[18]

Table 7-10 Average Per Unit Change in Annual Energy Use, Colorado

Building Type	Energy Code					
	2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-14.1	-4.5	-20.4	-6.5	-35.0	-11.1
APART06	-14.3	-4.5	-19.5	-6.2	-35.1	-11.1
DORMI04	-10.4	-3.3	-16.7	-5.3	-31.1	-9.9
DORMI06	-15.7	-5.0	-18.5	-5.9	-35.6	-11.3
HOTEL15	-13.0	-4.1	-5.5	-1.7	-24.8	-7.9
HIGHS02	-6.7	-2.1	-13.4	-4.3	-34.7	-11.0
OFFIC03	-3.0	-1.0	-11.1	-3.5	-23.8	-7.5
OFFIC08	-8.4	-2.7	-12.0	-3.8	-31.5	-10.0
OFFIC16	-7.8	-2.5	0.4	0.1	-23.1	-7.3
RETAIL1	-9.4	-3.0	-24.6	-7.8	-40.8	-13.0
RSTRNT1	-12.7	-4.0	-37.1	-11.8	-79.7	-25.3

The total annual reduction in energy use ranges widely across building designs, but the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs all decrease overall energy use across the state. Adopting *ASHRAE 90.1-2004* results in annual reductions of 18.7 GWh (63.7 GBtu) while adopting *ASHRAE 90.1-2007* saves 32.8 GWh (112.0 GBtu) annually. The adoption of the LEC design as the state's energy code would save energy for all building types and 67.2 GWh (229.5 GBtu) of total energy use annually for one year's worth of new construction for these building types.

[17] 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.
[18] State-level subcategory data are not available.

Table 7-11 Statewide Change in Annual Energy Use for One Year of Construction, Colorado

Building Type	Subcat. Weight.	m^2 (1000s)	ft^2 (1000s)	Energy Code					
				2004		2007		LEC	
				kWh	kBtu	kWh	kBtu	kWh	kBtu
APART04	44.9 %	183	1967	-2 581 945	-8 815 869	-3 724 753	-12 717 908	-6 401 934	-21 858 955
APART06	55.1 %	224	2410	-3 204 843	-10 942 711	-4 358 644	-14 882 284	-7 860 201	-26 838 104
HOTEL15	100.0 %	199	2147	-2 601 371	-8 882 201	-1 096 565	-3 744 144	-4 942 031	-16 874 218
HIGHS02	100.0 %	331	3561	-996 825	-3 403 588	-3 663 683	-12 509 390	-7 870 278	-26 872 513
OFFIC03	37.4 %	162	1739	-1 082 947	-3 697 645	-2 169 553	-7 407 787	-5 608 663	-19 150 389
OFFIC08	40.4 %	174	1875	-1 465 291	-5 003 132	-2 089 987	-7 136 114	-5 491 202	-18 749 324
OFFIC16	22.2 %	96	1032	-747 292	-2 551 575	40 723	139 045	-2 210 409	-7 547 288
RETAIL1	100.0 %	579	6235	-5 465 300	-18 660 885	-14 251 754	-48 661 618	-23 662 413	-80 793 652
RSTRNT1	100.0 %	40	428	-506 957	-1 730 969	-1 477 307	-5 044 160	-3 172 792	-10 833 277
Total		**1988**	**21 394**	**-18 652 769**	**-63 688 575**	**-32 791 523**	**-111 964 360**	**-67 219 923**	**-229 517 720**

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

Assuming that the buildings considered in this study, which represent 60.4 % 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 statewide energy use savings to be 111.3 GWh (380.0 GBtu) annually. Annual savings of 111.3 GWh (380.0 GBtu) implies 1113 GWh (3800.0 GBtu) in energy savings over the 10-year study period. In comparison, *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* would save 30.9 GWh and 54.3 GWh annually, or 308.8 GWh and 542.9 GWh over the 10-year study period, respectively.

The statewide change in energy use varies across the 9 building types with reported floor area data within a building design. Building types that represent a greater amount of new floor area realize the largest total 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, high schools, and high-rise apartment buildings -- rank 3rd, 11th , and 6th in percentage reduction, respectively, among the 11 building types, as reported in Table 7-2. The two high-rise buildings with 100 % window glazing realize the smallest statewide reductions in energy use for *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* due to the consolidation of climate zones from *ASHRAE 90.1-2001* to *ASHRAE 90.1-2004*, which relaxes the window U-factor requirements. *ASHRAE 90.1-2007* results in a small increase in energy use for 16-story office buildings due to relaxation of the window SHGC requirements relative to *ASHRAE 90.1-2004*.

7.2.2 Energy Costs

Table 7-12 reports the average per unit change in energy costs by building type and building design. Energy costs are calculated using the annual energy use, energy cost rates, and energy price escalation rates as defined in Section 3.2.

Table 7-12 Average Per Unit Change in Energy Costs, 10-Year, Colorado

Building Type	Energy Code					
	2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$15.02	-$1.40	-$16.75	-$1.56	-$27.18	-$2.53
APART06	-$15.15	-$1.41	-$16.53	-$1.54	-$28.24	-$2.62
DORMI04	-$12.36	-$1.15	-$13.75	-$1.28	-$22.76	-$2.11
DORMI06	-$16.54	-$1.54	-$17.28	-$1.60	-$29.72	-$2.76
HOTEL15	-$14.23	-$1.32	-$10.09	-$0.94	-$21.82	-$2.03
HIGHS02	-$5.75	-$0.53	-$7.96	-$0.74	-$20.85	-$1.94
OFFIC03	-$5.87	-$0.55	-$7.24	-$0.67	-$21.21	-$1.97
OFFIC08	-$6.45	-$0.60	-$7.04	-$0.65	-$19.61	-$1.82
OFFIC16	-$7.44	-$0.69	-$2.04	-$0.19	-$17.02	-$1.58
RETAIL1	-$8.50	-$0.79	-$12.52	-$1.16	-$23.00	-$2.14
RSTRNT1	-$12.57	-$1.17	-$18.75	-$1.74	-$45.76	-$4.25

Table 7-13 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: $18.5 million, $21.1 million, and $43.9 million for adopting *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC, respectively. All building types realize energy cost savings for all three of these building designs.

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 the total statewide energy cost savings of $30.6 million, $35.0 million, and $72.7 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code		
				2004	2007	LEC
APART04	44.9 %	183	1967	-$2 744 758	-$3 060 808	-$4 967 750
APART06	55.1 %	224	2410	-$3 391 792	-$3 700 430	-$6 321 780
HOTEL15	100.0 %	199	2147	-$2 839 304	-$2 012 375	-$4 352 321
HIGHS02	100.0 %	331	2403	-$1 284 340	-$1 776 264	-$4 653 715
OFFIC03	37.4 %	162	1739	-$948 189	-$1 169 098	-$3 426 305
OFFIC08	40.4 %	174	1875	-$1 122 606	-$1 226 719	-$3 415 693
OFFIC16	22.2 %	96	1032	-$712 783	-$195 861	-$1 630 928
RETAIL1	100.0 %	579	6235	-$4 921 446	-$7 250 291	-$13 324 499
RSTRNT1	100.0 %	40	428	-$500 117	-$746 212	-$1 821 095
Total		**1988**	**20 235**	**-$18 465 334**	**-$21 138 058**	**-$43 914 086**

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

7.2.3 Energy-related Carbon Emissions

Table 7-14 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 7-14 Average Per Unit Change in Carbon Emissions, 10-Year, Colorado

Building Type	Energy Code					
	2004		2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-239.5	-49.1	-263.1	-53.9	-425.3	-87.1
APART06	-241.6	-49.5	-260.3	-53.3	-443.0	-90.7
DORMI04	-198.3	-40.6	-216.0	-44.2	-354.7	-72.6
DORMI06	-263.8	-54.0	-273.6	-56.0	-467.4	-95.7
HOTEL15	-227.3	-46.6	-164.4	-33.7	-344.3	-70.5
HIGHS02	-93.8	-19.2	-123.8	-25.4	-328.9	-67.4
OFFIC03	-92.6	-19.0	-109.7	-22.5	-325.6	-66.7
OFFIC08	-100.8	-20.6	-107.7	-22.1	-301.5	-61.7
OFFIC16	-117.9	-24.2	-34.6	-7.1	-265.3	-54.3
RETAIL1	-134.3	-27.5	-188.5	-38.6	-350.3	-71.7
RSTRNT1	-199.6	-40.9	-282.2	-57.8	-698.1	-143.0

Table 7-15 applies the Table 7-14 results to one year's worth of new building construction in the state to estimate 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 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs all decrease carbon emissions. The adoption of *ASHRAE 90.1-2004* results in savings of 293 683 metric tons while adopting *ASHRAE 90.1-2007* saves 327 025 metric tons over a 10-year study period. The adoption of the LEC design as the state's energy code decreases carbon emissions by 680 244 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 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 486 230 tons, 541 432 tons, and 1.1 million tons over the 10-year study period, respectively.

Table 7-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Colorado – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code		
				2004	2007	LEC
APART04	44.9 %	183	1967	-43 777	-48 088	-77 740
APART06	55.1 %	224	2410	-54 085	-58 262	-99 177
HOTEL15	100.0 %	199	2147	-45 345	-32 784	-68 685
HIGHS02	100.0 %	331	2403	-20 947	-27 639	-73 418
OFFIC03	37.4 %	162	1739	-14 958	-17 723	-52 588
OFFIC08	40.4 %	174	1875	-17 552	-18 757	-52 512
OFFIC16	22.2 %	96	1032	-11 302	-3 318	-25 429
RETAIL1	100.0 %	579	6235	-77 772	-109 222	-202 911
RSTRNT1	100.0 %	40	428	-7 945	-11 232	-27 785
Total		**1988**	**20 235**	**-293 683**	**-327 025**	**-680 244**

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

7.2.4 Life-Cycle Costs

Table 7-16 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 7-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Colorado

Building Type	Energy Code					
	2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$15.22	-$1.41	-$18.23	-$1.69	-$12.01	-$1.12
APART06	-$15.11	-$1.40	-$17.33	-$1.61	-$11.56	-$1.07
DORMI04	-$22.39	-$2.08	-$26.87	-$2.50	-$39.72	-$3.69
DORMI06	-$19.81	-$1.84	-$20.91	-$1.94	-$18.12	-$1.68
HOTEL15	-$20.06	-$1.86	-$15.60	-$1.45	-$10.73	-$1.00
HIGHS02	-$6.15	-$0.57	-$8.93	-$0.83	-$15.15	-$1.41
OFFIC03	-$18.67	-$1.73	-$20.70	-$1.92	-$44.11	-$4.10
OFFIC08	-$19.31	-$1.79	-$21.44	-$1.99	-$42.52	-$3.95
OFFIC16	-$7.59	-$0.70	-$2.43	-$0.23	$1.10	$0.10
RETAIL1	-$13.66	-$1.27	-$18.25	-$1.70	-$12.78	-$1.19
RSTRNT1	-$32.22	-$2.99	-$59.08	-$5.49	-$98.13	-$9.12

Table 7-17 applies the Table 7-16 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 codes. Total reductions in life-cycle costs over the 10-year study period vary across building designs. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in a decrease in life-cycle costs for all 9 building types while the LEC design decreases life-cycle costs for 8 of 9 building types. The 16-story office building realizes the smallest total reductions in life-cycle costs for all three alternative building designs and, for the LEC design, realizes increases in life-cycle costs. *ASHRAE 90.1-2007* results in greater total reductions in life-cycle costs than *ASHRAE 90.1-2004* for the building types considered in this study ($32.5 million versus $27.8 million). The LEC design leads to the greatest total reductions in life-cycle costs of $36.0 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 *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide changes in life-cycle costs of $46.1 million, $53.9 million, and $59.7 million over the 10-year study period, respectively.

Table 7-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Colorado

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code		
				2004	2007	LEC
APART04	44.9 %	183	1967	-$2 780 914	-$3 331 475	-$2 195 187
APART06	55.1 %	224	2410	-$3 381 651	-$3 878 490	-$2 586 926
HOTEL15	100.0 %	199	2147	-$4 001 180	-$3 112 617	-$2 139 459
HIGHS02	100.0 %	331	2403	-$1 373 361	-$1 992 603	-$3 382 270
OFFIC03	37.4 %	162	1739	-$3 015 796	-$3 342 811	-$7 123 855
OFFIC08	40.4 %	174	1875	-$3 363 646	-$3 733 863	-$7 405 617
OFFIC16	22.2 %	96	1032	-$727 029	-$232 930	$105 555
RETAIL1	100.0 %	579	6235	-$7 915 065	-$10 570 652	-$7 401 280
RSTRNT1	100.0 %	40	428	-$1 282 163	-$2 351 325	-$3 905 355
Total		**1988**	**20 235**	**-$27 840 805**	**-$32 546 766**	**-$36 034 394**
Note: Dormitories are excluded because no floor area category is reported in the construction data.						

7.3 State Summary

Colorado is one of the few states that has adopted *ASHRAE 90.1-2001* as its state energy code for commercial buildings, and represents the Rocky Mountain region of the United States. On average, adopting a newer edition of *ASHRAE 90.1* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions. However, adopting *ASHRAE 90.1-2007* increases energy use for some location-building type combinations, particularly for 16-story office buildings. *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 some locations. Additionally, *ASHRAE 90.1-2007* further relaxes the window SHGC requirements for some locations.

Colorado is one of the few states that have at least one city that has adopted a more stringent energy standard edition than the state. Grand Junction has adopted *ASHRAE 90.1-2004*, which tempers the reductions in energy use, energy costs, and energy-related carbon emissions from the adoption of either the *ASHRAE 90.1-2007* or LEC designs.

Despite these factors, the adoption of more efficient building design requirements leads to savings in energy use and 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 543 GWh, energy cost savings of $35.0 million, life-cycle cost savings of $53.9 million, and 541 432 metric tons of carbon emissions reductions for one year's worth of commercial building construction. Adopting the LEC design would be even more beneficial for the state with savings of 1112.9 GWh (3800.0 GBtu),

$72.7 million in energy costs, 1.1 million metric tons of carbon emissions, and life-cycle cost savings of $59.7 million.

8 Florida

Florida was selected for this study for three reasons. First, the state represents the warmest and most humid climate zones in the United States. Second, the state had more new building construction than any other state from 2003 to 2007. Third, the state represents the southern area of the United States. Florida is one of four states in this study that have adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings.

Table 8-1 provides an overview of Florida's simulated energy use keyed to building type and energy standard edition. Average energy use varies across building types and building designs. The 4-story dormitory uses the least amount of energy at 79 kWh/m^2 to 95 kWh/m^2 (25 kBtu/ft^2 to 30 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy at 108 kWh/m^2 to 155 kWh/m^2 (34 kBtu/ft^2 to 49 kBtu/ft^2) annually.

Table 8-1 Average Annual Energy Use by Building Type and Energy Code, Florida

Building Type	Energy Code			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	129	41	108	34
APART06	130	41	107	34
DORMI04	95	30	79	25
DORMI06	139	44	114	36
HOTEL15	109	35	91	29
HIGHS02	126	40	99	31
OFFIC03	113	36	86	27
OFFIC08	109	35	87	28
OFFIC16	127	40	105	33
RETAIL1	114	36	93	29
RSTRNT1	155	49	108	34

The detailed analysis for this state reports changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design beyond the current state energy code. 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 for the state of Florida.

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*. The LEC design realizes changes in energy use ranging from -16.6 % to -30.5 %, with an average of -19.8 %. The lowest reduction in energy use for the LEC design occurs in the 4-story apartment building and hotel while the greatest reduction in energy use occurs in restaurants.

Table 8-2 Average Percentage Change from Adoption of a Newer Code, 10-Year, Florida

Building Type	LEC			
	Energy Use	Energy Costs	Carbon	LCC
APART04	-16.6	-17.7	-17.8	-0.3
APART06	-17.5	-18.9	-19.0	-0.4
DORMI04	-17.4	-18.4	-18.5	-2.1
DORMI06	-18.4	-20.0	-20.1	-0.9
HOTEL15	-16.7	-18.8	-19.0	-0.1
HIGHS02	-21.2	-23.4	-23.7	-1.9
OFFIC03	-24.0	-24.3	-24.3	-2.3
OFFIC08	-20.1	-20.2	-20.2	-2.6
OFFIC16	-17.6	-18.5	-18.5	-0.2
RETAIL1	-17.9	-18.2	-18.2	-0.7
RSTRNT1	-30.5	-31.5	-31.6	-5.3
Average	**-19.8**	**-20.9**	**-21.0**	**-1.5**

The LEC design realizes average changes in energy costs over 10 years of building operation ranging from -17.7 % to -31.5 % depending on the building type, with an average of -20.9 % overall. The 4-story apartment building realizes the smallest average percentage reductions in energy costs while the restaurant realizes the greatest average reductions in energy use. The reductions in energy costs are nearly identical to the reductions in energy use because electricity accounts for 95 % of total energy use for the *ASHRAE 90.1-2007* design. Therefore, any change in energy costs is driven by the change in use of a single fuel type, electricity.

The LEC design leads to average percentage changes in energy-related carbon emissions ranging from -17.8 % to -31.6 %, depending on the building type, with an average of -21.0 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage reduction in carbon emissions is nearly identical to the percentage reduction in energy use because electricity consumption accounts for 95 % of total energy use for the *ASHRAE 90.1-2007* design, which minimizes any impacts from shifting of energy use between electricity and natural gas consumption.

The LEC design results in average reductions in life-cycle costs for a 10-year study period for all 11 building types. The average percentage change in life-cycle costs for the LEC design ranges from -0.1 % to -5.3 %. The restaurant and 3- and 8-story office buildings realize the greatest average percentage reduction in life-cycle costs while the hotel and 16-story office building realize the smallest average percentage reduction in life-cycle costs. The LEC design is cost-effective for the state to adopt as its state energy code for commercial buildings.

8.1.2 City Comparisons

Simulations are run for 7 cities located in Florida: Key West and Miami in Climate Zone 1, and Daytona Beach, Jacksonville, Tallahassee, Tampa, and West Palm Beach in Zone 2A. The results 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 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 8-3, the average reduction in energy use for all building types from adopting the LEC design is slightly greater for the cities located in Zone 1 than in Zone 2. For the LEC design, Zone 1 realizes an average change in energy use of -22.0 % compared to -21.1 % for Zone 2. The average percentage change in energy use varies minimally within Zone 2, -20.9 % to -21.2 %, because of climate variation within the subzone. The cities located furthest north in the state, Jacksonville and Tallahassee, realize the smallest reductions in energy use.

Table 8-3 Average Percentage Change in Energy Use from Adoption of Newer Codes by City, 10-Year, Florida

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Key West	1	-21.3	-21.3	-22.1	-2.1
Miami	1	-21.2	-21.3	-22.0	-1.9
Daytona Beach	2A	-20.3	-21.4	-21.9	-1.4
Jacksonville	2A	-18.1	-20.4	-21.0	-1.1
Tallahassee	2A	-17.6	-20.5	-21.1	-1.1
Tampa	2A	-19.9	-20.8	-21.2	-1.5
West Palm Beach	2A	-20.3	-20.5	-20.9	-1.6
Average		**-19.8**	**-20.9**	**-21.5**	**-1.5**

The average reduction in energy costs for all building types is relatively constant across cities throughout the state. For the LEC design, Zone 1 realizes an average change in energy costs of -21.3 % compared to -20.7 % for Zone 2.

For all cities, the LEC design results in reductions in energy-related carbon emissions relative to *ASHRAE 90.1-2007*. There is minor variation across cities in the change in carbon emissions, -20.9 % versus -22.1 %, with Climate Zone 1 realizing slightly greater reductions.

The LEC design results in average percentage reductions in life-cycle costs relative to *ASHRAE 90.1-2007* across all cities in the state, ranging from 1.1 % to 2.1 %. These cost variations are probably a result of the variation in building envelope design requirements across climate zones combined with different local construction costs across the state. Cities located further north realize smaller percentage reductions in life-cycle costs.

8.2 Total Savings

How much can Florida 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 first 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 for the LEC design in the state.[19] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type. 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.[20]

[19] 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.

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

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

Building Type	Energy Code	
	LEC	
	kWh/m^2	kBtu/ft^2
APART04	-21.4	-6.8
APART06	-22.8	-7.2
DORMI04	-16.6	-5.3
DORMI06	-25.8	-8.2
HIGHS02	-18.2	-5.8
HOTEL15	-27.4	-8.7
OFFIC03	-26.7	-8.5
OFFIC08	-21.9	-6.9
OFFIC16	-22.4	-7.1
RETAIL1	-20.8	-6.6
RSTRNT1	-47.3	-15.0

The annual reduction in energy use ranges widely across building types, but the LEC design decreases overall energy use across the state relative to *ASHRAE 90.1-2007*. The adoption of the LEC design as the state's energy code would save energy for all building types, and 246 GWh (841 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 65.0 % 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 total statewide savings to be 379 GWh (1294.2 GBtu) per year. These savings imply over 3790.5 GWh (12942.3 GBtu) in energy savings over the 10-year study period.

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

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Energy Code LEC kWh	Energy Code LEC kBtu
APART04	44.9 %	1923	20 704	-41 125 439	-140 419 934
APART06	55.1 %	2356	25 359	-53 670 927	-183 255 624
HOTEL15	100.0 %	596	6414	-10 823 497	-36 956 072
HIGHS02	100.0 %	1552	16 705	-41 416 445	-141 413 553
OFFIC03	37.4 %	676	7277	-18 492 215	-63 140 373
OFFIC08	40.4 %	729	7848	-15 950 755	-54 462 735
OFFIC16	22.2 %	401	4318	-8 971 492	-30 632 532
RETAIL1	100.0 %	2381	25 627	-49 516 636	-169 071 088
RSTRNT1	100.0 %	136	1460	-6 413 952	-21 899 992
Total		**10 750**	**115 711**	**-246 381 359**	**-841 251 902**

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

The reduction in energy use varies across the 9 building types with reported floor area data. The greatest reductions in energy use occur for 6-story apartment buildings followed by retail stores, high schools, and 4-story apartment buildings while the smallest reductions occur for restaurants and the high-rise buildings. Building types that represent a greater amount of new floor area tend to realize the largest changes in energy use. The amount of new floor area overwhelms the minimal variation in the percentage reduction in energy use.

8.2.2 Energy Costs

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

Building Type	Energy Code	
	LEC	
	$/m²	$/ft²
APART04	-$18.85	-$1.75
APART06	-$20.25	-$1.88
DORMI04	-$14.60	-$1.36
DORMI06	-$22.97	-$2.13
HIGHS02	-$16.63	-$1.55
HOTEL15	-$24.03	-$2.23
OFFIC03	-$23.50	-$2.18
OFFIC08	-$18.64	-$1.73
OFFIC16	-$19.69	-$1.83
RETAIL1	-$17.79	-$1.65
RSTRNT1	-$40.76	-$3.79

Table 8-7 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. Overall, the reduction in energy costs totals $216 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. All building types realize energy cost savings for the LEC design. The greatest energy cost savings are realized by the apartment buildings, retail stores, and high schools. The smallest reductions in energy costs are realized by restaurants and 16-story office buildings. Assuming that the buildings considered in this study, which represent 65.0 % of all new 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 $333 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC
APART04	44.9 %	1923	20 704	-$36 256 290
APART06	55.1 %	2356	25 359	-$47 701 308
HOTEL15	100.0 %	596	6414	-$9 911 975
HIGHS02	100.0 %	1552	16 705	-$37 299 219
OFFIC03	37.4 %	676	7277	-$15 888 663
OFFIC08	40.4 %	729	7848	-$13 590 986
OFFIC16	22.2 %	401	4318	-$7 896 893
RETAIL1	100 %	2381	25 627	-$42 351 551
RSTRNT1	100 %	136	1460	-$5 527 562
Total		**10 750**	**115 711**	**-$216 424 446**

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

8.2.3 Energy-related Carbon Emissions

Table 8-8 reports the average energy-related reduction in 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, Florida

Building Type	Energy Code LEC	
	kg/m²	lb/ft²
APART04	-182.9	-37.5
APART06	-196.6	-40.3
DORMI04	-141.7	-29.0
DORMI06	-223.2	-45.7
HOTEL15	-161.9	-33.2
HIGHS02	-233.7	-47.9
OFFIC03	-227.5	-46.6
OFFIC08	-180.4	-36.9
OFFIC16	-191.0	-39.1
RETAIL1	-172.2	-35.3
RSTRNT1	-394.7	-80.8

Table 8-9 applies the Table 8-8 results to one year's worth of new building construction in the state to estimate statewide energy-related reduction in carbon emissions from adoption of a more energy efficient code. The total reduction in carbon emissions ranges widely across building types, and is correlated to the reductions in energy use. The adoption of the LEC design as the state's energy code for commercial buildings decreases carbon emissions by 2.1 million 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 building stock in the state, the results for the LEC design can be extrapolated to estimate total statewide reductions in carbon emissions of 3.2 million metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code
				LEC
APART04	44.9 %	1923	20 704	-351 846
APART06	55.1 %	2356	25 359	-463 242
HOTEL15	100.0 %	596	6414	-96 506
HIGHS02	100.0 %	1552	16 705	-362 638
OFFIC03	37.4 %	676	7277	-153 836
OFFIC08	40.4 %	729	7848	-131 490
OFFIC16	22.2 %	401	4318	-76 624
RETAIL1	100.0 %	2381	25 627	-409 884
RSTRNT1	100.0 %	136	1460	-53 533
Total		**10 750**	**115 711**	**-2 099 598**

Note: Dormitories are excluded because no 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. The average change in life-cycle costs per unit of floor area varies significantly across building types.

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

Building Type	Energy Code	
	LEC	
	$/$m^2$	$/$ft^2$
APART04	-$2.59	-$0.24
APART06	-$4.08	-$0.38
DORMI04	-$19.87	-$1.85
DORMI06	-$9.00	-$0.84
HOTEL15	-$0.69	-$0.06
HIGHS02	-$15.43	-$1.43
OFFIC03	-$19.75	-$1.83
OFFIC08	-$22.10	-$2.05
OFFIC16	-$1.59	-$0.15
RETAIL1	-$5.18	-$0.48
RSTRNT1	-$73.78	-$6.85

Table 8-11 applies the Table 8-10 results to one year's worth of new building construction in the state to estimate statewide change in total life-cycle costs from adoption of a more energy-efficient code. Adopting the LEC design decreases total life-cycle costs by $91.4 million, and reduces costs for all 9 building types. Hotels and high-rise office buildings realize the smallest reductions in life-cycle costs. Assuming that the buildings considered in this study are generally representative of the entire new building stock in the state, the results for the LEC design can be extrapolated to estimate an increase in total statewide life-cycle costs of $151.3 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC
APART04	44.9 %	1923	20 704	-$4 984 164
APART06	55.1 %	2356	25 359	-$9 607 112
HOTEL15	100.0 %	596	6414	-$409 194
HIGHS02	100.0 %	1552	16 705	-$23 950 746
OFFIC04	37.4 %	676	7277	-$13 353 416
OFFIC08	40.4 %	729	7848	-$16 112 836
OFFIC16	22.2 %	401	4318	-$638 697
RETAIL1	100.0 %	2381	25 627	-$12 330 802
RSTRNT1	100.0 %	136	1460	-$10 005 885
Total		**10 750**	**115 711**	**-$91 392 851**

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

8.3 State Summary

Florida has consistently been one of the earliest adopters of the most recent edition of the *ASHRAE 90.1* Standard as its state energy code for commercial buildings, and is one of the largest states in the country. The adoption of the LEC design, which goes beyond *ASHRAE 90.1-2007*, leads to sizeable total energy use, energy cost, and carbon emissions reductions while significantly decreasing life-cycle costs. Based on the average annual new commercial 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 energy savings of 3790.5 GWh (12942.3 GBtu), energy cost savings of $333 million, and carbon emissions savings of 3.2 million metric tons of carbon emissions, and life-cycle cost savings of $151.3 million for one year's worth of commercial building construction.

9 Maryland

Maryland is selected for this study for two reasons. First, Maryland represents the Middle Atlantic region of the United States. Second, the state is comparable in new construction volume to several other states selected for this study, which allows for comparisons across states. Maryland is located primarily in Climate Zone 4 with the northwestern portion of the state located in Zone 5. Only one city, Baltimore, is simulated for this study and is located in Zone 4. As of December 2011, the state had adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings.

Table 9-1 provides an overview of Maryland'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 80 kWh/m^2 to 100 kWh/m^2 (25 $kBtu/ft^2$ to 32 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 192 kWh/m^2 to 207 kWh/m^2 (61 $kBtu/ft^2$ to 66 $kBtu/ft^2$) annually.

Table 9-1 Average Annual Energy Use by Building Type and Energy Code, Maryland

Building Type	Energy Code			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	151	48	134	43
APART06	149	47	131	42
DORMI04	112	35	98	31
DORMI06	164	52	144	46
HOTEL15	153	48	132	42
HIGHS02	207	66	192	61
OFFIC03	107	34	85	27
OFFIC08	100	32	80	25
OFFIC16	148	47	124	39
RETAIL1	114	36	97	31
RSTRNT1	161	51	117	37

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 and total savings on a statewide basis. There is no within-state variation to consider for this state since only one city is simulated for the state (Baltimore).

9.1 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 a more energy efficient design for the state of Maryland.

Table 9-2 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 -7.2 % to -27.7 % with an average of -15.1 % relative to the *ASHRAE 90.1-2007* design. The greatest reduction in energy use for the LEC design occurs in restaurants followed by the small and mid-sized office buildings. The smallest reductions occur in the high school followed by the apartments and dormitories.

Table 9-2 Average Percentage Change from Adoption of a Newer Code, 10 Year, Maryland

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.9	-17.1	-16.4	0.2
APART06	-12.1	-19.9	-19.0	-0.0
DORMI04	-12.5	-17.8	-17.2	-0.2
DORMI06	-12.0	-19.7	-18.8	-0.4
HOTEL15	-13.4	-19.4	-18.7	-0.1
HIGHS02	-7.2	-16.9	-15.6	-1.7
OFFIC03	-20.0	-23.4	-23.1	-3.0
OFFIC08	-19.7	-21.4	-21.2	-2.9
OFFIC16	-16.0	-20.1	-19.7	-0.3
RETAIL1	-14.3	-17.3	-17.0	-0.1
RSTRNT1	-27.7	-33.5	-32.9	-9.0
Average	**-15.1**	**-20.6**	**-20.0**	**-1.6**

The LEC design realizes average changes in energy costs from -16.9 % to -33.5 % depending on the building type, with an average of -20.6 % overall over 10 years of operation. The high school and 4-story apartment building realize the smallest average reductions in energy costs while the restaurant realizes the greatest average reductions in energy use. 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.

The LEC design leads to average changes in carbon emissions ranging from -15.6 % to -32.9 % depending on the building type, with an average of -20.0 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use because the energy efficiency measures adopted decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity consumption leads to additional emissions reductions because the average emissions reduction per unit of energy from natural gas consumption is much lower than the average emissions reductions from electricity consumption.

The average change in life-cycle costs for the LEC design over a 10-year study period ranges from -9.0 % to 0.2 %. The 4-story apartment building is the only building type that realizes a percentage increase in life-cycle costs. The restaurant, 3-story office building, and 8-story office building are the building types that realize the greatest reductions in average life-cycle costs. Given that 10 of 11 buildings types realize an average percentage decrease in life-cycle costs, the LEC design is cost-effective for the state to adopt as its state energy code for commercial buildings.

9.2 Total Savings

How much can Maryland 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 first necessary to estimate savings per unit of floor area for each building type in the state.

9.2.1 Energy Use

Table 9-3 reports the average per unit change in annual energy use by building type for the LEC design in the state.[21] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type. Table 9-4 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

[21] 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.

office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[22]

Table 9-3 Average Per Unit Change in Annual Energy Use, Maryland

Building Type	Energy Code LEC	
	kWh/m²	kBtu/ft²
APART04	-16.4	-5.2
APART06	-18.0	-5.7
DORMI04	-14.0	-4.4
DORMI06	-19.7	-6.3
HOTEL15	-20.5	-6.5
HIGHS02	-21.3	-6.8
OFFIC03	-14.9	-4.7
OFFIC08	-19.6	-6.2
OFFIC16	-23.6	-7.5
RETAIL1	-16.2	-5.2
RSTRNT1	-44.6	-14.2

The annual reduction in energy use ranges widely across building types with reported floor area data, but the LEC design decreases overall energy use across the state. The adoption of the LEC design as the state's energy code would save energy for all building types and 37.3 GWh (127.5 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 60.0 % 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 the total statewide savings to be 62.2 GWh (212.4 GBtu) per year. These savings imply 622.2 GWh (2124.5 GBtu) in energy savings over the 10-year study period.

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

Table 9-4 Statewide Change in Annual Energy Use for One Year of Construction, Maryland

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC kWh	Energy Code LEC kBtu
APART04	44.9 %	300	3233	-4 912 108	-16 772 048
APART06	55.1 %	368	3960	-6 629 761	-22 636 856
HOTEL15	100.0 %	165	1778	-3 376 646	-11 529 321
HIGHS02	100.0 %	305	3286	-4 561 245	-15 574 052
OFFIC03	37.4 %	210	2258	-4 473 057	-15 272 939
OFFIC08	40.4 %	226	2435	-4 436 129	-15 146 851
OFFIC16	22.2 %	124	1340	-2 942 128	-10 045 692
RETAIL1	100.0 %	310	3334	-5 028 330	-17 168 881
RSTRNT1	100.0 %	22	235	-972 937	-3 322 027
Total		**2031**	**21 859**	**-37 332 341**	**-127 468 665**

Note: Dormitories are excluded because no 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 for 6-story apartment buildings followed by retail stores, 4-story apartment buildings, high schools, and 3- and 8-story office buildings. The smallest reductions are for restaurants followed by the high-rise buildings. Building types that represent a greater amount of new floor area realize the largest changes in energy use. 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. The building types that lead to the greatest estimated reductions in energy use -- retail stores and 6- and 4-story apartment buildings-- only rank 5th, 8th, and 10th in percentage reduction, respectively, among the 11 building types, as reported in Table 9-2.

9.2.2 Energy Costs

Table 9-5 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 9-5 Average Per Unit Change in Energy Costs, 10-Year, Maryland

Building Type	Energy Code LEC	
	$/m²	$/ft²
APART04	-$17.00	-$1.58
APART06	-$19.83	-$1.84
DORMI04	-$13.62	-$1.27
DORMI06	-$21.45	-$1.99
HOTEL15	-$19.85	-$1.84
HIGHS02	-$20.88	-$1.94
OFFIC03	-$21.12	-$1.96
OFFIC08	-$19.05	-$1.77
OFFIC16	-$23.97	-$2.23
RETAIL1	-$15.57	-$1.45
RSTRNT1	-$41.93	-$3.90

Table 9-6 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. Overall, total reductions in energy costs total $37.4 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study, which represent 60.0 % 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 energy cost savings of $62.4 million over the 10-year study period.

Table 9-6 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Maryland

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Energy Code LEC
APART04	44.9 %	300	3233	-$5 107 758
APART06	55.1 %	368	3960	-$7 296 692
HOTEL15	100.0 %	165	1778	-$3 278 577
HIGHS02	100.0 %	305	3286	-$4 301 405
OFFIC03	37.4 %	210	2258	-$4 430 681
OFFIC08	40.4 %	226	2435	-$4 309 892
OFFIC16	22.2 %	124	1340	-$2 983 322
RETAIL1	100.0 %	310	3334	-$4 823 614
RSTRNT1	100.0 %	22	235	-$913 865
Total		**2031**	**21 859**	**-$37 445 805**

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

9.2.3 Energy-related Carbon Emissions

Table 9-7 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 9-7 Average Per Unit Change in Carbon Emissions, 10-Year, Maryland

Building Type	Energy Code LEC	
	kg/m^2	lb/ft^2
APART04	-116.1	-23.8
APART06	-134.8	-27.6
DORMI04	-93.5	-19.1
DORMI06	-145.9	-29.9
HOTEL15	-136.3	-27.9
HIGHS02	-139.6	-28.6
OFFIC03	-144.7	-29.6
OFFIC08	-130.8	-26.8
OFFIC16	-163.9	-33.6
RETAIL1	-107.0	-21.9
RSTRNT1	-288.6	-59.1

Table 9-8 applies the Table 9-7 results to one year's worth of new building construction in the state to estimate statewide reduction in carbon emissions from adoption of a more energy efficient code. The total reduction in carbon emissions ranges widely across building types, and is correlated with each building's total reductions in energy use. However, there is not a perfect correlation because the magnitude of the offsetting natural gas increase for 10 of 11 building types varies. The adoption of the LEC design as the state's energy code decreases carbon emissions by 269 357 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 448 928 tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code
				LEC
APART04	44.9 %	300	3233	-34 859
APART06	55.1 %	368	3960	-49 581
HOTEL15	100 %	165	1778	-22 508
HIGHS02	100.0 %	305	3286	-42 619
OFFIC03	37.4 %	210	2258	-30 361
OFFIC08	40.4 %	226	2435	-29 581
OFFIC16	22.2 %	124	1340	-20 407
RETAIL1	100.0 %	310	3334	-33 138
RSTRNT1	100.0 %	22	235	-6301
Total		**2031**	**21 859**	**-269 357**

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

9.2.4 Life-Cycle Costs

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

Building Type	Energy Code	
	LEC	
	$/$m^2$	$/$ft^2$
APART04	$2.13	$0.20
APART06	-$0.28	-$0.03
DORMI04	-$1.52	-$0.14
DORMI06	-$4.34	-$0.40
HOTEL15	-$0.64	-$0.06
HIGHS02	-$14.23	-$1.32
OFFIC03	-$26.42	-$2.45
OFFIC08	-$26.11	-$2.43
OFFIC16	-$2.22	-$0.21
RETAIL1	-$0.59	-$0.05
RSTRNT1	-$131.12	-$12.18

Table 9-10 applies the Table 9-9 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. The change in life-cycle costs varies widely across building types, with 8 of 9 building types realizing reductions in life-cycle costs. Three-story and 8-story office buildings realize total reductions in life-cycle costs of greater than $5.5 million.

The LEC design leads to statewide reductions in life-cycle costs of $17.3 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 statewide life-cycle cost increases of $28.8 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code
				LEC
APART04	44.9 %	300	3233	$640 249
APART06	55.1 %	368	3960	-$104 036
HOTEL15	100.0 %	165	1778	-$106 294
HIGHS02	67.5 %	305	3286	-$2 931 692
OFFIC03	37.4 %	210	2258	-$5 541 957
OFFIC08	40.4 %	226	2435	-$5 907 246
OFFIC16	22.2 %	124	1340	-$276 765
RETAIL1	100.0 %	310	3334	-$183 061
RSTRNT1	100.0 %	22	235	-$2 857 706
Total		**2031**	**21 859**	**-$17 268 507**

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

9.3 State Summary

As of December 2011, Maryland had 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 impressive energy use, energy cost, and energy-related carbon emissions reductions 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 savings of 622.2 GWh (2124.5 GBtu), energy cost savings of $62.4 million, and carbon emissions reductions of 448 928 metric tons while decreasing life-cycle costs by $28.8 million for one year's worth of commercial building construction.

10 Oregon

Oregon is selected for this study because the state represents the Northwest and the associated climate zones (Zone 4C and Zone 5B) in that region of the United States. Oregon is one of four states selected for this study that has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, allowing comparisons across states.

Table 10-1 provides an overview of Oregon'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 72 kWh/m^2 to 91 kWh/m^2 (23 kBtu/ft^2 to 29 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 179 kWh/m^2 to 188 kWh/m^2 (57 kBtu/ft^2 to 60 kBtu/ft^2).

Table 10-1 Average Annual Energy Use by Building Type and Energy Code, Oregon

Building Type	Energy Code			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	124	39	112	35
APART06	125	40	111	35
DORMI04	96	30	84	27
DORMI06	136	43	122	39
HOTEL15	133	42	115	37
HIGHS02	188	60	179	57
OFFIC03	96	30	76	24
OFFIC08	91	29	72	23
OFFIC16	132	42	109	34
RETAIL1	104	33	90	29
RSTRNT1	142	45	102	32

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 a more stringent energy code for commercial buildings. 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 and locations within a state. This section discusses the average percentage changes from investing in a more energy efficient design in the state of Oregon.

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*. There is significant variation in the percentage change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -4.9 % to -28.5 % depending on the building type with an overall average of -15.0 %.

Table 10-2 Average Percentage Change in Energy Use from Adoption of a Newer Code, 10-Year, Oregon

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.0	-15.0	-15.4	1.1
APART06	-10.9	-17.1	-17.7	1.0
DORMI04	-12.7	-16.7	-17.0	-1.0
DORMI06	-10.6	-16.7	-17.1	0.7
HOTEL15	-13.8	-18.4	-18.8	0.9
HIGHS02	-4.9	-11.5	-12.1	-0.0
OFFIC03	-21.2	-23.5	-23.6	-3.5
OFFIC08	-20.9	-22.0	-22.0	-3.0
OFFIC16	-17.8	-20.9	-21.1	1.0
RETAIL1	-13.2	-15.3	-15.4	0.8
RSTRNT1	-28.5	-33.0	-33.4	-4.5
Average	**-15.0**	**-19.1**	**-19.4**	**-0.6**

There is a significant variation in the average percentage change in energy costs for the LEC design, ranging from -11.5 % to -33.0 % depending on the building type, with an average of -19.1 % 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. In fact, for all 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 59.9 % 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 percentage change in energy-related carbon emissions for the LEC design across building types, ranging from -12.1 % to -33.4 %

with an average of -19.4 %. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use because the energy efficiency measures adopted decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity consumption leads to additional emissions reductions because the average emissions reduction per unit of energy from natural gas consumption is much lower than the average emissions reductions from electricity consumption.

The LEC design results in significant variations in life-cycle costs across building types. Of the 11 building types, 5 realize a reduction in life-cycle costs for a 10-year study period. The percentage change in life-cycle costs for the LEC design ranges from -4.5 % to 1.1 %. Based on the overall average change of -0.6 % in life-cycle costs, the LEC design may be cost-effective for the state to adopt as its state energy code.

10.1.2 City Comparisons

Simulations are run for 9 cities located in Oregon: Astoria, Eugene, Medford, North Bend, Portland, and Salem in Climate Zone 4C and Burns, Pendleton, and Redmond in Climate Zone 5B. The results vary across cities within the state for several reasons. First, the state is covered by two climate zones. The LEC 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 10-3 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.

Table 10-3 Average Percentage Change in Energy Use from Adoption of Newer Codes by City, 10-Year, Oregon

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Astoria	4C	-14.2	-18.5	-18.8	-0.5
Eugene	4C	-15.6	-19.6	-20.0	-0.7
Medford	4C	-15.6	-19.6	-20.0	-0.9
North Bend	4C	-16.2	-20.6	-20.8	-0.3
Portland	4C	-16.0	-19.7	-20.0	-0.2
Salem	4C	-15.3	-19.3	-19.7	-0.7
Burns	5B	-12.9	-17.4	-17.8	-0.8
Pendleton	5B	-15.1	-19.0	-19.5	-0.9
Redmond	5B	-13.7	-18.2	-18.7	-0.6
Average		**-15.0**	**-19.1**	**-19.5**	**-0.6**

The average percentage change in energy use for all building types from adopting the LEC design varies across cities from -12.9 % to -16.2 %. Cities in Zone 4C realize slightly greater reductions in energy use relative to Zone 5B. The average change in energy costs for all building types varies across cities, from -17.4 % to -20.6 %, with Zone 4C realizing a slightly larger change than Zone 5B for 10 years of building operation. For all cities, the LEC design results in percentage changes in carbon emissions ranging from -17.8 % to -20.8 % with an overall average of -19.5 %. Reductions in energy costs and carbon emissions are larger than the reductions in energy use because electricity consumption decreases while natural gas consumption increases. Adoption of the LEC design results in average percentage reductions in life-cycle costs for all cities for a 10-year study period, ranging from -0.2 % to -0.9 %.

10.2 Total Savings

How much can Oregon 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 first 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 in the state.[23] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new

[23] 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.

construction of each building type. 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.[24]

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

Building Type	Energy Code LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-12.4	-3.9
APART06	-13.6	-4.3
DORMI04	-12.0	-3.8
DORMI06	-14.4	-4.6
HOTEL15	-18.2	-5.8
HIGHS02	-20.2	-6.4
OFFIC03	-9.3	-2.9
OFFIC08	-19.1	-6.0
OFFIC16	-23.4	-7.4
RETAIL1	-13.6	-4.3
RSTRNT1	-40.3	-12.8

The LEC design decreases overall energy use across the state. The adoption of the LEC design as the state's energy code saves energy for all building types and 13.9 GWh (47.4 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 53.1 % 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 to be 26.1 GWh (89.2 GBtu) in energy savings per year. These savings imply 261.4 GWh (892.4 GBtu) in energy savings over the 10-year study period.

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

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC kWh	Energy Code LEC kBtu
APART04	44.9 %	113	1213	-1 394 046	-4 759 872
APART06	55.1 %	138	1486	-1 871 932	-6 391 581
HOTEL15	100.0 %	72	776	-1 314 161	-4 487 110
HIGHS02	100.0 %	130	1401	-1 208 058	-4 124 830
OFFIC03	37.4 %	69	743	-1 397 542	-4 771 808
OFFIC08	40.4 %	74	801	-1 418 430	-4 843 130
OFFIC16	22.2 %	41	441	-957 706	-3 270 019
RETAIL1	100.0 %	276	2976	-3 771 343	-12 876 986
RSTRNT1	100.0 %	14	146	-544 826	-1 860 269
Total		**927**	**9982**	**-13 878 043**	**-47 385 606**

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

The statewide change in total energy use varies across building types. Building types that represent a greater amount of new floor area realize the largest 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 6-story apartment buildings -- only rank 6^{th} and 8^{th} 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, Oregon

Building Type	Energy Code LEC	
	$/m^2	$/ft^2
APART03	-$8.38	-$0.78
APART06	-$9.70	-$0.90
DORMI03	-$7.51	-$0.70
DORMI06	-$10.26	-$0.95
HOTEL15	-$11.33	-$1.05
HIGHS02	-$9.48	-$0.88
OFFIC03	-$12.39	-$1.15
OFFIC08	-$11.44	-$1.06
OFFIC16	-$14.61	-$1.36
RETAIL1	-$8.25	-$0.77
RSTRNT1	-$24.09	-$2.24

Table 10-7 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 of building operation. The LEC design leads to statewide reductions in energy costs of $9.2 million. All building types realize energy cost savings, ranging from $325 917 to $2.3 million. The total reductions in energy costs are correlated with total reductions in energy use, but there is some variation due to the variation in the energy source of the reductions.

Assuming that the buildings considered in this study, which represent 53.1 % 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 the LEC design can be extrapolated to estimate the total statewide energy cost savings of $17.4 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC
APART04	44.9 %	113	1213	-$944 794
APART06	55.1 %	138	1486	-$1 338 087
HOTEL15	100.0 %	72	776	-$816 090
HIGHS02	67.5 %	130	1401	-$1 233 331
OFFIC03	37.4 %	69	743	-$855 651
OFFIC08	40.4 %	74	801	-$851 595
OFFIC16	22.2 %	41	441	-$598 644
RETAIL1	100.0 %	276	2976	-$2 281 802
RSTRNT1	100.0 %	14	146	-$325 917
Total		**927**	**9982**	**-$9 245 909**

Note: Dormitories are excluded because no 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 and building design. The carbon emissions estimation approach is defined in Section 5.3.

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

Building Type	Energy Code LEC kg/m^2	Energy Code LEC lb/ft^2
APART04	-70.4	-14.4
APART06	-81.7	-16.7
DORMI04	-62.8	-12.9
DORMI06	-86.4	-17.7
HOTEL15	-94.7	-19.4
HIGHS02	-81.0	-16.6
OFFIC03	-103.5	-21.2
OFFIC08	-95.4	-19.5
OFFIC16	-122.2	-25.0
RETAIL1	-68.9	-14.1
RSTRNT1	-201.0	-41.2

Table 10-9 applies the Table 10-8 results to one year's worth of new building construction in the state to estimate statewide total reduction in carbon emissions from adoption of a more energy efficient code. Adoption of the LEC design as the state's energy code decreases carbon emissions by 77 601 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 total statewide reduction in carbon emissions of 146 141 metric tons over the 10-year study period. The total reduction in carbon emissions for each building type is correlated with its total reduction in energy use.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC
APART04	44.9 %	113	1213	-7 937
APART06	55.1 %	138	1486	-11 272
HOTEL15	100.0 %	72	776	-6823
HIGHS02	67.5 %	130	1401	-10 544
OFFIC03	37.4 %	69	743	-7148
OFFIC08	40.4 %	74	801	-7105
OFFIC16	22.2 %	41	441	-5007
RETAIL1	100.0 %	276	2976	-19 047
RSTRNT1	100.0 %	14	146	-2719
Total		**927**	**9982**	**-77 601**

Note: Dormitories are excluded because no 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, Oregon

Building Type	Energy Code LEC $/m²	Energy Code LEC $/ft²
APART04	$10.86	$1.01
APART06	$9.96	$0.93
DORMI04	-$9.75	-$0.91
DORMI06	$7.11	$0.66
HOTEL15	$8.64	$0.80
HIGHS02	-$0.13	-$0.01
OFFIC03	-$28.91	-$2.69
OFFIC08	-$26.16	-$2.43
OFFIC16	$8.19	$0.76
RETAIL1	$5.27	$0.49
RSTRNT1	-$62.04	-$5.76

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 a more energy-efficient code. The LEC design leads to an increase in statewide life-cycle costs of $213 782 and increases life-cycle costs for 5 of 9 building types. Retail stores and hotels account for a $2.1 million ($1.5 million and $622 209, respectively) increase in life-cycle costs.

Assuming that the buildings considered in this study are generally representative of the entire new building stock in the state, the results for the LEC design can be extrapolated to estimate the increase in total statewide life-cycle costs of $402 602 over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC
APART04	44.9 %	113	1213	$1 223 170
APART06	55.1 %	138	1486	$1 374 597
HOTEL15	100.0 %	72	776	$622 209
HIGHS02	100.0 %	130	1401	-$17 512
OFFIC03	37.4 %	69	743	-$1 995 630
OFFIC08	40.4 %	74	801	-$1 947 568
OFFIC16	22.2 %	41	441	$335 656
RETAIL1	100.0 %	276	2976	$1 458 084
RSTRNT1	100.0 %	14	146	-$839 223
Total		**927**	**9982**	**$213 782**

Note: Dormitories are excluded because no floor area category is

10.3 State Summary

Oregon 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, but does not do so in a cost-effective manner. Based on the average annual new commercial 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 statewide energy savings of 261.4 GWh (892.4 GBtu), energy cost savings of $17.4 million, and carbon emissions reductions of 146 141 metric tons at a life-cycle cost of $402 602 for one year's worth of commercial building construction. Oregon is one of two states in this report that realize an increase in life-cycle costs from adopting the LEC design.

11 Tennessee

Tennessee was selected for this study for two reasons. First, Tennessee is one of the four states in the country that have adopted *ASHRAE 90.1-2004* as its state energy code for commercial buildings. Second, the state is comparable in new construction volume to several other states selected for this study, which allows for comparisons across states. Third, the state represents the Appalachian Mountain region of the U.S. and two climate zones.

Table 11-1 provides an overview of Tennessee's simulated energy use keyed to building types and energy standard edition. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 80 kWh/m^2 to 104 kWh/m^2 (25 kBtu/ft^2 to 33 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 157 kWh/m^2 to 180 kWh/m^2 (50 kBtu/ft^2 to 57 kBtu/ft^2) annually.

Table 11-1 Average Annual Energy Use by Building Type and Energy Code, Tennessee

Building Type	Energy Code					
	2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	141	45	136	43	118	37
APART06	139	44	135	43	115	37
DORMI04	104	33	100	32	86	27
DORMI06	152	48	148	47	127	40
HOTEL15	127	40	135	43	115	37
HIGHS02	180	57	175	55	157	50
OFFIC03	109	35	104	33	81	26
OFFIC08	104	33	100	32	80	25
OFFIC16	131	42	139	44	115	36
RETAIL1	118	37	108	34	90	29
RSTRNT1	161	51	154	49	108	34

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 Tennessee.

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 6.4 % to -8.4 % with an average of -2.3 %. 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 window U-factor in Zone 3 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 energy loss enough to overwhelm the energy efficiency gains obtained from other measures, such increased insulation R-values.

Table 11-2 Average Percentage Change in Energy Use from Adoption of Newer Codes, Tennessee

Building Type	Energy Code	
	2007	LEC
APART04	-3.7	-16.1
APART06	-3.1	-17.3
DORMI04	-3.6	-17.3
DORMI06	-2.1	-16.1
HOTEL15	5.8	-9.6
HIGHS02	-3.1	-12.9
OFFIC03	-4.6	-25.3
OFFIC08	-4.0	-23.4
OFFIC16	6.4	-12.3
RETAIL1	-8.4	-23.1
RSTRNT1	-4.4	-32.9
Average	**-2.3**	**-18.8**

The LEC design realizes greater percentage changes in energy use relative to *ASHRAE 90.1-2004,* ranging from -9.6 % to -32.9 % with an average of -18.8 %. 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 assumed building occupancy. Some of the additional energy efficiency measures adopted by the LEC design, particularly daylighting and overhangs, decrease electricity use while increasing natural gas use.

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 6.8 % to -5.3 % depending on the building type, with an average of -1.2 %. 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 larger 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. Eight of 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. Only the 6-story dormitory realizes a slightly greater reduction in energy costs than its reduction in energy use because electricity consumption decreases by a greater percentage than natural gas consumption.

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

Building Type	Energy Code	
	2007	LEC
APART04	-3.4	-20.5
APART06	-2.9	-22.9
DORMI04	-2.8	-20.4
DORMI06	-2.3	-21.9
HOTEL15	6.7	-13.6
HIGHS02	-2.5	-19.9
OFFIC03	-2.6	-25.8
OFFIC08	-1.8	-22.7
OFFIC16	6.8	-15.0
RETAIL1	-5.3	-22.6
RSTRNT1	-2.9	-35.6
Average	**-1.2**	**-21.9**

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 -13.6 % to -35.6 % with an overall average of -21.9 % for 10 years of building operation. The reductions in energy costs are greater than the reductions in energy use for 9 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. The remaining two 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 6.9 % to -4.9 % with an average of -1.0 %. The LEC design leads to significant changes in average carbon emissions, ranging from -14.3 % to -36.1 % depending on the building type with an average of -22.5 % 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 10 of the 11 building types for the *ASHRAE 90.1-2007* design. Similar to the reductions in energy costs, this result is due to the fuel source of the reductions in energy use. For the eight building types that realize smaller reductions in carbon emissions than energy use, the percentage reduction in natural gas consumption is 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. Similarly, the LEC design realizes a greater percentage reduction in natural gas consumption than electricity consumption for 2 of 11 building types. The remaining building type for the *ASHRAE 90.1-2007* design and 9 building types for the LEC design realize greater percentage reductions in electricity consumption than natural gas consumption.

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

Building Type	Energy Code	
	2007	LEC
APART04	-3.3	-21.3
APART06	-2.8	-23.9
DORMI04	-2.7	-20.9
DORMI06	-2.3	-22.9
HOTEL15	6.9	-14.3
HIGHS02	-2.3	-21.3
OFFIC03	-2.3	-25.9
OFFIC08	-1.5	-22.6
OFFIC16	6.8	-15.4
RETAIL1	-4.9	-22.5
RSTRNT1	-2.6	-36.1
Average	**-1.0**	**-22.5**

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 lower life-cycle costs for the hotel and 16-story office building.

For 9 building types, *ASHRAE 90.1-2007* leads to small percentage reductions in life-cycle costs (-0.9 % or less). 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 *ASHRAE 90.1-2007* will decrease total life-cycle costs.

The LEC design results in reductions in life-cycle costs for 9 building types for a 10-year study period. The percentage change in life-cycle costs ranges from -7.7 % to 0.8 %. Based on the overall average percentage change of -1.4 % in life-cycle costs, the LEC design is likely to be cost-effective for the state to adopt as its state energy code for commercial buildings.

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

Building Type	Energy Code	
	2007	LEC
APART04	**-0.4**	-0.1
APART06	**-0.3**	-0.3
DORMI04	-0.7	**-1.1**
DORMI06	-0.2	**-0.5**
HOTEL15	0.6	0.8
HIGHS02	-0.4	**-1.7**
OFFIC03	-0.4	**-2.6**
OFFIC08	-0.8	**-3.0**
OFFIC16	0.8	0.8
RETAIL1	**-0.4**	-0.4
RSTRNT1	-0.9	**-7.7**
Average	**-0.3**	**-1.4**

11.1.5 City Comparisons

Simulations are run for 5 cities located in Tennessee: Memphis in Zone 3A and Bristol, Chattanooga, Knoxville, and Nashville in Zone 4A. The results 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 varies little both across and within climate zones. For the *ASHRAE 90.1-2007* design, the percentage change in average energy use ranges from -1.4 % to -2.8 % with an average of -2.3 %. For the LEC design, the percentage change in average energy use ranges from -17.8 % to -19.4 % with an average of -18.8 %. Across both building design alternatives, Zone 3A realizes slightly lower reductions in energy use than Zone 4A.

Table 11-6 Average Percentage Change in Energy Use from Adoption of Newer Codes by City, Tennessee

Cities	Zone	Energy Code	
		2007	LEC
Memphis	3A	-1.4	-17.8
Bristol	4A	-2.8	-18.8
Chattanooga	4A	-2.3	-19.4
Knoxville	4A	-2.2	-19.3
Nashville	4A	-2.5	-18.5
Average		**-2.3**	**-18.8**

The variations in energy costs across cities are a result of two factors, the reductions 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 minimally across and within climate zones. For the *ASHRAE 90.1-2007* design, the percentage change in average energy costs ranges from -0.7 % to -2.6 % with an average of -1.2 %. The average percentage change in energy costs is greater in Zone 3A (-2.6 %) than Zone 4A (-0.8 %). For the LEC design, the percentage change in average energy costs ranges from -21.3 % to -22.1 % with an average of -21.9 %. Zone 3A realizes slightly greater changes in energy use (-22.1 %) than Zone 4A (-21.9 %).

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

Cities	Zone	Energy Code	
		2007	LEC
Memphis	3A	-2.6	-22.1
Bristol	4A	-0.9	-22.0
Chattanooga	4A	-0.8	-22.1
Knoxville	4A	-0.7	-22.1
Nashville	4A	-0.9	-21.3
Average		**-1.2**	**-21.9**

Table 11-8 reports energy-related carbon emissions by city for the state. For all cities, the more energy efficient designs result in greater reduction in carbon emissions. The city in Zone 3A realizes a slightly greater average percentage change in carbon emissions than the cities in Zone 4A for *ASHRAE 90.1-2007*, -2.9 % versus -1.0 %. The average emissions reduction does not significantly vary across cities for the LEC design, ranging from 22.4 % to 23.3 %.

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

Cities	Zone	Energy Code	
		2007	LEC
Memphis	3A	-2.9	-23.3
Bristol	4A	-1.0	-23.1
Chattanooga	4A	-1.0	-23.1
Knoxville	4A	-0.9	-23.2
Nashville	4A	-1.1	-22.4
Average		**-1.0**	**-23.0**

The data reported in Table 11-9 show that the *ASHRAE 90.1-2007* design decreases life-cycle costs across all cities, with changes in life-cycle cost ranging minimally from -0.2 % to -0.4 %. 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 across climate zones.

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

Cities	Zone	Energy Code	
		2007	LEC
Memphis	3A	-0.4	-1.3
Bristol	4A	-0.3	-1.6
Chattanooga	4A	-0.2	-1.2
Knoxville	4A	-0.2	-1.5
Nashville	4A	-0.3	-1.5
Average		**-0.3**	**-1.4**

11.2 Total Savings

How much can Tennessee 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 first 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.[25] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type. 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.[26]

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

Building Type	Energy Code			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	-5.2	-1.6	-22.7	-7.2
APART06	-4.3	-1.4	-24.1	-7.6
DORMI04	-3.8	-1.2	-18.1	-5.7
DORMI06	-3.2	-1.0	-24.5	-7.8
HOTEL15	7.4	2.3	-12.2	-3.9
HIGHS02	-5.0	-1.6	-27.6	-8.8
OFFIC03	-5.6	-1.8	-23.1	-7.3
OFFIC08	-4.2	-1.3	-24.4	-7.8
OFFIC16	8.3	2.6	-16.1	-5.1
RETAIL1	-9.8	-3.1	-27.2	-8.6
RSTRNT1	-7.2	-2.3	-53.1	-16.8

The annual reduction in energy use ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs both decrease total statewide energy use across the state. The adoption of the *ASHRAE 90.1-2007* design results in reductions of 10.1 GWh (34.4 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.

[25] 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.

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

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code			
				2007		LEC	
				kWh	kBtu	kWh	kBtu
APART04	44.9 %	89	955	-458 546	-1 565 674	-2 010 540	-6 864 847
APART06	55.1 %	109	1169	-463 283	-1 581 847	-2 615 546	-8 930 598
HOTEL15	100.0 %	136	1469	1 004 599	3 430 133	-1 669 894	-5 701 738
HIGHS02	100.0 %	362	3895	-2 026 243	-6 918 463	-8 372 078	-28 585 875
OFFIC03	37.4 %	172	1850	-865 790	-2 956 178	-4 739 500	-16 182 692
OFFIC08	40.4 %	185	1995	-769 189	-2 626 341	-4 526 951	-15 456 957
OFFIC16	22.2 %	102	1098	850 344	2 903 441	-1 645 100	-5 617 078
RETAIL1	100.0 %	716	7710	-7 068 817	-24 135 982	-19 482 585	-66 521 922
RSTRNT1	100.0 %	40	429	-285 475	-974 734	-2 115 887	-7 224 547
Total		**1911**	**20 571**	**-10 082 399**	**-34 425 646**	**-47 178 081**	**-161 086 253**

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

The adoption of the LEC design as the state's energy code for commercial buildings would save 47.2 GWh (161.1 GBtu) of total statewide 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 58.4 % 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 statewide savings to be 80.8 GWh (275.8 GBtu) per year. These savings imply over 807.8 GWh (2758.3 GBtu) in energy 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 37.5 % and 18.9 %, respectively, of the new construction in the state while all other building types represent less than 10 %. 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 4th 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, Tennessee

Building Type	Energy Code			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$2.88	-$0.27	-$17.37	-$1.61
APART06	-$2.47	-$0.23	-$19.35	-$1.80
DORMI04	-$1.83	-$0.17	-$13.12	-$1.22
DORMI06	-$2.17	-$0.20	-$20.21	-$1.88
HOTEL15	$5.11	$0.47	-$10.34	-$0.96
HIGHS02	-$2.46	-$0.23	-$19.86	-$1.84
OFFIC03	-$1.95	-$0.18	-$19.65	-$1.83
OFFIC08	-$1.37	-$0.13	-$17.07	-$1.59
OFFIC16	$6.06	$0.56	-$13.46	-$1.25
RETAIL1	-$4.16	-$0.39	-$17.60	-$1.63
RSTRNT1	-$3.07	-$0.29	-$38.03	-$3.53

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: $3.8 million and $34.3 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 58.4 % 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 *ASHRAE 90.1-2007* and LEC can be extrapolated to estimate the total statewide energy cost savings of $6.5 million and $58.7 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code	
				2007	LEC
APART04	44.9 %	89	955	-$255 316	-$1 540 657
APART06	55.1 %	109	1169	-$268 637	-$2 102 662
HOTEL15	100.0 %	136	1469	$697 170	-$1 410 958
HIGHS02	100.0 %	362	3895	-$888 648	-$7 184 973
OFFIC03	37.4 %	172	1850	-$335 849	-$3 377 105
OFFIC08	40.4 %	185	1995	-$253 116	-$3 164 579
OFFIC16	22.2 %	102	1098	$618 451	-$1 373 321
RETAIL1	100.0 %	716	7710	-$2 981 169	-$12 603 521
RSTRNT1	100.0 %	40	429	-$122 325	-$1 515 615
Total		**1911**	**20 571**	**-$3 789 438**	**-$34 273 392**

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

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, Tennessee

Building Type	Energy Code			
	2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-29.4	-6.0	-186.9	-38.3
APART06	-25.5	-5.2	-209.5	-42.9
DORMI04	-18.2	-3.7	-140.1	-28.7
DORMI06	-22.9	-4.7	-219.5	-45.0
HOTEL15	54.2	11.1	-112.6	-23.1
HIGHS02	-23.8	-4.9	-216.7	-44.4
OFFIC03	-18.3	-3.7	-209.2	-42.9
OFFIC08	-12.1	-2.5	-181.3	-37.1
OFFIC16	64.8	13.3	-146.5	-30.0
RETAIL1	-39.9	-8.2	-184.6	-37.8
RSTRNT1	-29.5	-6.0	-405.3	-83.0

Table 11-15 applies the Table 11-14 results to one year's worth of new building construction in the state to estimate statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but *ASHRAE 90.1-2007* and LEC decrease carbon emissions for the state as a whole. The adoption of *ASHRAE 90.1-2007* saves 35 084 metric tons over a 10-year study period. The adoption of the LEC design decreases carbon emissions by 366 027 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 statewide reduction in carbon emissions of 60 076 tons and 626 759 tons over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code	
				2007	LEC
APART04	44.9 %	89	955	-2609	-16 580
APART06	55.1 %	109	1169	-2764	-22 757
HOTEL15	100.0 %	136	1469	7394	-15 366
HIGHS02	100.0 %	362	3895	-8602	-78 417
OFFIC03	37.4 %	172	1850	-3140	-35 960
OFFIC08	40.4 %	185	1995	-2237	-33 602
OFFIC16	22.2 %	102	1098	6607	-14 940
RETAIL1	100.0 %	716	7710	-28 557	-132 250
RSTRNT1	100.0 %	40	429	-1177	-16 154
Total		**1911**	**20 571**	**-35 084**	**-366 027**

Note: Dormitories are excluded because no 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, Tennessee

Building Type	Energy Code			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$3.45	-$0.32	-$0.99	-$0.09
APART06	-$2.86	-$0.27	-$2.40	-$0.22
DORMI04	-$6.39	-$0.59	-$9.79	-$0.91
DORMI06	-$2.18	-$0.20	-$5.01	-$0.47
HOTEL15	$5.47	$0.51	$7.09	$0.66
HIGHS02	-$2.68	-$0.25	-$12.57	-$1.17
OFFIC03	-$3.18	-$0.30	-$18.90	-$1.76
OFFIC08	-$6.44	-$0.60	-$23.22	-$2.16
OFFIC16	$5.66	$0.53	$5.78	$0.54
RETAIL1	-$2.67	-$0.25	-$2.38	-$0.22
RSTRNT1	-$11.42	-$1.06	-$96.02	-$8.92

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 $4.4 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 $16.4 million, while reducing life-cycle costs for 7 of 9 building types. The *ASHRAE 90.1-2007* and the LEC designs lead to an increase in life-cycle costs for hotels and 16-story office 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 $7.5 million and $28.1 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code	
				2007	LEC
APART04	44.9 %	89	955	-$306 372	-$87 633
APART06	55.1 %	109	1169	-$310 942	-$260 597
HOTEL15	100.0 %	136	1469	$747 205	$967 430
HIGHS02	100.0 %	362	3895	-$968 977	-$4 548 170
OFFIC03	37.4 %	172	1850	-$547 253	-$3 248 330
OFFIC08	40.4 %	185	1995	-$1 193 900	-$4 305 144
OFFIC16	22.2 %	102	1098	$577 169	$589 230
RETAIL1	100.0 %	716	7710	-$1 913 574	-$1 703 531
RSTRNT1	100.0 %	40	429	-$455 105	-$3 827 052
Total		**1911**	**20 571**	**-4 371 749**	**-16 423 797**

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

11.3 State Summary

Tennessee is one of the few states that have adopted *ASHRAE 90.1-2004* as their 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 savings of 10.1 GWh (34.4 GBtu), energy cost savings of $6.5 million, carbon emissions reductions of 66 072 metric tons, and life-cycle cost savings of $7.5 million. The life-cycle cost savings are greater than the energy cost savings. The relaxation of the U-factor 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 be even more beneficial for the state with savings of 807.8 GWh (2758.3 GBtu), energy cost savings of $58.7 million, and carbon emissions reductions of 689 317 metric tons while decreasing life-cycle costs by $28.1 million for one year's worth of commercial building construction.

12 Wisconsin

Wisconsin is selected for this study for three reasons. First, the state represents the Midwest region of the United States. Second, Wisconsin is located in the coldest climates in the contiguous United States. Third, Wisconsin is one of four states in this study that have adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, which allows for comparisons across states.

Table 12-1 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 12-1 Average Annual Energy Use by Building Type and Energy Code, Wisconsin

Building Type	Energy Code			
	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 a more stringent energy code. 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 a more energy efficient design in the state of Wisconsin.

12.1.1 Statewide Building Comparison

Table 12-2 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 12-2 Average Percentage Change in Energy Use from Adoption of Newer Codes, 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 for the state to adopt as its state energy code.

12.1.2 City Comparisons

Simulations are run for 5 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 12-3 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 12-3 Average Percentage Change in Energy Use from Adoption of Newer Codes by City, 10-Year, 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 %.

12.2 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 first necessary to estimate savings per unit of floor area for each building type in the state.

12.2.1 Energy Use

Table 12-4 reports the average per unit change in annual energy use by building type and building design in the state.[27] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type. Table 12-5 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.[28]

Table 12-4 Average Per Unit Change in Annual Energy Use, Wisconsin

Building Type	Energy Code	
	LEC	
	kWh/m²	kBtu/ft²
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

[27] 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.

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

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 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 GBtu) in energy 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. 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 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 12-2.

Table 12-5 Statewide Change in Annual Energy Use for One Year of Construction, Wisconsin

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code LEC	
				kWh	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 floor area category is reported in the construction data.

12.2.2 Energy Costs

Table 12-6 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 12-6 Average Per Unit Change in Energy Costs, 10-Year, Wisconsin

Building Type	Energy Code LEC	
	$/m²	$/ft²
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 12-7 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 $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 12-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Wisconsin

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Energy Code 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 floor area category is reported in the construction data.

12.2.3 Energy-related Carbon Emissions

Table 12-8 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 12-8 Average Per Unit Change in Carbon Emissions, 10-Year, Wisconsin

Building Type	Energy Code 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 12-9 applies the Table 12-8 results to one year's worth of new building construction in the state to estimate statewide reduction in carbon emissions from adoption of more energy efficient codes. 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 12-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Wisconsin – Metric Tons

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Energy Code 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 floor area category is reported in the construction data.

12.2.4 Life-Cycle Costs

Table 12-10 reports the average change in life-cycle cost over 10 years, per m² (ft²), 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 12-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Wisconsin

Building Type	Energy Code LEC $/m²	Energy Code LEC $/ft²
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 12-11 applies the Table 12-10 results to one year's worth of new building construction in the state to estimate statewide life-cycle cost changes from adoption of the more energy-efficient code. 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 increase 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 12-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Wisconsin

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Energy Code 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 floor area category is reported in the construction data.

12.3 State Summary

Wisconsin is one of the states that 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, but not 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 savings of 491.0 GWh (1676.3 GBtu), energy cost savings of $33.2 million, and carbon emissions reductions of 383 682 metric tons while decreasing life-cycle costs by $14.8 million for one year's worth of commercial building construction.

13 Total Savings Comparisons for Selected States

By comparing the aggregate results from the detailed state-by-state analysis, some interesting trends emerge. Table 13-1 shows the total savings in energy use, energy costs, life-cycle costs, and carbon emissions from adopting the LEC design as the commercial building energy code for each of the 7 representative states for a 10-year study period. In general, there is a strong correlation among energy use and energy costs, life-cycle 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 energy production fuel mix.

Table 13-1 Total Reductions by State for Adoption of the LEC Design, 10-Year

State	Code	Floor Area Ranking	Average Annual New Floor Area 1000 m^2 (1000 ft^2)	Energy Use (GWh)	Energy Costs ($million)	Carbon (1000 tCO_2e)	LCC ($million)
AK	None	46	290 (3116)	99.4	9.8	58.4	2.4
CO	2001	17	3292 (35 437)	1112.9	72.7	1126.2	59.7
FL	2007	1	16 542 (178 061)	3790.5	333.0	3230.2	151.3
MD	2007	16	3385 (36 433)	622.2	62.4	448.9	28.8
OR	2007	27	1745 (18 788)	261.4	17.4	146.1	-0.4
TN	2004	18	3272 (35 219)	807.8	58.7	626.8	28.1
WI	2007	22	2386 (25 679)	491.0	33.2	383.7	14.8

Total energy 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 located in warmer climate zones benefit more from the overhangs and daylighting installed in the LEC design. Third, a state's current state energy code for commercial buildings drives the variation in energy use. Consider the reductions in energy use for two states with similar amounts of new floor area, Colorado and Maryland. Even though Maryland has slightly more new floor area construction and a warmer climate, Colorado realizes 79 % more reductions in energy use. Colorado has adopted *ASHRAE 90.1-2001* as its state energy code for commercial buildings while Maryland has adopted *ASHRAE 90.1-2007*. The newer edition of *ASHRAE 90.1* leads to less energy savings potential than the older standard edition.

Table 13-3 shows the reduction in energy use per unit of newly constructed floor area by state. Alaska realizes the greatest reduction in energy use per unit of floor area followed by Colorado while Florida is 4th out of the 7 states considered in this study. These results vary significantly from the total reductions in energy use, where Florida is first (3790 GWh), Colorado is a distant second (1113 GWh), and Alaska is last (99 GWh). The three states that have not yet adopted *ASHRAE 90.1-2007* realize the greatest total reductions in energy use per unit of newly constructed floor area.

Table 13-2 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 m^2 (1000 ft^2)	Energy Use Reduction		
				GWh	kWh/m^2	kBtu/ft^2
AK	None	46	290 (3116)	99.4	343	109
CO	2001	17	3292 (35 437)	1112.9	338	107
TN	2004	18	3272 (35 219)	807.8	247	78
FL	2007	1	16 542 (178 061)	3790.5	229	73
WI	2007	22	2386 (25 679)	491.0	206	65
MD	2007	16	3385 (36 433)	622.2	184	58
OR	2007	27	1745 (18 788)	261.4	150	48

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 cost of electricity and natural gas and the energy source fuel mix of reductions in energy use by the buildings in a state. Table 13-3 shows each state's natural gas rate, electricity rate, weighted average fraction of the reduction in electricity consumption offset by the change in natural gas consumption, and average reduction in energy costs from adopting the LEC design.[29] 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 and are always cheaper than natural gas per unit of energy. Other than a state's energy prices, the most important factor is the fraction of total reductions in electricity consumption offset by a change in natural gas consumption. There is some minor fluctuation in the results due to the regional energy price escalation rates used to estimate changes in price levels in the future.

[29] 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 13-3 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)
AK	None	-24.9	14.5	2.8	0.10
MD	2007	13.3	12.0	3.2	0.10
FL	2007	4.0	10.8	3.2	0.09
TN	2004	-9.4	9.6	3.1	0.07
WI	2007	-25.9	9.6	2.6	0.07
CO	2001	8.6	8.2	2.2	0.07
OR	2007	18.8	7.5	3.5	0.07

*Percentage of the reduction in electricity consumption offset by change in natural gas consumption.

Table 13-4 shows the reduction in cradle-to-grave energy-related carbon emissions per unit of reduction in energy use, the CO_2e emissions rate for electricity and natural gas generation, and the weighted average fraction of the reduction in electricity consumption offset by a change in natural gas consumption. 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. Florida realizes greater reductions per unit of energy than Wisconsin even though its electricity carbon emissions rate is relatively smaller, because Florida's offset reflects an increase in natural gas consumption while Wisconsin's reflects a decrease.

Table 13-4 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)
CO	2001	8.6	994	241	1012
FL	2007	4.0	826	241	852
WI	2007	-25.9	905	241	781
TN	2004	-9.4	819	241	776
MD	2007	13.3	652	241	722
AK	None	-24.9	663	241	588
OR	2007	18.8	494	241	559

*Percentage of the reduction in electricity consumption offset by change in natural gas consumption.

The relative life-cycle cost reduction per unit of new floor area is shown in Table 13-5. There is a correlation between the energy use savings and the life-cycle cost-effectiveness of adopting the LEC design. Colorado realizes the greatest reductions per unit of floor area for both energy use and life-cycle costs for a 10-year study period. Meanwhile, Oregon realizes the smallest reductions in energy use per unit of floor area and is the only state to realize an increase in life-cycle costs for a 10-year study period. The life-cycle cost savings per unit of floor area does not have a strong correlation with the current energy code adopted in a state. Additional factors, such as climate zone, local construction costs, electricity and natural gas rates, fuel mix, and building stock mix, must also be influencing the life-cycle cost-effectiveness of adopting the LEC design.

Table 13-5 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
CO	2001	17	338	59.7	18.13	1.68
FL	2007	1	229	151.3	9.15	0.85
TN	2004	18	247	28.1	8.59	0.80
MD	2007	16	184	28.8	8.51	0.79
AK	1999	46	343	2.4	8.29	0.77
WI	2007	22	206	14.8	6.20	0.58
OR	2007	27	150	-0.4	-0.23	-0.02

14 Savings from Nationwide Adoption of Low Energy Case

One purpose of this study is to determine which states could benefit the most from adopting a more stringent state energy code for commercial buildings. This section analyzes benefits from nationwide adoption of the LEC design relative to the current collection of state energy codes. Benefits are evaluated across several dimensions: geography (state and climate zone), time, and building type.

It would be expected that states with energy codes based on older editions of *ASHRAE 90.1*, or no energy code at all, would realize greater benefits from adopting the LEC design because buildings in those states are expected to be built in a less energy efficient manner. Figure 14-1 shows the 14 states with energy codes based on older editions of *ASHRAE 90.1* (*-1999*, *-2001*, or no energy code).[30] Many of the central U.S. states have adopted older energy standard editions, as have a few states in the south, West Virginia, Arizona, Maine, and Alaska.

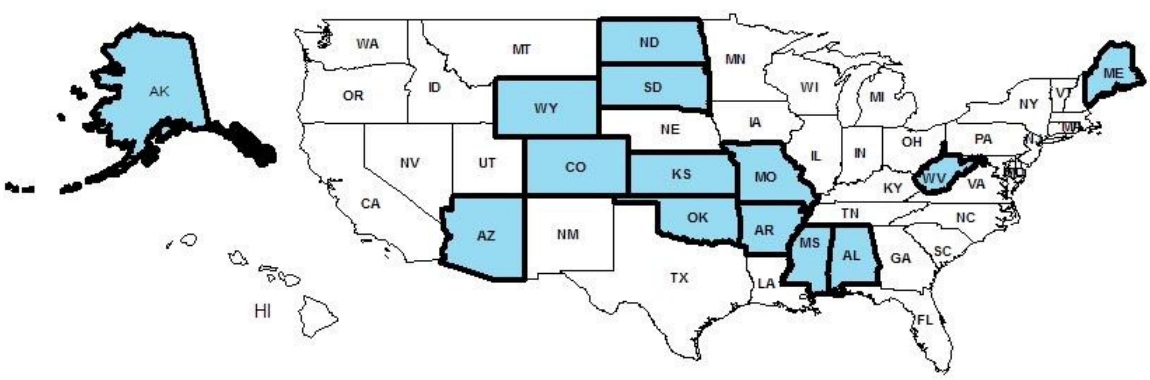

Figure 14-1 States that have Adopted *ASHRAE 90.1-2001* or No Energy Code

As in the state-by-state analysis of benefits from adopting the LEC design, it is necessary to assume a particular study period length because energy costs fluctuate on an annual basis. A 10-year study period is used as the baseline because it is one of the most realistic investor time horizons out of the 9 study period length options in BIRDS. The significance of the study period length will be tested in Section 14.2.

14.1 State Comparisons

State benefit comparisons are made based on the simple average changes for the cities analyzed in each state by building type. One building type is chosen to illustrate the detailed analysis possible with the powerful BIRDS database compiled for this study. Energy use, energy costs, life-cycle costs, and cradle-to-grave energy-related carbon emissions are analyzed for the most common existing building type, small office

[30] All maps are generated in ArcMap 10.1.

buildings. Summary results for the other 10 building types are reported in Table B-1 through Table B-10 in the Appendix B. No states have adopted the LEC design so all should realize impacts across the four metrics listed above.

14.1.1 3-Story Office Building

Table 14-1 summaries the percentage changes in energy use, energy costs, life-cycle costs, and carbon emissions for the 3-story office building. 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.

Table 14-1 Average Percentage Change by State, 3-Story Office Building, 10-Year

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-25.5	-27.6	-26.9	-0.5	MT	-18.0	-20.1	-19.9	-1.9
AL	-36.3	-36.6	-36.8	-0.7	NC	-21.9	-23.3	-23.7	-2.1
AR	-30.4	-33.0	-33.9	-3.8	ND	-29.5	-30.5	-30.6	0.8
AZ	-34.7	-34.9	-35.0	-3.1	NE	-18.2	-23.0	-23.5	-2.3
CA	-24.5	-25.5	-25.1	-3.0	NH	-18.1	-20.4	-20.1	-2.8
CO	-29.3	-32.1	-32.4	-5.5	NJ	-19.6	-23.6	-22.9	-2.5
CT	-17.9	-23.4	-21.8	-3.1	NM	-23.3	-25.5	-25.6	-3.1
DE	-20.0	-22.7	-23.2	-3.4	NV	-25.3	-26.7	-26.3	-4.3
FL	-24.0	-24.3	-24.3	-2.3	NY	-16.9	-22.0	-20.2	-3.0
GA	-21.6	-22.9	-23.3	-1.2	OH	-17.5	-22.1	-22.7	-2.5
HI	-28.0	-28.0	-28.0	-5.7	OK	-30.8	-33.7	-35.7	2.0
IA	-17.7	-21.4	-21.9	-1.7	OR	-21.2	-23.5	-23.6	-3.5
ID	-19.7	-22.0	-22.1	-2.7	PA	-17.5	-21.5	-22.1	-2.7
IL	-17.5	-23.0	-23.0	-2.4	RI	-18.5	-22.5	-22.3	-2.8
IN	-18.3	-22.4	-23.0	-2.1	SC	-23.8	-24.9	-25.0	-2.0
KS	-31.9	-34.3	-35.1	0.7	SD	-28.1	-30.2	-30.4	-0.7
KY	-19.8	-22.4	-23.5	-2.4	TN	-25.3	-25.8	-25.9	-2.6
LA	-21.9	-22.7	-23.0	-0.3	TX	-21.7	-23.1	-23.1	-1.9
MA	-17.6	-22.8	-21.8	-2.6	UT	-20.8	-24.6	-23.7	-3.0
MD	-20.0	-23.4	-23.1	-3.0	VA	-22.1	-24.1	-24.5	-2.2
ME	-31.1	-31.6	-31.6	-0.7	VT	-17.6	-20.1	-19.8	-2.6
MI	-16.4	-21.0	-21.5	-2.6	WA	-19.6	-21.9	-22.4	-2.7
MN	-26.1	-23.7	-23.4	-1.8	WI	-17.5	-20.1	-20.2	-1.7
MO	-31.6	-33.4	-34.4	1.4	WV	-30.4	-31.4	-32.4	-4.3
MS	-41.9	-39.1	-39.0	0.4	WY	-30.1	-31.8	-31.8	0.3
					Avg.	**-23.0**	**-25.2**	**-25.3**	**-2.2**

These detailed results can be readily analyzed in mappings of the United States. Figure 14-2, Figure 14-3, Figure 14-5, and Figure 14-4 overlay Figure 14-1 and display the average percentage energy savings, energy cost savings, life-cycle cost savings, and carbon emissions reduction for a 10-year study period by state, respectively. The states with codes based on older editions of *ASHRAE 90.1*, or no energy code at all, are shown with cross hatching and bolded state borders. Figure 14-2 shows that 31 of 50 states realize energy use savings of 20 % or more by adopting the LEC design over their current state energy code. Many of the states that realize the greatest energy use savings are the ones that currently have energy codes based on older editions of *ASHRAE 90.1*, or no energy code at all. Of the 18 states that realize energy use savings of at least 25 %, 14 are states with either no energy code or a code based on *ASHRAE 90.1-1999* or *ASHRAE 90.1-2001*, including all 10 states that realize energy use savings of more than 30 %.

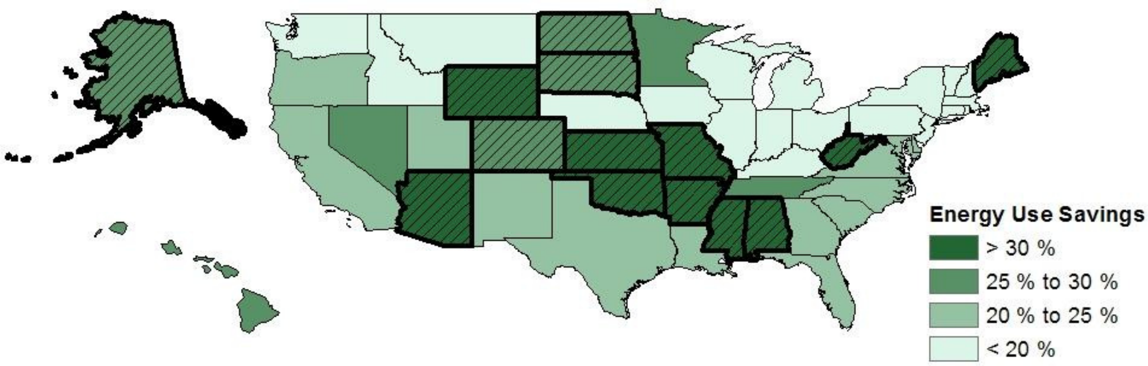

Figure 14-2 Average Energy Use Savings by State, 3-Story Office Building, 10-Year

Figure 14-3 overlays Figure 14-1 with the average energy cost savings over 10 years by state from adopting the LEC design in small office buildings. Every state reduces energy costs by at least 20 %. The states that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* realize the greatest energy cost savings, with all 13 states realizing savings of greater than 30 %. Of the 19 states that have cost savings greater than 25 %, 18 have adopted no state energy code, *ASHRAE 90.1-1999*, *-2001*, or *-2004*.

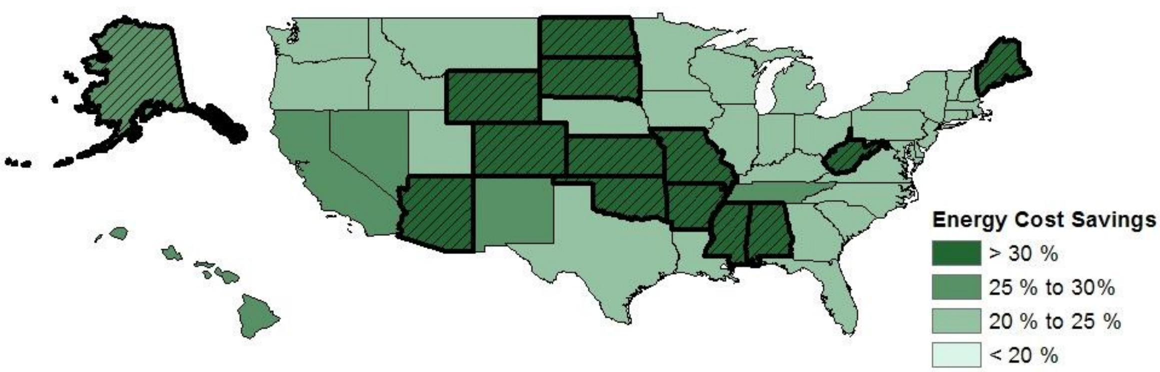

Figure 14-3 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year

Figure 14-4 overlays Figure 14-1 with the average reduction in energy-related carbon emissions by state from adopting the LEC design. Only two states, Vermont and Montana, do not reduce carbon emissions by at least 20 %. The states that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* realize the greatest reduction in carbon emissions, with all 14 states realizing savings of greater than

25 % and all but Alaska realizing savings of greater than 30 %. None of the states that have adopted *ASHRAE 90.1-2004* or *-2007* realize reductions in carbon emissions of greater than 30 %.

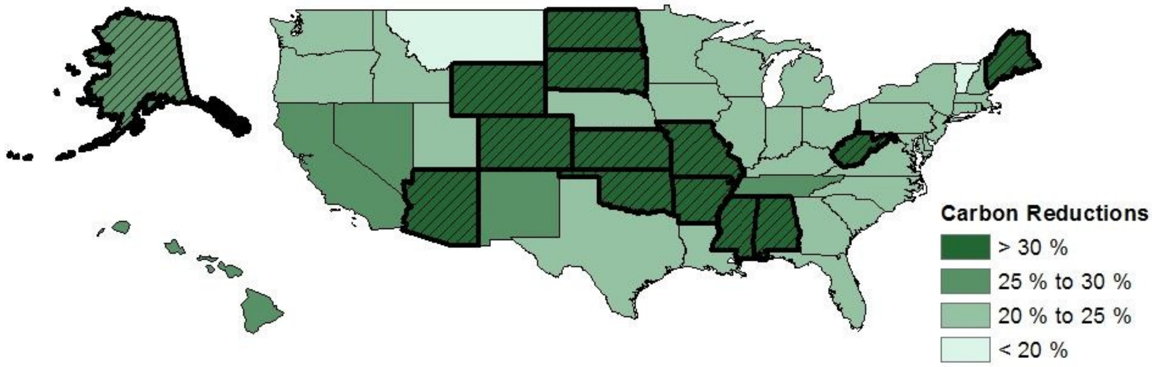

Figure 14-4 Average Energy-related Carbon Emissions Reduction by State, 3-Story Office Building, 10-year

Figure 14-5 overlays Figure 14-1 with the average life-cycle cost savings over 10 years by state from adopting the LEC design. The resulting map shows two interesting trends. First, all states that realize an increase in life-cycle costs as a result of adopting the LEC design as its state energy code currently have no state energy code or have adopted an older edition of *ASHRAE 90.1*. The energy cost savings of the more efficient LEC design are not enough to overwhelm the additional construction and MRR costs associated with the required energy efficiency measures. Second, states located in the central and southern U.S. tend to realize life-cycle cost savings less than 2 %. States located in the West and Northeast U.S. tend to realize life-cycle cost savings greater than 2 %. The energy cost savings may be greater in the west and northeast due to higher energy prices.

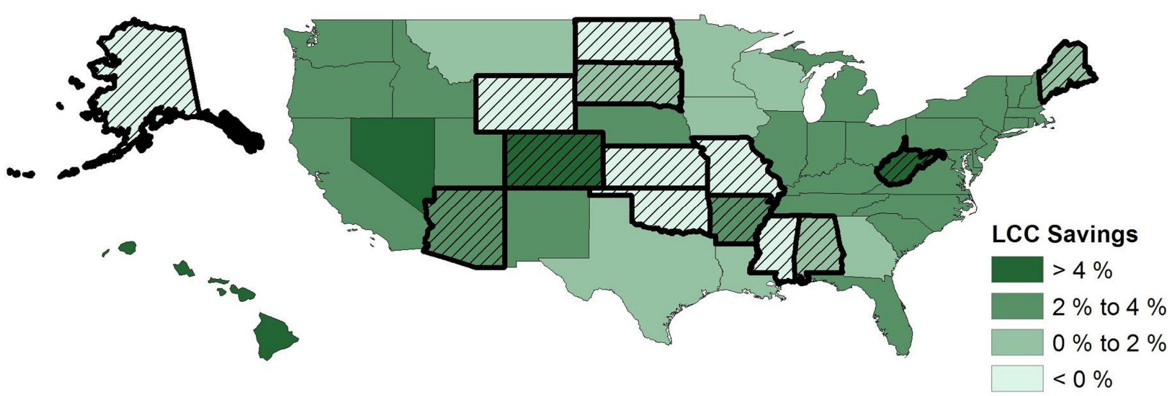

Figure 14-5 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year

For a 3-story office building and a 10-year study period, states that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* have the most to gain in percentage terms in energy use, energy cost, and carbon emissions savings from adopting more stringent state energy codes. However, these same states realize an average increase in life-cycle costs over the same 10-year study period, raising questions as to the cost-effectiveness of these additional energy efficiency measures.

14.2 Results by Study Period Length

The nationwide analysis up to this point has 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 reduction in energy use from adoption of the LEC design is constant over all study period lengths because energy efficiency is assumed to be constant over time. The national average reduction in energy use across all cities in the study ranges from -10.6 % to -30.7 %, depending on the building type, with an overall national average of -17.8 %. Table 14-2 shows these results.

Table 14-2 Nationwide Average Percentage Change in Energy Use by Building Type

Building Type	Percentage Change
APART04	-14.8
APART06	-15.6
DORMI04	-16.9
DORMI06	-15.2
HOTEL15	-13.9
HIGHS02	-10.6
OFFIC03	-23.0
OFFIC08	-21.5
OFFIC16	-15.3
RETAIL1	-18.9
RSTRNT1	-30.7
Average	**-17.8**

As shown in Table 14-3, reductions in energy costs vary slightly, in percentage terms, over increasing study period lengths. The national average reduction in energy costs across all location-building type combinations changes from -22.8 % for a 1-year study period to -22.3 % for a 40-year study period. The minor variation is a result of the escalation rates used to adjust future energy prices, which vary by Census Region. The national average reduction ranges from -17.4 % to -35.6 %, depending on the building type and study period.

Table 14-3 Nationwide 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	-21.5	-21.3	-21.2	-21.1	-21.0	-21.0	-20.9	-20.8	-20.7
APART06	-23.2	-23.0	-22.9	-22.8	-22.7	-22.6	-22.5	-22.4	-22.4
DORMI04	-22.4	-22.3	-22.2	-22.1	-22.1	-22.0	-21.9	-21.9	-21.8
DORMI06	-22.7	-22.5	-22.4	-22.3	-22.2	-22.1	-22.0	-22.0	-21.9
HOTEL15	-19.8	-19.6	-19.6	-19.5	-19.4	-19.3	-19.3	-19.2	-19.2
HIGHS02	-18.3	-18.1	-18.0	-17.9	-17.8	-17.7	-17.6	-17.5	-17.4
OFFIC03	-25.3	-25.2	-25.2	-25.2	-25.2	-25.2	-25.1	-25.1	-25.1
OFFIC08	-22.8	-22.8	-22.8	-22.8	-22.8	-22.8	-22.7	-22.7	-22.7
OFFIC16	-18.4	-18.4	-18.3	-18.3	-18.3	-18.2	-18.2	-18.2	-18.1
RETAIL1	-20.9	-20.9	-20.9	-20.9	-20.8	-20.8	-20.8	-20.8	-20.8
RSTRNT1	-35.6	-35.5	-35.4	-35.3	-35.3	-35.2	-35.2	-35.1	-35.1
Average	**-22.8**	**-22.7**	**-22.6**	**-22.6**	**-22.5**	**-22.5**	**-22.4**	**-22.3**	**-22.3**

Since the national average reduction in energy use across all location-building type combinations is constant over all study periods, the average energy-related carbon emissions are also assumed constant at -22.9 %.[31] The national average reduction in carbon emissions ranges from -18.5 % to -35.6 % depending on the building type, as shown in Table 14-4.

Table 14-4 Nationwide Average Percentage Change in Carbon Emissions by Building Type

Building Type	Percentage Change
APART04	-21.6
APART06	-23.3
DORMI04	-22.6
DORMI06	-22.8
HOTEL15	-20.0
HIGHS02	-18.5
OFFIC03	-25.3
OFFIC08	-22.8
OFFIC16	-18.5
RETAIL1	-21.0
RSTRNT1	-35.6
Average	**-22.9**

[31] Electricity fuel mixes are assumed to be fixed over all study periods.

Table 14-5 shows that the nationwide average percentage change in life-cycle costs varies significantly over increasing study period lengths, with the average change across all location-building type combinations ranging from -3.8 % to -1.1 %.

Table 14-5 National 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	-1.1	0.0	-0.1	-0.5	-0.4	-0.5	-0.7	-0.8	-0.7
APART06	-0.1	0.1	-0.2	-0.6	-0.6	-0.7	-0.9	-1.1	-1.0
DORMI04	-7.0	-1.6	-1.2	-1.5	-1.3	-1.4	-1.5	-1.6	-1.5
DORMI06	0.5	-0.3	-0.6	-1.1	-1.0	-1.2	-1.4	-1.6	-1.5
HOTEL15	1.4	0.3	-0.1	-0.6	-0.7	-1.0	-1.2	-1.4	-1.4
HIGHS02	-1.5	-1.2	-1.3	-1.6	-1.6	-1.8	-2.0	-2.2	-2.1
OFFIC03	-10.1	-2.7	-2.2	-2.4	-2.1	-2.3	-2.4	-2.6	-2.5
OFFIC08	-4.1	-2.2	-2.1	-2.5	-2.2	-2.4	-2.5	-2.7	-2.6
OFFIC16	2.1	0.8	0.3	-0.4	-0.4	-0.7	-1.0	-1.2	-1.2
RETAIL1	-9.1	-0.3	-0.1	-0.6	-0.3	-0.5	-0.8	-0.9	-0.8
RSTRNT1	-12.2	-5.2	-4.2	-5.0	-4.7	-5.0	-5.3	-5.4	-5.4
Average	**-3.8**	**-1.1**	**-1.1**	**-1.5**	**-1.4**	**-1.6**	**-1.8**	**-1.9**	**-1.9**

Figure 14-6 shows the graphical representation of the national average change in life-cycle costs by building type. For a 1-year study period, the average percentage change in life-cycle costs ranges from -12.2 % to 2.1 % depending on the building type. The significant variation is driven by the residual value of the building and its components. Since the study period is only one year, the residual values are almost as large as the first costs of building construction, amplifying even minor variations in life-cycle costs.

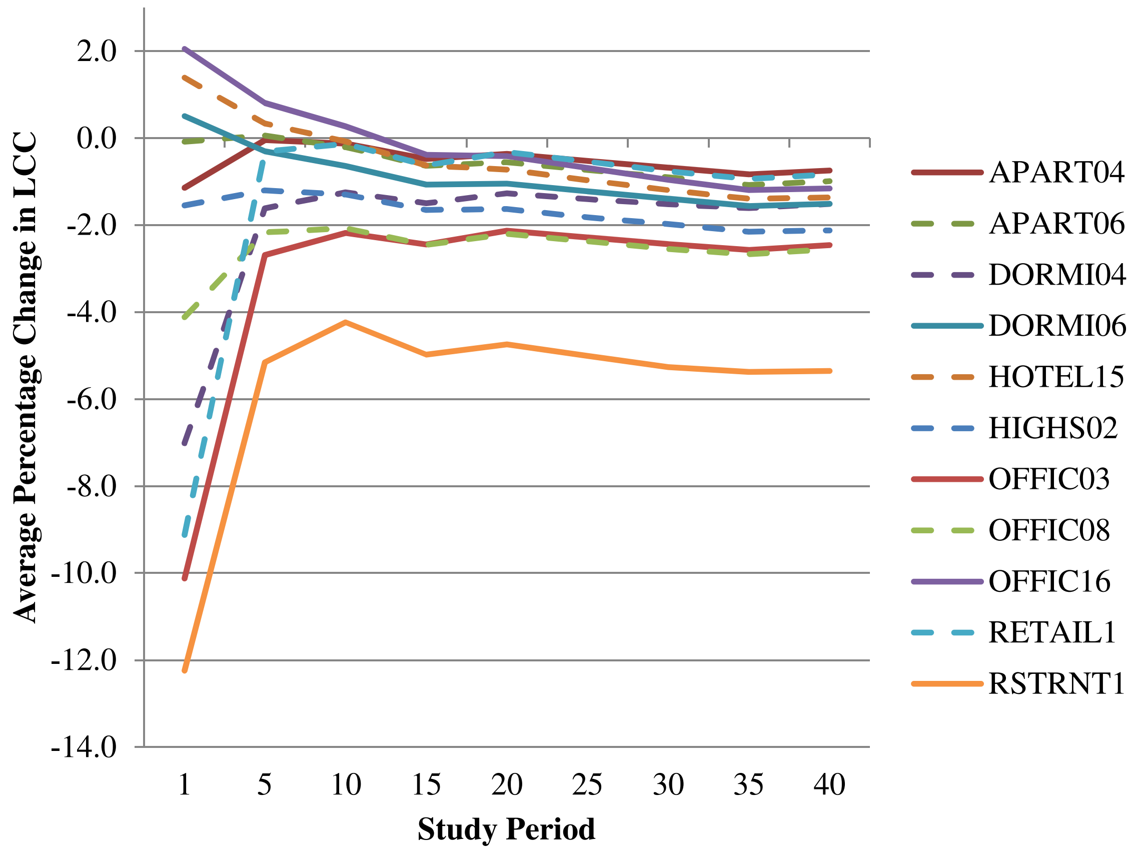

Figure 14-6 Nationwide Average Percentage Change in Life-cycle Costs from Nationwide Adoption of the LEC Design by Building Type and Study Period Length

From the 1-year to 10-year study period, there is a convergence towards zero followed by a slow but steady decrease from a 10-year to a 40-year study period. For building types that are not cost-effective for a 1-year study period slowly become cost-effective as the study period length increases. Building types that are cost-effective for a 1- year study period remain cost-effective for all longer study period lengths. All building types are cost-effective for study periods lengths of 15 years or greater.

14.3 Results by Building Type

Table 14-6 shows the simple average changes by building type, in percentage terms, from adopting the LEC design for a 10-year study period. The restaurant realizes the greatest reductions while the high school realizes the smallest reductions in energy use, energy cost, and energy-related carbon emissions.

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.

The restaurant realizes the greatest life-cycle cost savings while the 16-story office building is the only building to realize an increase in life-cycle costs, on average. Overall, all buildings realize significant reductions in energy use, energy costs, and carbon emissions.

Table 14-6 Nationwide Average Percentage Change for LEC by Building Type, 10-Year

Building Type		Percentage Change		
	Energy Use	Energy Cost	Carbon	LCC
APART04	-14.8	-21.2	-21.6	-0.1
APART06	-15.6	-22.9	-23.3	-0.2
DORMI04	-16.9	-22.2	-22.6	-1.2
DORMI06	-15.2	-22.4	-22.8	-0.6
HOTEL15	-13.9	-19.6	-20.0	-0.1
HIGHS02	-10.6	-18.0	-18.5	-1.3
OFFIC03	-23.0	-25.2	-25.3	-2.2
OFFIC08	-21.5	-22.8	-22.8	-2.1
OFFIC16	-15.3	-18.3	-18.5	0.3
RETAIL1	-18.9	-20.9	-21.0	-0.1
RSTRNT1	-30.7	-35.4	-35.6	-4.2
Average	**-17.8**	**-22.6**	**-22.9**	**-1.1**

14.4 Results by Climate Zone

Table 14-7 shows the nationwide average change in energy use by *ASHRAE* climate zone for the adoption of the LEC design relative to current state energy codes for all building types. Average reduction in energy use nationwide is 17.8 %. Zone 1 realizes the greatest average reduction in energy use, 22.1 %, while Zone 8 realizes the smallest, 10.2 %. For Zone 1 through Zone 5, 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. Warmer climates 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.

Zone 7 realizes a greater overall average reduction in energy use (19.8 %) than Zone 6 (16.1 %), Zone 5 (14.9 %), or Zone 4 (18.6 %). To explain this result, the average percentage change in energy use by climate zone is segmented by a location's current energy code in Table 14-7. Considering only the states that have adopted *ASHRAE 90.1-2007*, the average percentage reduction in energy use consistently decreases from Zone 4 (-15.7 %) to Zone 7 (-11.1 %) where the warmer the climate zone, the greater the reduction in energy use.

Table 14-7 Average Percentage Change in Energy Use for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change by State Energy Code				
	1999	2001	2004	2007	All
1			**-23.1**	**-21.2**	**-22.1**
2	**-38.3**		**-26.4**	**-18.2**	**-20.7**
A	-37.4			-18.3	-19.3
B	-39.2		-26.4	-17.6	-27.4
3	**-32.8**	**-27.4**	**-19.1**	**-18.6**	**-21.3**
A	-32.8	-27.4	-18.5	-17.3	-22.6
B			-21.3	-19.7	-19.8
C				-17.5	-17.5
4	**-27.4**	**-26.4**	**-19.0**	**-15.7**	**-18.6**
A	-26.7	-26.4	-19.0	-15.8	-19.5
B	-31.0			-16.9	-19.7
C				-14.9	-14.9
5	**-27.8**	**-25.1**	**-17.1**	**-13.3**	**-14.9**
A	-25.2	-22.8		-13.1	-13.5
B	-30.4	-25.9	-17.1	-14.3	-17.8
6	**-23.0**	**-22.0**	**-16.1**	**-12.9**	**-16.1**
A	-21.9	-20.8	-16.1	-12.5	-15.1
B	-23.8	-22.7		-13.3	-17.5
7	**-22.7**		**-20.1**	**-11.1**	**-19.8**
8	**-10.2**				**-10.2**
Grand Total	**-25.5**	**-25.2**	**-19.1**	**-15.3**	**-17.8**

Table 14-8 shows that the overall average reduction in energy costs over a 10-year study period ranges from 21.0 % to 25.5 % depending on the climate zone. The greatest overall reductions in in energy costs are realized by cities located in Zone 7 followed by Zone 3. Similar to energy use, this result can largely be explained by segmenting the average percentage change in energy costs for a climate zone by a location's current energy code. Considering only the states that have adopted *ASHRAE 90.1-2007*, the average percentage reductions in energy costs trend lower from the warmer to colder climate zones. However, there is some additional variation that results from each location's average cost per unit of energy. For example, cities in Zone 3 realize the greatest reductions in energy costs, particularly the cities in California located in Subzone 3C because the state average cost of electricity in California is the 9th highest in the United States.

Table 14-8 Average Percentage Change in Energy Costs for LEC by Climate Zone and State Energy Code, 10-Year

Climate Zone/Subzone	Percentage Change by State Energy Code				
	1999	2001	2004	2007	All
1			**-23.1**	**-21.3**	**-22.2**
2	**-39.5**		**-26.4**	**-20.4**	**-22.6**
A	-39.1			-20.4	-21.4
B	-39.9		-26.4	-20.0	-28.2
3	**-36.8**	**-33.7**	**-22.9**	**-22.2**	**-25.3**
A	-36.8	-33.7	-22.3	-20.2	-26.4
B			-25.0	-23.4	-23.5
C				-25.0	-25.0
4	**-33.5**	**-30.2**	**-21.9**	**-20.2**	**-23.2**
A	-32.9	-30.2	-21.9	-20.3	-24.0
B	-37.2			-23.3	-26.1
C				-18.8	-18.8
5	**-34.9**	**-33.4**	**-21.8**	**-19.4**	**-21.0**
A	-33.3	-26.5		-19.5	-20.0
B	-36.4	-35.7	-21.8	-18.8	-23.3
6	**-30.8**	**-31.6**	**-17.7**	**-16.7**	**-21.2**
A	-29.7	-28.5	-17.7	-16.7	-19.8
B	-31.7	-33.2		-16.7	-23.0
7	**-30.4**		**-19.7**	**-16.8**	**-25.5**
8	**-23.4**				**-23.4**
Grand Total	**-32.4**	**-32.3**	**-21.8**	**-19.7**	**-22.6**

Average energy-related carbon emissions are assumed constant across study period lengths. The data reported in Table 14-9 show that the average reduction in energy-related carbon emissions for the LEC design ranges from 18.5 % to 25.8 % depending on climate zone. Even though carbon emissions are a function of electricity and natural gas consumption, greater reductions in energy use do not necessarily lead to greater reduction in carbon emissions. The greatest reductions in carbon emissions occur in Zone 3 (25.8 %) followed by Zone 7 (25.1 %). The lowest reduction occurs in Zone 8 (18.5 %) followed by Zone 6 (21.3 %) and Zone 5 (21.4 %).

Similar to energy use and energy costs, this result can largely be explained by segmenting the average percentage change in energy-related carbon emissions for a climate zone by a location's current energy code. Considering only the states that have adopted *ASHRAE 90.1-2007*, the average percentage reductions in carbon emissions trend lower from the warmer to colder climate zones. However, there is some additional variation that results from two factors. First, cities that realize a greater shift in energy use from electricity to natural gas realize greater reductions in carbon emissions. Second, cities with a greater differential in average emissions per unit of electricity relative to natural gas will realize greater reductions per unit of energy shifted from natural gas to electricity.

Table 14-9 Average Change in Energy-related Carbon Emissions for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change by State Energy Code				
	1999	2001	2004	2007	All
1			**-23.9**	**-22.0**	**-23.0**
2	**-40.1**		**-27.3**	**-21.0**	**-23.2**
A	-39.9			-21.0	-22.0
B	-40.3		-27.3	-20.3	-28.8
3	**-38.8**	**-36.2**	**-23.6**	**-22.2**	**-25.8**
A	-38.8	-36.2	-23.3	-21.3	-27.9
B			-24.5	-22.9	-23.0
C				-21.8	-21.8
4	**-36.3**	**-34.8**	**-23.0**	**-20.7**	**-24.3**
A	-35.9	-34.8	-23.0	-21.0	-25.6
B	-38.7			-22.4	-25.7
C				-19.3	-19.3
5	**-37.0**	**-36.1**	**-21.5**	**-19.6**	**-21.4**
A	-36.2	-33.9		-19.8	-20.5
B	-37.9	-36.8	-21.5	-18.9	-23.4
6	**-31.0**	**-32.8**	**-18.4**	**-16.7**	**-21.3**
A	-30.4	-29.6	-18.4	-16.9	-20.1
B	-31.5	-34.5		-16.4	-23.0
7	**-29.3**		**-20.1**	**-17.8**	**-25.1**
8	**-18.5**				**-18.5**
Grand Total	**-32.9**	**-35.1**	**-22.3**	**-20.0**	**-22.9**

The results reported in Table 14-10 show that changes in life-cycle costs vary across climate zones and study periods. The LEC design is cost-effective for all study periods across all climate zones. The percentage reduction in life-cycle costs becomes smaller from the 1-year to 5-year and 10-year study periods, and then slowly increases from the 10-year to 40-year study period. For study period lengths of 10 years or greater, the warmer the climate zone, the greater the percentage reduction in life-cycle costs. For example, the average percentage reduction for the 40-year study period ranges from 3.0 % in Zone 1 to 0.6 % for Zone 8.

Table 14-10 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and Study Period

Climate Zone/Subzone	Study Period Length								
	1	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**
1	**-10.7**	**-3.3**	**-2.5**	**-2.9**	**-2.6**	**-2.7**	**-2.9**	**-3.0**	**-3.0**
2	**-2.7**	**-1.4**	**-1.4**	**-2.1**	**-2.0**	**-2.1**	**-2.3**	**-2.5**	**-2.4**
A	-1.8	-1.1	-1.2	-1.9	-1.7	-1.9	-2.1	-2.2	-2.2
B	-6.9	-2.8	-2.5	-3.4	-3.1	-3.3	-3.5	-3.6	-3.6
3	**-3.1**	**-1.3**	**-1.3**	**-1.6**	**-1.8**	**-2.2**	**-2.4**	**-2.5**	**-2.4**
A	-2.9	-1.3	-1.3	-1.7	-2.0	-2.4	-2.6	-2.7	-2.6
B	-3.4	-1.5	-1.4	-1.6	-1.8	-2.1	-2.3	-2.4	-2.2
C	-2.8	-0.6	-0.6	-0.9	-0.6	-1.0	-1.4	-1.5	-1.4
4	**-2.3**	**-0.9**	**-0.9**	**-1.8**	**-1.6**	**-1.8**	**-2.1**	**-2.2**	**-2.1**
A	-2.2	-0.9	-1.0	-2.0	-1.8	-2.0	-2.3	-2.5	-2.4
B	-2.7	-1.2	-1.2	-2.0	-1.8	-2.1	-2.4	-2.6	-2.4
C	-2.4	-0.4	-0.4	-1.1	-0.8	-0.9	-1.2	-1.3	-1.2
5	**-4.6**	**-1.2**	**-1.0**	**-1.4**	**-1.2**	**-1.3**	**-1.5**	**-1.7**	**-1.7**
A	-3.9	-0.9	-0.9	-1.2	-1.0	-1.2	-1.4	-1.6	-1.6
B	-6.1	-1.7	-1.4	-1.8	-1.5	-1.6	-1.8	-2.0	-1.9
6	**-3.6**	**-0.8**	**-0.8**	**-1.0**	**-0.8**	**-0.9**	**-1.0**	**-1.2**	**-1.1**
A	-3.8	-0.9	-0.9	-1.1	-0.9	-1.1	-1.2	-1.3	-1.2
B	-3.4	-0.7	-0.7	-0.9	-0.7	-0.8	-0.9	-1.0	-0.9
7	**-3.4**	**-0.8**	**-1.0**	**-1.2**	**-1.1**	**-1.2**	**-1.4**	**-1.5**	**-1.5**
8	**-19.4**	**-1.7**	**-0.6**	**-0.5**	**-0.3**	**-0.4**	**-0.6**	**-0.7**	**-0.6**
Average	**-3.8**	**-1.1**	**-1.1**	**-1.5**	**-1.4**	**-1.6**	**-1.8**	**-1.9**	**-1.9**

14.5 Low Energy Case Summary

The LEC design is the most energy efficient building design considered in this study, which leads to the greatest percentage savings in energy use, energy costs, and carbon emissions overall. There are several factors that impact the percentage savings from adopting the LEC design, including the current state energy code, selected study period length, building type, and climate zone of the location.

On average, the nationwide adoption of the LEC design as the building energy code for a 3-story office building significantly decreases energy use (23.0 %), energy costs (25.2 %), and carbon emissions (22.9 %), while reducing life-cycle costs (2.2 %) for a 10-year study period. The LEC design is cost-effective for 43 of 50 states. All seven states that realize an increase in life-cycle costs have adopted no energy code or a code based on *ASHRAE 90.1-1999/2001*.

The study period length impacts the resulting reductions in life-cycle costs. For a 5-year study period, four of 11 building types realize an increase in life-cycle costs, on average across the United States. These same four building types become cost-effective as the study period becomes longer, with all four becoming cost-effective for a 15-year study period. Setting the study period length is a determinant to some degree of the size of the life-cycle cost savings, in percentage terms, for the most energy efficient commercial buildings.

Different building types realize different national average percentage reductions in energy use, energy costs, life-cycle costs, and carbon emissions. The buildings with the greatest window-to-wall ratios tend to realize the lowest energy use, energy costs, and carbon emissions reductions while restaurants and small office buildings realize the greatest reductions. The greatest reductions in life-cycle costs for a 10-year study period are realized by restaurants followed by 3- and 8-story office buildings while the only building type to realize an increase in life-cycle costs is the 16-story office building.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, carbon emissions, and life-cycle costs. After controlling for the current state energy code, the warmest climates realize the greatest average percentage reductions in energy use. The average percentage reduction in energy costs is correlated with reductions in energy use, but there is less variation because colder locations realize a shift in energy use from more expensive electricity to cheaper natural gas. So even though overall energy use does not decrease as much in the colder climate zones, the overall energy cost savings are greater per percentage reduction in energy use. The shift in energy use from electricity to natural gas consumption also decreases carbon emissions because natural gas is “cleaner” than electricity in terms of cradle-to-grave energy-related carbon emissions. Therefore, the reductions in carbon emissions per percentage reduction in energy use are greater in the colder climate zones. In general, the warmer the climate, the greater the percentage reduction in life-cycle costs from adopting the LEC design, particularly for longer study periods.

15 Savings from Nationwide Adoption of *ASHRAE 90.1-2007*

This section analyzes benefits from nationwide adoption of *ASHRAE 90.1-2007* relative to the current collection of state energy codes. Benefits are evaluated across several dimensions: geography (state and climate zone), time, and building type.

It would be expected that states with energy codes based on older editions of *ASHRAE 90.1*, or no energy code at all, would realize greater benefits from adopting *ASHRAE 90.1-2007* because buildings in those states are expected to be built in a less energy efficient manner. Figure 15-1 shows the 14 states with energy codes based on older editions of *ASHRAE 90.1* (*-1999*, *-2001*, or no energy code).[32] Most of the central U.S. states have adopted older energy standard editions, as have a few states in the south, West Virginia, Maine, Arizona, and Alaska.

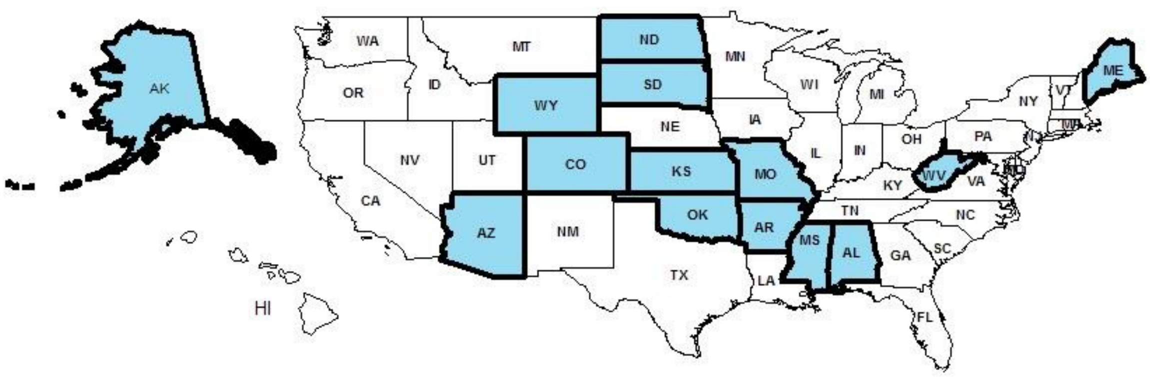

Figure 15-1 States that have Adopted *ASHRAE 90.1-2001* or No Energy Code

The 32 states that have adopted *ASHRAE 90.1-2007*, highlighted gray in Figure 15-2, are spread out across the nation from the West Coast across to the Northeast and down to Florida. These states will be white in the figures in this section, and are excluded from the analysis because there are no impacts to report.

[32] All maps are generated in ArcMap 10.1.

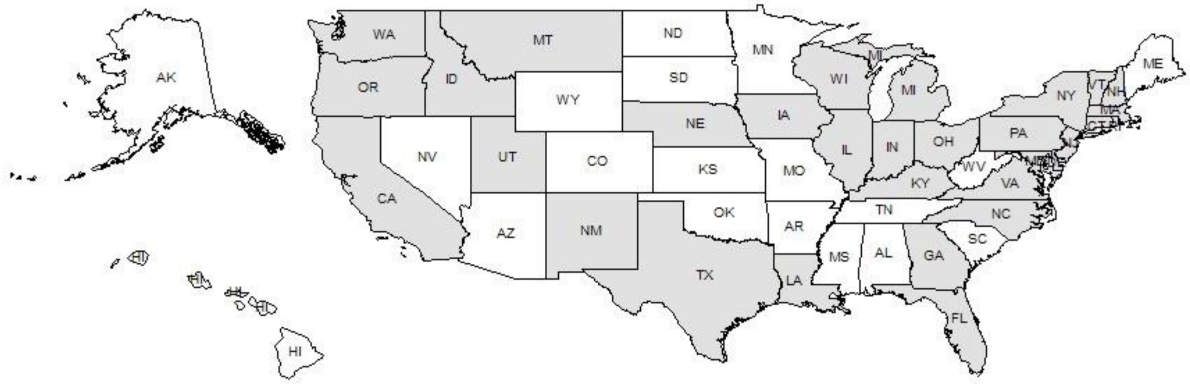

Figure 15-2 States that have Adopted *ASHRAE 90.1-2007*

As in the state-by-state analysis of the LEC design, analyzing benefits from adopting the *ASHRAE 90.1-2007* design requires an assumption on the study period length because costs to maintain and operate a building fluctuate over time. A 10-year study period is used as the baseline because it is one of the most realistic investor time frames of the 9 study period length options in BIRDS. The significance of the study period length will be tested in Section 15.2.

15.1 State Comparisons

State benefit comparisons are made based on the simple average changes for the cities analyzed in each state by building type.[33] One building type is chosen to illustrate the detailed analysis possible with the powerful BIRDS database compiled for this study. Energy use, energy costs, life-cycle costs, and carbon emissions 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-11 through Table B-20 in Appendix B.

15.1.1 3-Story Office Building

Table 15-1 summarizes the percentage changes in energy use, energy costs, life-cycle costs, and carbon emissions for the 3-story office building for a 10-year study period. On average, adoption of *ASHRAE 90.1-2007* for a 3-story office building decreases energy use, energy costs, and energy-related carbon emissions by over 10 % each while increasing life-cycle costs (0.5 %). These results exclude the states that have already adopted *ASHRAE 90.1-2007*.

[33] City-level data are not available to weight by amount of building construction in each city.

Table 15-1 Average Percentage Change by State, 3-Story Office Building, 10-Year

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-8.0	-10.6	-9.7	0.9	MS	-26.4	-21.1	-20.9	1.7
AL	-19.0	-18.3	-17.9	1.2	ND	-12.5	-12.9	-13.0	2.4
AR	-12.2	-13.8	-14.3	-3.4	NV	-5.7	-2.7	-3.5	-0.4
AZ	-15.8	-14.1	-13.7	0.6	OK	-13.8	-15.6	-16.8	2.6
CO	-11.3	-10.9	-10.9	-2.6	SC	-2.6	-2.4	-2.4	-0.6
HI	-1.6	-1.6	-1.6	-0.3	SD	-12.6	-12.8	-12.8	0.8
KS	-15.0	-14.4	-14.3	3.3	TN	-4.6	-2.6	-2.3	-0.4
ME	-14.2	-13.8	-13.8	1.6	WV	-13.5	-13.1	-12.1	-2.1
MN	-9.2	-4.3	-3.8	-0.5	WY	-13.3	-13.6	-13.6	2.2
MO	-14.8	-14.2	-13.9	3.0	**Avg.**	**-11.4**	**-10.6**	**-10.5**	**0.5**

These detailed results can be readily analyzed in mappings of the United States. Figure 15-3, Figure 15-4, Figure 15-6, and Figure 15-5 overlay Figure 15-1 and display the average percentage energy savings, energy cost savings, life-cycle cost savings, and carbon emissions reduction by state, respectively. The states with codes based on older editions of *ASHRAE 90.1*, or no energy code at all, are shown with cross hatching and bolded state borders. The 31 states that have already adopted *ASHRAE 90.1-2007* are shown in white and are excluded from the analysis. Figure 15-3 shows that 16 of 19 states realize energy use savings greater than 5 % by adopting *ASHRAE 90.1-2007* over their current state energy code. Many of the states that realize the greatest energy use savings are the ones that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* including all 13 states that realize energy use savings of more than 10 %.

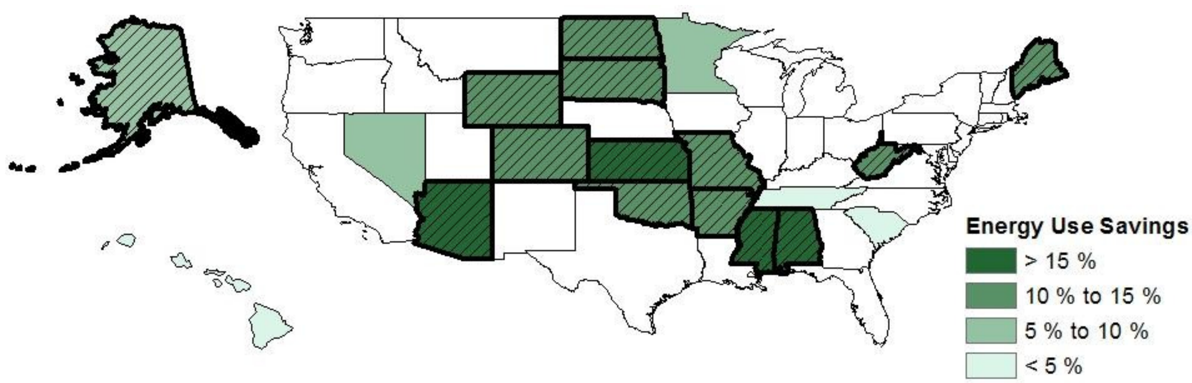

Figure 15-3 Average Energy Use Savings by State, 3-Story Office Building, 10-Year

Figure 15-4 overlays Figure 15-1 with the average energy cost savings over 10 years by state from adopting *ASHRAE 90.1-2007* in small office buildings. Every state reduces energy costs. The 14 states that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* are the top 14 in energy cost savings, with all 14 states realizing savings of greater than 10 %.

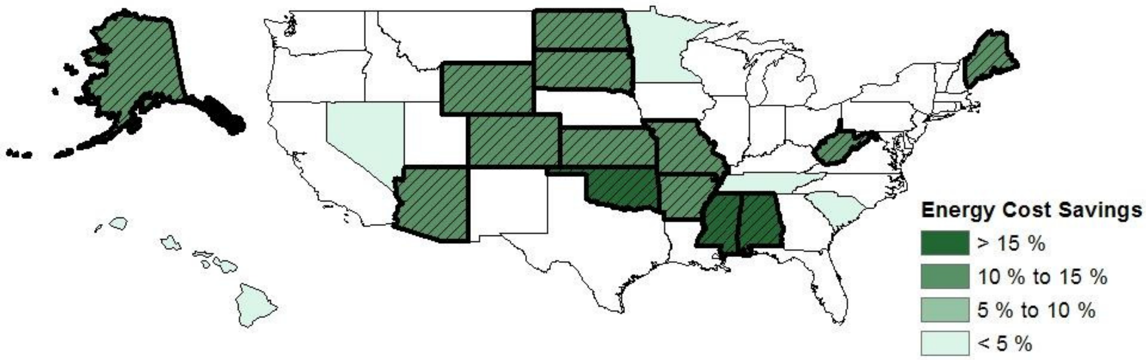

Figure 15-4 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year

Figure 15-5 overlays Figure 15-1 with the average energy-related reduction in carbon emissions by state from adopting *ASHRAE 90.1-2007*. All states reduce carbon emissions. The states that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* realize the greatest reduction in carbon emissions, with all 14 states realizing savings of greater than 5 % and 13 states realizing reductions of over 10 %. All 5 states that have adopted *ASHRAE 90.1-2004* as its state energy code realize reductions in carbon emissions of less than 5 %.

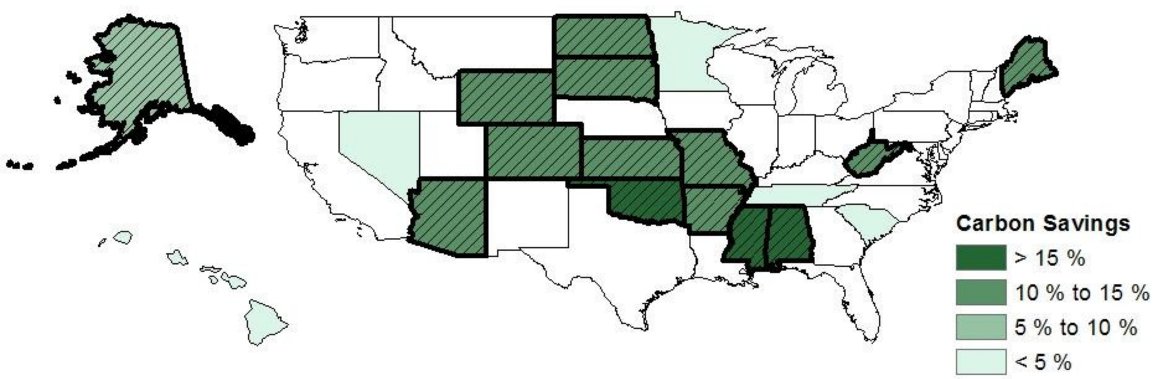

Figure 15-5 Average Carbon Reduction by State, 3-Story Office Building, 10-Year

For a 3-story office building, as expected, states that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* have the most to gain in percentage terms in energy use, energy cost, and carbon emissions savings from adopting more stringent state energy codes. However, the life-cycle cost-effectiveness of such adoptions varies across states.

Figure 15-6 overlays Figure 15-1 with the average life-cycle cost savings over 10 years by state from adopting *ASHRAE 90.1-2007*. Of the 19 states, 8 realize a decrease in life-cycle costs, on average. All 5 of the states that have adopted *ASHRAE 90.1-2004* as its state energy code realize reductions in life-cycle costs. There is significant variation in the average percentage change for the states that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1*.

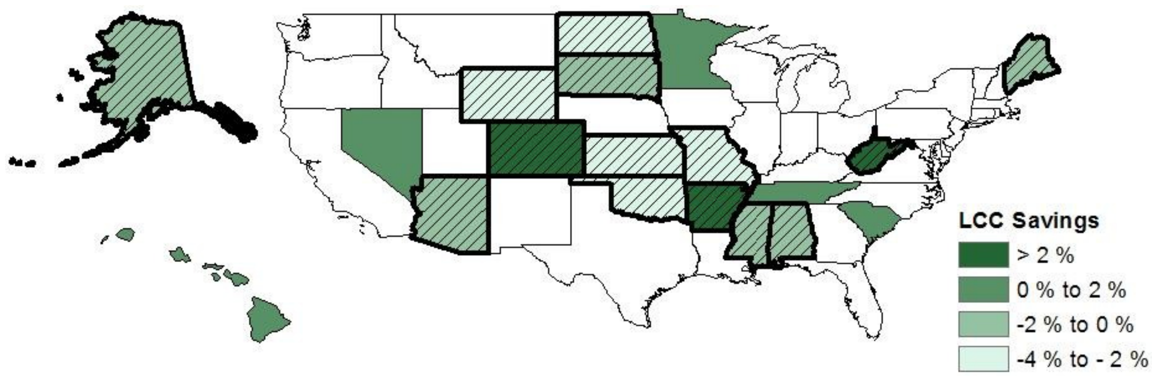

Figure 15-6 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year

15.2 Results by Study Period Length

The nationwide analysis up to this point has 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 periods 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 reduction in energy use from adoption of *ASHRAE 90.1-2007* is constant over all study period lengths because energy efficiency is assumed to be constant over time. The national average change in energy use across all cities in the study ranges from -15.6 % to 0.5 %, depending on the building type, with an overall national average of -9.6 %. The 16-story office building realizes a percentage increase in energy use because the relaxation of the window requirements overwhelms the impacts from the other energy efficiency measures required by *ASHRAE 90.1-2007*. Table 15-2 shows these results.

Table 15-2 Nationwide Average Percentage Change in Energy Use by Building Type

Building Type	Percentage Change
APART04	-11.4
APART06	-11.0
DORMI04	-12.3
DORMI06	-10.7
HOTEL15	-3.2
HIGHS02	-5.8
OFFIC03	-11.4
OFFIC08	-9.8
OFFIC16	0.5
RETAIL1	-15.2
RSTRNT1	-15.6
Average	**-9.6**

As shown in Table 15-3, savings in energy costs varies slightly, in percentage terms, over increasing study period lengths. The national average change in energy costs across all location-building type combinations ranges from -12.3 % to -12.0 % for all study period lengths. There is minor variation of up to 0.6 percentage points for some building types across study periods as a result of the escalation rates used to adjust future energy prices, which vary by U.S. Census Region.

Table 15-3 Nationwide 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	-16.9	-16.7	-16.7	-16.6	-16.5	-16.4	-16.3	-16.3	-16.3
APART06	-16.6	-16.4	-16.3	-16.2	-16.2	-16.1	-16.0	-16.0	-16.0
DORMI04	-17.4	-17.3	-17.2	-17.1	-17.1	-17.0	-16.9	-16.9	-16.9
DORMI06	-16.5	-16.4	-16.3	-16.2	-16.1	-16.0	-16.0	-16.0	-16.0
HOTEL15	-8.3	-8.2	-8.1	-8.0	-8.0	-7.9	-7.8	-7.8	-7.8
HIGHS02	-7.8	-7.7	-7.7	-7.7	-7.6	-7.6	-7.6	-7.6	-7.6
OFFIC03	-10.6	-10.6	-10.6	-10.6	-10.6	-10.7	-10.7	-10.7	-10.7
OFFIC08	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5	-9.5
OFFIC16	-0.9	-0.8	-0.8	-0.8	-0.8	-0.8	-0.7	-0.7	-0.7
RETAIL1	-15.1	-15.1	-15.1	-15.1	-15.1	-15.1	-15.1	-15.1	-15.1
RSTRNT1	-15.5	-15.5	-15.5	-15.5	-15.5	-15.5	-15.5	-15.5	-15.5
Average	**-12.3**	**-12.2**	**-12.2**	**-12.1**	**-12.1**	**-12.1**	**-12.0**	**-12.0**	**-12.0**

Since the national average reduction in energy use across all location-building type combinations is constant over all study period lengths, the average change in energy-related carbon emissions is also constant at -4.0 %. The national average change in carbon emissions ranges from -5.7 % to -0.3 % depending on the building type, as shown in Table 15-4.

Table 15-4 Nationwide Average Percentage Change in Carbon Emissions by Building Type

Building Type	Percentage Change
APART04	-17.4
APART06	-17.1
DORMI04	-17.9
DORMI06	-17.1
HOTEL15	-11.5
HIGHS02	-8.8
OFFIC03	-8.2
OFFIC08	-10.5
OFFIC16	-9.3
RETAIL1	-0.9
RSTRNT1	-15.0
Average	-15.6

Table 15-5 shows that the percentage change in life-cycle costs varies slightly over increasing study period lengths, with the average change across all location-building type combinations ranging from -1.9 % for a 1-year study period to -0.7 % for a 10-year study period. The national average change in life-cycle costs ranges from -6.7 % to 2.3 % depending on the building type for a 1-year study period. The nationwide change in life-cycle costs averages -0.7 % for a 10-year study period length, ranging from -1.7 % to 0.5 % depending on the building type. As the study period length increases from 10 years to 40 years, the percentage reduction in national average life-cycle costs increases, with an overall average percentage change of -0.7 % to -1.1 %, respectively. Also, the number of building types that realize reductions in life-cycle costs increases from 7 for a 20-year study period to 10 for a 40-year study period.

Table 15-5 National 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	-1.8	-1.8	-1.7	-1.8	-1.9	-1.9	-1.9	-2.0	-2.0
APART06	-1.1	-1.6	-1.6	-1.8	-1.8	-1.9	-1.9	-2.0	-2.0
DORMI04	-4.1	-1.1	-0.9	-1.0	-1.1	-1.2	-1.2	-1.3	-1.4
DORMI06	-2.1	-2.1	-2.0	-2.1	-2.1	-2.2	-2.2	-2.3	-2.3
HOTEL15	-1.4	-1.3	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2	-1.2
HIGHS02	-1.4	-0.8	-0.8	-0.9	-0.9	-1.0	-1.1	-1.1	-1.1
OFFIC03	-3.1	0.4	0.5	0.3	0.2	0.1	0.1	0.0	-0.1
OFFIC08	0.2	0.6	0.5	0.3	0.1	-0.0	-0.0	-0.1	-0.2
OFFIC16	-1.5	-0.3	-0.1	0.1	0.1	0.2	0.2	0.2	0.3
RETAIL1	-6.7	-1.2	-0.9	-1.1	-1.2	-1.3	-1.4	-1.4	-1.5
RSTRNT1	2.3	0.8	0.4	0.0	-0.2	-0.4	-0.5	-0.6	-0.7
Average	**-1.9**	**-0.8**	**-0.7**	**-0.8**	**-0.9**	**-1.0**	**-1.0**	**-1.1**	**-1.1**

15.3 Results by Building Type

Table 15-6 shows the simple average changes, in percentage terms, from adopting *ASHRAE 90.1-2007* by building type for a 10-year study period length. The tallest buildings realize the lowest reductions in energy use. The only building type that realizes an increase in energy use is the 16-story office building. The hotel and high school realize reductions in energy use of 3.2 % and 5.8 %, respectively. The remaining building types all realize reductions in energy use greater than 9.8 %. All building types realize reductions in energy costs, ranging from 0.8 % to 17.2 %. The 16-story office building realizes small reductions in energy costs even though its energy use increases because energy use is shifted from electricity to natural gas. The apartments and dormitories realize the greatest reductions in energy costs. All building types realize reductions in energy-related carbon emissions, ranging from 0.9 % to 17.9 %. The greatest reductions in carbon emissions are realized by the apartment buildings and dormitories at over 15.0 % while the smallest reductions are realized by the 16-story office building. Of the 11 building types, 8 realize a decrease in life-cycle costs. The greatest reductions in life-cycle costs are realized by the 6-story dormitory (2.0 %) and 4-story apartment building (1.7 %). The greatest life-cycle cost increases are realized by the 3-and 8-story office buildings (0.5 % each) and the restaurant (0.4 %).

Table 15-6 Nationwide Percentage Change for *ASHRAE 90.1-2007* by Building Type, 10-Year

Building Type	Percentage Change			
	Energy Use	Energy Cost	LCC	Carbon
APART04	-11.4	-16.7	-1.7	-17.4
APART06	-11.0	-16.3	-1.6	-17.1
DORMI04	-12.3	-17.2	-0.9	-17.9
DORMI06	-10.7	-16.3	-2.0	-17.1
HOTEL15	-3.2	-8.1	-1.2	-11.5
HIGHS02	-5.8	-7.7	-0.8	-8.8
OFFIC03	-11.4	-10.6	0.5	-8.2
OFFIC08	-9.8	-9.5	0.5	-10.5
OFFIC16	0.5	-0.8	-0.1	-9.3
RETAIL1	-15.2	-15.1	-0.9	-0.9
RSTRNT1	-15.6	-15.5	0.4	-15.0
Average	**-9.6**	**-12.2**	**-0.7**	**-15.6**

Overall, the buildings with the greatest window-to-wall ratios realize the lowest reductions, or even increases, in energy use, energy costs, and carbon emissions while the residential buildings (apartments and dormitories), retail stores, and restaurants realize the greatest reductions.

15.4 Results by Climate Zone

Table 15-7 shows the nationwide average change in energy use by *ASHRAE* climate zone. These changes are for the adoption of *ASHRAE 90.1-2007* relative to current state energy codes for all building types. The warmest and coldest climate zones, Zone 1 and Zone 8, realize the smallest overall percentage changes in energy use. Zone 8 realizes an increase of energy use of 1.7 % while Zone 1 realizes a small decrease of 1.1 %. Zone 2 realizes the highest reductions in energy use at 16.3 % followed by Zone 3 (12.0 %) and Zone 4 (10.4 %).

Table 15-7 Average Percentage Change in Energy Use for *ASHRAE 90.1-2007* by Climate Zone

Climate Zone/Subzone	Percentage Change			
	1999	2001	2004	All
1			**-1.1**	**-1.1**
2	**-24.0**		**-8.6**	**-16.3**
A	-23.9			-23.9
B	-24.2		-8.6	-13.8
3	**-19.6**	**-13.8**	**-1.9**	**-12.0**
A	-19.6	-13.8	-1.7	-12.7
B			-2.7	-2.7
4	**-14.0**	**-12.9**	**-2.5**	**-10.4**
A	-13.6	-12.9	-2.5	-10.0
B	-16.1			-16.1
5	**-14.5**	**-12.3**	**-3.5**	**-7.9**
A	-12.7	-11.2		-11.9
B	-16.2	-12.7	-3.5	-7.2
6	**-11.2**	**-10.3**	**-4.4**	**-9.7**
A	-10.6	-9.6	-4.4	-8.2
B	-11.7	-10.7		-11.4
7	**-10.5**		**-7.4**	**-9.7**
8	**1.7**			**1.7**
Grand Total	**-12.9**	**-12.3**	**-3.7**	**-9.6**

Similar to the LEC design, the current state energy codes are a key driver of these results. The variation across climate zones diverges depending on the state energy code. For locations in states that have not adopted any state energy code or have adopted older editions of *ASHRAE 90.1* (*-1999* or *-2001*), warmer climate zones realize greater percentage reductions in energy use. For states that have no state energy code or have adopted *ASHRAE 90.1-1999*, cities in Zone 2 realize an average percentage reduction of 24.0 % while Zone 8 realizes an increase of 1.7 % from adopting the *ASHRAE 90.1-2007* design. For cities located in states that have adopted *ASHRAE 90.1-2004*, the percentage reductions in energy use are much smaller, ranging from 1.1 % to 8.6 %, and do not follow the same trend where colder climate zones realize smaller reductions in energy use. Instead the percentage changes are the greatest for cities in Zone 2 followed by Zone 7 and smallest for cities in Zone 1 and Zone 3.

Table 15-8 shows that the average reduction in energy costs over a 10-year study period ranges from 1.1 % to 15.2 % depending on the climate zone. Zone 2, Zone 3, Zone 6, and Zone 7 realize reductions in energy costs over 13 %. Zone 1 realizes reductions in energy costs of only 1.1 %. The reductions in energy costs for Zone 8 of 10.2 % could be considered surprising given that Zone 8 realizes an increase in energy use.

Table 15-8 Average Percentage Change in Energy Costs for *ASHRAE 90.1-2007* by Climate Zone, 10-Year

Climate Zone/Subzone	Percentage Change			
	1999	**2001**	**2004**	**All**
1			**-1.1**	**-1.1**
2	**-24.1**		**-6.4**	**-15.2**
A	-24.1			-24.1
B	-24.1		-6.4	-12.3
3	**-21.5**	**-18.1**	**-2.9**	**-14.1**
A	-21.5	-18.1	-2.7	-14.9
B			-3.7	-3.7
4	**-17.1**	**-14.7**	**-0.9**	**-11.9**
A	-16.7	-14.7	-0.9	-11.4
B	-19.1			-19.1
5	**-18.0**	**-16.4**	**-1.4**	**-8.6**
A	-17.0	-13.0		-15.0
B	-19.0	-17.6	-1.4	-7.4
6	**-16.6**	**-17.1**	**-1.9**	**-13.8**
A	-15.9	-14.7	-1.9	-10.5
B	-17.1	-18.4		-17.5
7	**-16.5**		**-4.2**	**-13.4**
8	**-9.8**			**-9.8**
Grand Total	**-17.4**	**-16.6**	**-2.3**	**-12.1**

These results are similar to those realized for reductions in energy use in that they can be better explained after controlling for the current state energy codes. Reductions in energy use can explain some, but not all of the variation in energy costs. The remainder is a result of a shift in energy use from one energy source to another. For example, the adoption of *ASHRAE 90.1-2007* leads to a percentage change in energy use of -24.0 % and 1.7 % for cities in Zone 2 and Zone 8, respectively. Meanwhile, the percentage change in energy costs is -24.1 % and -9.8 %, respectively. The percentage change in energy use explains the entire percentage change in energy costs for cities in Zone 2. However, cities in Zone 8 realize a percentage increase in energy use and a seemingly contradictory decrease in energy costs. The adoption of *ASHRAE 90.1-2007* decreases electricity consumption, but increases natural gas consumption by a greater amount. Due to the higher cost of electricity for cities in Zone 8, energy use is increased while energy costs are decreased. Similar shifts occur for cities throughout the other climate zones, where the size of the impact depends on the size of the fuel shift and the differential between the average cost of electricity and average cost of natural gas.

Average energy-related carbon emissions are constant across study period lengths. The data reported in Table 15-9 show that the average reduction in energy-related carbon emissions for the LEC design ranges from 1.2 % to 15.3 % depending on the climate zone. Zone 1, Zone 8, and Zone 5 realize the smallest percentage reductions in carbon emissions while Zone 2 and Zone 3 realize the greatest reduction. Similar to reductions in energy costs, reductions in energy use can explain some, but not all of the variation in the reductions in carbon emissions. The remainder is a result of a shift in energy use from one energy source to another. For example, the adoption of *ASHRAE 90.1-2007* leads to a percentage change in energy use of 1.7 % and a percentage change in carbon emissions of -5.8 % for cities in Zone 8. For Alaska, the average carbon emissions rate for electricity is greater than the average carbon emissions rate for natural gas. The shift in energy use from electricity to natural gas leads to an overall decrease in carbon emissions while total energy use increases.

Table 15-9 Average Change in Energy-related Carbon Emissions for *ASHRAE 90.1-2007* by Climate Zone

Climate Zone/Subzone	Percentage Change			
	1999	2001	2004	All
1			**-1.2**	**-1.2**
2	**-24.0**		**-6.5**	**-15.3**
A	-23.8			-23.8
B	-24.1		-6.5	-12.4
3	**-22.5**	**-19.7**	**-3.2**	**-15.0**
A	-22.5	-19.7	-3.0	-15.9
B			-3.7	-3.7
4	**-18.3**	**-16.9**	**-1.0**	**-13.1**
A	-18.1	-16.9	-1.0	-12.5
B	-19.6			-19.6
5	**-18.9**	**-17.7**	**-2.1**	**-9.5**
A	-18.3	-16.8		-17.5
B	-19.5	-18.0	-2.1	-8.0
6	**-16.6**	**-17.9**	**-1.9**	**-14.0**
A	-16.3	-15.3	-1.9	-10.8
B	-17.0	-19.2		-17.6
7	**-15.6**		**-3.9**	**-12.7**
8	**-5.8**			**-5.8**
Grand Total	**-17.4**	**-18.0**	**-2.5**	**-12.4**

The results reported in Table 15-10 show that changes in life-cycle costs vary across climate zones and study periods. Adopting *ASHRAE 90.1-2007* is cost-effective for all study periods, on average, in Zone 2, Zone 3, Zone 5, Zone 6, Zone 7, and Zone 8. Adopting *ASHRAE 90.1-2007* is not cost-effective in Zone 1 and Zone 4 over a 1-year study period, but is cost-effective at 5 years and 10 years, respectively.

Table 15-10 Average Percentage Change in Life-Cycle Costs for *ASHRAE 90.1-2007* by Climate Zone and Study Period

Climate Zone/Subzone	Study Period Length								
	1	5	10	15	20	25	30	35	40
1	**0.7**	**-0.1**	**-0.2**	**-0.3**	**-0.3**	**-0.3**	**-0.3**	**-0.3**	**-0.3**
2	**-4.9**	**-1.4**	**-1.2**	**-1.4**	**-1.4**	**-1.6**	**-1.5**	**-1.6**	**-1.7**
A	-1.1	-0.5	-0.8	-1.2	-1.4	-1.6	-1.6	-1.8	-1.9
B	-6.2	-1.7	-1.3	-1.5	-1.5	-1.5	-1.5	-1.6	-1.6
3	**-0.6**	**-0.9**	**-1.0**	**-1.2**	**-1.5**	**-1.6**	**-1.7**	**-1.7**	**-1.8**
A	-0.6	-1.0	-1.1	-1.3	-1.5	-1.7	-1.7	-1.8	-1.9
B	-0.6	-0.5	-0.4	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
4	**1.0**	**-0.0**	**-0.2**	**-0.5**	**-0.5**	**-0.6**	**-0.6**	**-0.7**	**-0.7**
A	0.8	-0.1	-0.3	-0.5	-0.5	-0.6	-0.6	-0.7	-0.7
B	2.6	0.5	0.1	-0.4	-0.5	-0.6	-0.6	-0.7	-0.8
5	**-3.2**	**-1.2**	**-0.9**	**-1.0**	**-0.9**	**-0.9**	**-0.9**	**-1.0**	**-1.0**
A	-2.1	-1.1	-1.1	-1.2	-1.2	-1.3	-1.3	-1.5	-1.6
B	-3.4	-1.2	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9	-0.9
6	**-2.2**	**-0.8**	**-0.8**	**-0.8**	**-0.9**	**-1.0**	**-1.0**	**-1.1**	**-1.1**
A	-2.5	-0.7	-0.6	-0.6	-0.7	-0.7	-0.8	-0.8	-0.9
B	-1.8	-1.0	-1.0	-1.1	-1.1	-1.2	-1.2	-1.3	-1.4
7	**-6.1**	**-1.0**	**-0.7**	**-0.7**	**-0.7**	**-0.8**	**-0.8**	**-0.9**	**-0.9**
8	**-0.7**	**-0.2**	**-0.2**	**-0.3**	**-0.4**	**-0.4**	**-0.5**	**-0.5**	**-0.6**
Average	**-1.9**	**-0.8**	**-0.7**	**-0.8**	**-0.9**	**-1.0**	**-1.0**	**-1.1**	**-1.1**

Figure 2-2 shows that the average change in life-cycle costs converges at the 10-year study period, with cities in all climate zones realizing reductions in life-cycle costs by for study period of 5 years or greater. In general, the cost-effectiveness of adopting *ASHRAE 90.1-2007* increases as the study period length increases from 10 years to 40 years. These results emphasize the importance of selecting the appropriate study period for the analysis.

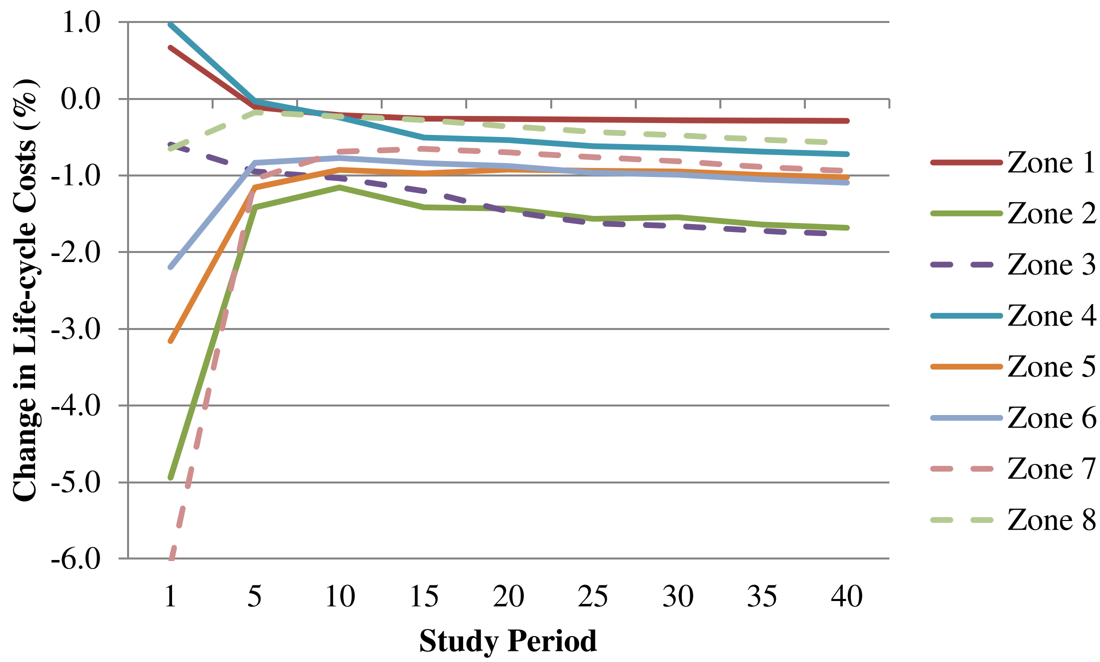

Figure 15-7 Percentage Change in Life-Cycle Cost from Nationwide Adoption of *ASHRAE 90.1-2007* by Study Period Length and *ASHRAE* Climate Zone

15.5 *ASHRAE 90.1-2007* Summary

ASHRAE 90.1-2007 is the most recent edition of *ASHRAE 90.1* considered in this study, and is the newest edition to be adopted by a state as its commercial building energy code as of December 2011.

Overall, the adoption of *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and carbon emissions. There are several factors that impact the percentage savings from adopting *ASHRAE 90.1-2007*, including the current state energy code, selected study period length, building type, and climate zone of the location.

The nationwide adoption of *ASHRAE 90.1-2007* as the commercial building energy code for a 3-story office building decreases energy use (11.4 %), energy costs (10.6 %), and carbon emissions (10.3 %) while increasing life-cycle costs (0.5 %) for a 10-year study period, on average. Although *ASHRAE 90.1-2007* leads to reductions for all states for energy use, energy costs, and carbon emissions, the magnitude of the reductions varies across states due to each state's adopted energy code. States with no energy code or a code based on *ASHRAE 90.1-1999/2001* realize the greatest percentage savings in energy use, energy costs, and carbon emissions.

The study period length impacts the resulting percentage change in life-cycle costs. For a 20-year study period, 8 of the 11 building types realize an average reduction in life-cycle costs with a percentage change in life-cycle costs of -2.1 % to 0.2 %. Two additional building types (10 of 11) become cost-effective at a 40-year study period, with a percentage change in life-cycle costs of -2.3 % to -0.1 %. Selecting the appropriate study period length is a major determinant in the life-cycle cost-effectiveness of adopting ASHRAE 90.1-2007 as a state energy code for commercial buildings.

Different building types realize different national average percentage changes in energy use, energy costs, life-cycle costs, and carbon emissions. Overall, the buildings with the greatest window-to-wall ratios realize the lowest reductions in energy use, energy costs, and carbon emissions while the residential buildings (apartments and dormitories), retail stores, and restaurants realize the greatest reductions.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, carbon emissions, and life-cycle costs. After controlling for each state's energy code, cities in warmer climates tend to realize greater percentage reductions in energy use. The average percentage reduction in energy use can explain some, but not all the variation in the average percentage reductions in energy costs and carbon emissions. The remaining variation is driven by the relative cost and emissions rate per unit of energy for the two energy sources, where electricity is higher in both categories. There is a high correlation in the warmest climate zone (Zone 1) because nearly all energy use is from electricity consumption. For locations in which both electricity and natural gas consumption decreases, the energy cost and carbon emissions reductions are less than the reductions in energy use. For locations in which electricity consumption decreases while natural gas consumption increases (a.k.a. a shift from cooling loads to heating loads), the energy cost and carbon emissions reductions are greater than the reductions in energy use. In the extreme case (Zone 8), the increase in natural gas use is greater than the decrease in electricity use, leading to an increase in energy use while the shift to natural gas decreases energy costs and carbon emissions. In general, cities in warmer climate zones tend to realize a greater percentage reduction in life-cycle costs.

16 Discussion

This study analyzes the impacts of adopting new, more stringent state energy codes for 228 cities located across the United States for 11 prototypical building types. Results are summarized at the national level as well as the state level for 7 representative states. This section will discuss the key findings, limitations of the research, and recommended directions for future research.

16.1 Key Findings

Overall, adoption of *ASHRAE 90.1-2007* for the 19 states that have not yet adopted it as their state energy code leads to reductions in energy use, energy costs, and energy-related carbon emissions. The average state reduction in energy use for new commercial buildings is 9.6 % while energy costs and carbon emissions realize average reductions of 12.2 % and 12.4 %, respectively for a 10-year study period. The reductions in energy use and carbon emissions are cost-effective, with average life-cycle costs decreasing by 0.7 %.

However, *ASHRAE 90.1-2007* does not lead to energy efficiency improvements over older editions of *ASHRAE 90.1* for all locations in the U.S. for two reasons. First, the simplification of the *ASHRAE* climate zones from 26 zones in *ASHRAE 90.1-2001* to 8 zones in *ASHRAE 90.1-2004* resulted in the relaxation of some building envelope requirements for some locations. Second, *ASHRAE 90.1-2007* has less stringent solar heat gain coefficient (SHGC) requirements relative to *ASHRAE 90.1-2004* for some climate zones. As a result, high-rise, 100 % glazed buildings realize smaller reductions, and occasionally increases, in energy use because the less stringent window requirements overwhelm the stricter requirements for other energy efficiency measures analyzed in this study.

Overall, adoption of the LEC design in all 50 states leads to nationwide reductions in energy use, energy costs, and carbon emissions greater than those realized by *ASHRAE 90.1-2007*. The average state reduction in energy use is 17.8 % over current state energy codes while energy costs and carbon emissions realize average reductions of 22.6 % and 20.4 %, respectively. The reductions in energy use and carbon emissions are cost-effective, with life-cycle costs decreasing by 1.1 % on average for a 10-year study period.

States with current energy codes based on older editions of *ASHRAE 90.1* realize greater reductions in energy use, energy costs, and carbon emissions for the *ASHRAE 90.1-2007* design. For a small office building, the 13 states with reductions in energy use of at least 10 % have no state energy code or have adopted *ASHRAE 90.1-1999/2001*. For the LEC design, 14 of the 18 states that realize reductions in energy use greater than 25 % have no state energy code or have adopted *ASHRAE 90.1-1999/2001*, including all 13 states with reductions greater than 30 %. Similar trends hold for energy costs and energy-related carbon emissions.

Over all building types, states located in the warmest climates realize the greatest reductions in energy use from adopting the "Low Energy Case" (LEC) design because several of the energy efficiency improvements (e.g., overhangs and daylighting controls) are more beneficial for warmer climates. However, states in colder climates see greater percentage reductions in energy costs and carbon emissions per percentage reduction in energy use because the energy efficiency measures tend to shift some energy use from electricity to natural gas consumption. Electricity is more expensive per unit of energy and typically has greater CO_2e emissions factors per unit of energy relative to natural gas. Therefore the shift of energy consumption from electricity to natural gas can lead to greater reductions in energy costs and energy-related carbon emissions than reductions in total energy use. In an extreme case, cities located in Zone 8 realize a reduction in energy costs and carbon emissions while realizing an increase in total energy use.

The results for the *ASHRAE 90.1-2007* design have some similarities and some differences relative to the results for the LEC design. Similar to the LEC design, the current state energy codes are a key driver of variation in the results. The variation across climate zones diverges depending on the state energy code. For locations in states that have not adopted any state energy code or have adopted older editions of *ASHRAE 90.1* (*-1999* or *-2001*), warmer climate zones realize greater percentage reductions in energy use. For cities located in states that have adopted *ASHRAE 90.1-2004*, the percentage reductions in energy use do not follow the same trend. Instead the percentage changes are the greatest for cities in Zone 2 followed by Zone 7 and smallest for cities in Zone 1 and Zone 3.

Similar to the LEC design, many cities realize a shift in energy use from electricity to natural gas, which decreases energy costs and carbon emissions by a greater percentage than the percentage decrease in energy consumption. However, nearly all zones realize smaller percentage reductions in carbon emissions than the percentage reductions in energy use because adopting *ASHRAE 90.1-2007* decreases consumption of both electricity and natural gas for most cities.

The length of the study period impacts life-cycle cost-effectiveness to some degree. Assuming nationwide adoption of the LEC design, a 10-year study period realizes average life-cycle cost decreases of 1.1 % for all building types and locations. The percentage decrease in life-cycle costs is 1.4 % for a 20-year, and 1.8 % for a 30-year, and 1.9 % for a 40-year study period. As the study period length increases from 5 to 40 years, the life-cycle cost-effectiveness tends to increase for more energy efficient commercial building designs. This result is supported by the state-level aggregated impact estimates, with only one of the seven states in this study realizing an increase in total life-cycle costs from the adoption of the LEC design.

States with the most newly constructed commercial building floor area realize the greatest total energy use, energy cost, and energy-related carbon emissions reductions from adopting *ASHRAE 90.1-2007* or the LEC design even if those states do not realize the greatest percentage reductions. Maryland and Oregon, both of which have adopted *ASHRAE 90.1-2007*, realize reductions in energy use of 15 % for the LEC design. However, Maryland realizes total reductions in energy use of 622 GWh while Oregon realizes reductions of 261 GWh because Maryland has almost twice the amount of newly constructed floor area. Similarly, Florida, which ranks 1st in the country for new floor area, realizes greater aggregate reductions in energy costs and reductions in energy-related carbon emissions than Maryland even though both states realize approximately the same percentage reductions in these two metrics.

In general, the states that realize the greatest reductions in energy use also realize the greatest reductions in energy costs and energy-related carbon emissions. However, states with higher electricity and natural gas rates will realize greater reductions in energy costs. For example, Tennessee realizes greater aggregate reductions in energy use than Maryland (808 GWh versus 622 GWh), but less total energy cost savings ($58.7 million versus $62.4 million). Also, states that rely heavily on coal-fired electricity will realize greater emissions reductions per unit of energy reduced than those states using more alternative energy sources. For example, Colorado relies on coal for 72 % of electricity generation and decreases carbon emissions by over 1000 tons per GWh of electricity generation. Meanwhile, Oregon relies on coal for 7 % of electricity generation and only saves 559 tons per GWh.

For a 10-year study period, adopting the *ASHRAE 90.1-2007* design reduces total life-cycle costs for the three states in this study that have adopted an older edition of *ASHRAE 90.1* or have not yet adopted a state energy code for commercial buildings: $1.4 million for Alaska, $53.9 million for Colorado, and $7.5 million for Tennessee. Meanwhile, adopting the LEC design would decrease life-cycle costs for six of the seven states selected for this study, ranging from $2.4 million to $151.3 million. The variation is primarily driven by the amount of new construction in a state. The life-cycle cost savings realized by these six states makes the increase in life-cycle costs realized by Oregon insignificant.

16.2 Limitations and Future Research

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.

The statewide average percentage changes estimated for this study for across state comparisons should not be used to determine the total benefits and costs of adopting a more stringent state energy code. In order to translate these results into total energy use, energy cost, life-cycle cost, and carbon emissions estimates, it is necessary to control for the floor area constructed in each state. This study only analyzes 7 of the 50 states in detail, and cannot be extrapolated to estimate the magnitude of nationwide savings. In addition, extensive analysis by Census Region 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. 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. 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 source options, such as heating oil use in the New England area.

Additional data are needed to refine and expand the BIRDS database. First, the study uses simple averages to summarize energy use, energy cost, life-cycle cost, and carbon emissions changes across all locations in a state. 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. 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, 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. 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.

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 the assumed plug and process loads have on the overall energy savings realized by energy efficiency improvements to buildings.

This study only compares the current state energy code to newer, more stringent standard editions. 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. 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.

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A Building Type, New Construction, and Emissions Rates

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

Category	Subcategory
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

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

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 (S-I)

State	Building Construction Floor Area (1,000 m^2)										
	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total
AK	19	130	126	226	111	13	208	231	126	259	1448
AL	801	705	853	1504	639	169	2485	1534	842	1740	11 272
AR	118	465	483	647	335	77	1359	1295	335	815	5928
AZ	1043	1505	1047	4030	1180	271	4891	2294	3721	3808	23 790
CA	9761	3310	3129	9219	3092	534	10 623	7085	13 364	12 345	72 462
CO	2033	1387	997	2158	708	199	2896	1654	1541	2889	16 461
CT	611	403	489	618	510	65	1245	1194	817	1271	7223
DC	1174	71	111	1462	112	4	104	191	34	830	4092
DE	70	155	124	224	119	16	237	290	160	323	1719
FL	21 397	3399	2979	9031	3124	678	11 904	7760	9692	12 748	82 712
GA	3696	1551	1510	3630	1212	331	5893	5580	7449	5350	36 202
HI	1280	91	92	171	59	9	273	92	132	485	2682
IA	143	639	427	999	657	74	1350	1262	621	1062	7234
ID	233	372	221	716	230	46	699	636	360	496	4008
IL	7303	1765	1304	2930	1714	232	5660	3083	6473	4179	34 643
IN	360	1728	856	1746	1323	255	3302	2558	3771	2415	18 313
KS	98	533	353	877	295	97	1122	826	513	670	5384
KY	268	757	643	1167	760	138	1667	1270	2001	1106	9778
LA	169	650	807	1175	593	135	1736	842	1011	1379	8498
MA	2959	728	884	1103	632	121	1772	1356	854	2484	12895
MD	3341	813	826	2802	580	109	1549	1527	1989	3388	16 924
ME	64	209	166	224	134	34	566	313	281	494	2485
MI	446	1797	713	1696	1359	200	3245	2058	864	2442	14 820
MN	1437	1018	473	1633	527	102	2135	1175	803	2342	11 645
MO	875	940	881	1226	780	158	2513	1626	819	1972	11 791
MS	150	336	479	631	411	55	1166	743	1593	692	6255
MT	45	122	118	149	94	18	253	174	76	142	1190
NC	1607	1362	1178	3368	1119	230	4472	3418	1910	3520	22 185
ND	7	118	91	138	113	14	331	174	57	100	1145
NE	147	453	303	631	331	54	1149	514	340	676	4599
NH	141	227	226	276	154	51	648	411	191	438	2763
NJ	2807	796	943	1235	774	112	2494	2627	3008	2587	17 382
NM	89	247	418	617	350	62	765	752	292	491	4083
NV	2867	528	2963	1626	1195	157	2382	960	1669	3231	17 579
NY	11 622	1639	1959	3330	1075	210	3633	2247	1286	3354	30 354
OH	635	2452	925	2674	1266	372	5132	4452	3382	3243	24 533
OK	115	794	512	763	878	141	1364	1179	932	1271	7950
OR	1253	918	360	922	383	68	1382	651	1142	1648	8727
PA	1503	1908	1406	2424	1354	219	3762	3660	3512	3556	23 305
RI	238	60	192	251	81	26	278	197	114	236	1674
SC	1981	746	563	1539	539	168	2600	2222	1101	2132	13 590
SD	13	119	86	257	126	13	341	268	88	205	1515
TN	987	1036	683	2296	733	199	3581	1809	2698	2337	16 360
TX	5548	4508	3571	8328	3325	849	13 121	12 693	10 609	9676	72 230
UT	622	569	314	1365	475	76	1424	1269	1274	1201	8590
VA	3502	1011	1361	3693	1096	200	3014	2387	1826	4406	22 495
VT	161	99	96	113	71	6	63	136	88	165	998
WA	3397	1085	871	2435	833	107	2504	1841	1880	3598	18 551
WI	906	1519	583	1556	746	137	2489	1129	882	1981	11 928
WV	65	215	148	193	117	39	668	484	179	288	2397
WY	4	72	166	66	127	9	158	254	67	228	1151
Total	100 111	48 059	41 007	92 089	38 550	7661	128 609	94 383	98 773	118 693	767 935

Table A-3 New Commercial Building Construction Floor Area for 2003 through 2007 by State and Building Type (I-P)

State	Building Construction Floor Area (1,000 ft^2)									
	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total
AK	201	1401	1357	2428	1190	137	2240	2484	1356	2787	15 581
AL	8619	7587	9184	16 191	6876	1821	26 748	16 514	9060	18 729	121 329
AR	1272	5000	5198	6962	3611	829	14 624	13 936	3609	8768	63 810
AZ	11 223	16 195	11 272	43 383	12 701	2918	52 646	24 692	40 052	40 986	256 068
CA	105 071	35 633	33 678	99 228	33 281	5747	114 344	76 262	143 853	132 882	779 978
CO	21 885	14 926	10 735	23 225	7618	2142	31 177	17 804	16 582	31 094	177 186
CT	6582	4333	5261	6651	5485	698	13 403	12 856	8798	13 679	77 746
DC	12 636	769	1199	15 734	1202	38	1122	2051	363	8934	44 047
DE	755	1672	1330	2410	1282	173	2551	3126	1722	3480	18 501
FL	230 315	36 591	32 071	97 212	33 622	7299	128 133	83 524	104 327	137 213	890 306
GA	39 780	16 699	16 254	39 076	13 043	3563	63 430	60 062	80 180	57 586	389 672
HI	13 773	979	989	1838	630	95	2939	985	1417	5220	28 865
IA	1542	6875	4598	10 749	7069	796	14 534	13 586	6688	11 426	77 863
ID	2506	4001	2375	7703	2478	493	7526	6847	3876	5343	43 147
IL	78 609	18 998	14 037	31 542	18 451	2497	60 928	33 180	69 674	44 977	372 893
IN	3875	18 600	9210	18 791	14 242	2747	35 539	27 535	40 591	25 992	197 123
KS	1057	5734	3795	9442	3178	1039	12 076	8892	5521	7216	57 950
KY	2888	8150	6922	12 558	8185	1489	17 941	13 672	21 538	11 906	105 248
LA	1823	7001	8689	12 647	6386	1454	18 681	9061	10 886	14 841	91 469
MA	31 854	7832	9516	11 868	6808	1306	19 079	14 599	9197	26 742	138 802
MD	35 967	8750	8888	30 163	6242	1173	16 672	16 432	21 414	36 463	182 163
ME	687	2245	1791	2411	1441	368	6088	3374	3021	5320	26 745
MI	4800	19 346	7671	18 251	14 629	2153	34 934	22 151	9305	26 283	159 523
MN	15 465	10 954	5093	17 575	5673	1098	22 985	12 643	8643	25 212	125 342
MO	9420	10 121	9483	13 197	8395	1705	27 054	17 497	8818	21 226	126 915
MS	1613	3618	5153	6789	4423	587	12 551	7999	17 146	7447	67 326
MT	481	1313	1265	1602	1007	195	2723	1871	821	1533	12 810
NC	17 294	14 663	12 678	36 249	12 044	2481	48 139	36 794	20 559	37 891	238 792
ND	76	1265	982	1490	1221	155	3567	1871	617	1077	12 320
NE	1586	4880	3263	6790	3562	577	12 369	5533	3660	7279	49 498
NH	1523	2440	2437	2974	1653	548	6970	4421	2059	4717	29 741
NJ	30 209	8563	10 145	13 295	8335	1210	26 842	28 280	32 383	27 841	187 103
NM	957	2655	4499	6636	3770	670	8235	8097	3142	5290	43 950
NV	30 856	5684	31 894	17 504	12 863	1691	25 644	10 337	17 969	34 776	189 218
NY	125 095	17 639	21 083	35 842	11 572	2259	39 107	24 186	13 845	36 104	326 732
OH	6832	26 393	9959	28 780	13 630	4004	55 245	47 919	36 400	34 909	264 071
OK	1242	8547	5511	8216	9450	1523	14 686	12 691	10 032	13 680	85 577
OR	13 492	9885	3878	9927	4118	728	14 881	7004	12 291	17 738	93 941
PA	16 177	20 535	15 135	26 096	14 577	2361	40 489	39 397	37 805	38 280	250 852
RI	2559	649	2069	2707	877	278	2990	2125	1228	2540	18 021
SC	21 321	8033	6056	16 562	5801	1810	27 984	23 920	11 848	22 949	146 284
SD	142	1285	922	2767	1354	138	3668	2884	950	2202	16 312
TN	10 621	11 152	7347	24 718	7891	2145	38 548	19 476	29 045	25 152	176 095
TX	59 723	48 519	38 437	89 641	35 794	9142	141 238	136 629	114 193	104 156	777 473
UT	6695	6123	3384	14 698	5110	822	15 331	13 657	13 716	12 926	92 462
VA	37 694	10 887	14 646	39 749	11 794	2149	32 438	25 691	19 659	47 422	242 129
VT	1736	1063	1030	1214	765	68	674	1463	946	1777	10 737
WA	36 566	11 683	9378	26 209	8964	1147	26 954	19 817	20 236	38 731	199 685
WI	9754	16 350	6273	16 751	8030	1474	26 793	12 148	9497	21 325	128 395
WV	697	2314	1592	2081	1259	421	7191	5215	1930	3098	25 797
WY	42	774	1787	713	1370	97	1696	2737	718	2453	12 387
Total	1 077 585	517 302	441 399	991 233	414 953	82 459	1 384 339	1 015 925	1 063 186	1 277 597	8 265 977

Table A-4 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
AK	1.3 %	9.0 %	8.7 %	15.6 %	7.6 %	0.9 %	14.4 %	15.9 %	8.7 %	17.9 %	100.0 %	56.8 %
AL	7.1 %	6.3 %	7.6 %	13.3 %	5.7 %	1.5 %	22.0 %	13.6 %	7.5 %	15.4 %	100.0 %	65.2 %
AR	2.0 %	7.8 %	8.1 %	10.9 %	5.7 %	1.3 %	22.9 %	21.8 %	5.7 %	13.7 %	100.0 %	67.1 %
AZ	4.4 %	6.3 %	4.4 %	16.9 %	5.0 %	1.1 %	20.6 %	9.6 %	15.6 %	16.0 %	100.0 %	57.1 %
CA	13.5 %	4.6 %	4.3 %	12.7 %	4.3 %	0.7 %	14.7 %	9.8 %	18.4 %	17.0 %	100.0 %	55.7 %
CO	12.4 %	8.4 %	6.1 %	13.1 %	4.3 %	1.2 %	17.6 %	10.0 %	9.4 %	17.5 %	100.0 %	60.4 %
CT	8.5 %	5.6 %	6.8 %	8.6 %	7.1 %	0.9 %	17.2 %	16.5 %	11.3 %	17.6 %	100.0 %	58.5 %
DC	28.7 %	1.7 %	2.7 %	35.7 %	2.7 %	0.1 %	2.5 %	4.7 %	0.8 %	20.3 %	100.0 %	74.4 %
DE	4.1 %	9.0 %	7.2 %	13.0 %	6.9 %	0.9 %	13.8 %	16.9 %	9.3 %	18.8 %	100.0 %	55.9 %
FL	25.9 %	4.1 %	3.6 %	10.9 %	3.8 %	0.8 %	14.4 %	9.4 %	11.7 %	15.4 %	100.0 %	65.0 %
GA	10.2 %	4.3 %	4.2 %	10.0 %	3.3 %	0.9 %	16.3 %	15.4 %	20.6 %	14.8 %	100.0 %	57.0 %
HI	47.7 %	3.4 %	3.4 %	6.4 %	2.2 %	0.3 %	10.2 %	3.4 %	4.9 %	18.1 %	100.0 %	71.4 %
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 %
ID	5.8 %	9.3 %	5.5 %	17.9 %	5.7 %	1.1 %	17.4 %	15.9 %	9.0 %	12.4 %	100.0 %	63.6 %
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 %
KY	2.7 %	7.7 %	6.6 %	11.9 %	7.8 %	1.4 %	17.0 %	13.0 %	20.5 %	11.3 %	100.0 %	52.7 %
LA	2.0 %	7.7 %	9.5 %	13.8 %	7.0 %	1.6 %	20.4 %	9.9 %	11.9 %	16.2 %	100.0 %	57.2 %
MA	22.9 %	5.6 %	6.9 %	8.6 %	4.9 %	0.9 %	13.7 %	10.5 %	6.6 %	19.3 %	100.0 %	63.6 %
MD	19.7 %	4.8 %	4.9 %	16.6 %	3.4 %	0.6 %	9.2 %	9.0 %	11.8 %	20.0 %	100.0 %	60.0 %
ME	2.6 %	8.4 %	6.7 %	9.0 %	5.4 %	1.4 %	22.8 %	12.6 %	11.3 %	19.9 %	100.0 %	55.0 %
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 %
MS	2.4 %	5.4 %	7.7 %	10.1 %	6.6 %	0.9 %	18.6 %	11.9 %	25.5 %	11.1 %	100.0 %	51.5 %
MT	3.8 %	10.2 %	9.9 %	12.5 %	7.9 %	1.5 %	21.3 %	14.6 %	6.4 %	12.0 %	100.0 %	63.5 %
NC	7.2 %	6.1 %	5.3 %	15.2 %	5.0 %	1.0 %	20.2 %	15.4 %	8.6 %	15.9 %	100.0 %	64.3 %
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 %
NH	5.1 %	8.2 %	8.2 %	10.0 %	5.6 %	1.8 %	23.4 %	14.9 %	6.9 %	15.9 %	100.0 %	63.5 %
NJ	16.1 %	4.6 %	5.4 %	7.1 %	4.5 %	0.6 %	14.3 %	15.1 %	17.3 %	14.9 %	100.0 %	58.8 %
NM	2.2 %	6.0 %	10.2 %	15.1 %	8.6 %	1.5 %	18.7 %	18.4 %	7.1 %	12.0 %	100.0 %	66.2 %
NV	16.3 %	3.0 %	16.9 %	9.3 %	6.8 %	0.9 %	13.6 %	5.5 %	9.5 %	18.4 %	100.0 %	62.3 %
NY	38.3 %	5.4 %	6.5 %	11.0 %	3.5 %	0.7 %	12.0 %	7.4 %	4.2 %	11.1 %	100.0 %	75.8 %
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 %
OK	1.5 %	10.0 %	6.4 %	9.6 %	11.0 %	1.8 %	17.2 %	14.8 %	11.7 %	16.0 %	100.0 %	51.3 %
OR	14.4 %	10.5 %	4.1 %	10.6 %	4.4 %	0.8 %	15.8 %	7.5 %	13.1 %	18.9 %	100.0 %	53.1 %
PA	6.4 %	8.2 %	6.0 %	10.4 %	5.8 %	0.9 %	16.1 %	15.7 %	15.1 %	15.3 %	100.0 %	55.7 %
RI	14.2 %	3.6 %	11.5 %	15.0 %	4.9 %	1.5 %	16.6 %	11.8 %	6.8 %	14.1 %	100.0 %	70.6 %
SC	14.6 %	5.5 %	4.1 %	11.3 %	4.0 %	1.2 %	19.1 %	16.4 %	8.1 %	15.7 %	100.0 %	66.8 %
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 %
TN	6.0 %	6.3 %	4.2 %	14.0 %	4.5 %	1.2 %	21.9 %	11.1 %	16.5 %	14.3 %	100.0 %	58.4 %
TX	7.7 %	6.2 %	4.9 %	11.5 %	4.6 %	1.2 %	18.2 %	17.6 %	14.7 %	13.4 %	100.0 %	61.1 %
UT	7.2 %	6.6 %	3.7 %	15.9 %	5.5 %	0.9 %	16.6 %	14.8 %	14.8 %	14.0 %	100.0 %	59.0 %
VA	15.6 %	4.5 %	6.0 %	16.4 %	4.9 %	0.9 %	13.4 %	10.6 %	8.1 %	19.6 %	100.0 %	62.9 %
VT	16.2 %	9.9 %	9.6 %	11.3 %	7.1 %	0.6 %	6.3 %	13.6 %	8.8 %	16.6 %	100.0 %	57.6 %
WA	18.3 %	5.9 %	4.7 %	13.1 %	4.5 %	0.6 %	13.5 %	9.9 %	10.1 %	19.4 %	100.0 %	60.1 %
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 %
WV	2.7 %	9.0 %	6.2 %	8.1 %	4.9 %	1.6 %	27.9 %	20.2 %	7.5 %	12.0 %	100.0 %	66.7 %
WY	0.3 %	6.2 %	14.4 %	5.8 %	11.1 %	0.8 %	13.7 %	22.1 %	5.8 %	19.8 %	100.0 %	57.1 %
Total	13.0 %	6.3 %	5.3 %	12.0 %	5.0 %	1.0 %	16.7 %	12.3 %	12.9 %	15.5 %	100.0 %	60.4 %

Table A-5 CO_2, CH_4, and N_2O Emissions Rates Electricity Generation by State

State	CO_2 (t/GWh)	CH4 (t/GWh)	N2O (t/GWh)
AK	603.4	57.9	1.9
AL	804.2	42.7	0.5
AR	695.9	58.6	1.7
AZ	746.9	53.2	1.2
CA	450.0	45.8	1.5
CO	938.8	54.0	0.8
CT	550.4	47.0	1.4
DE	618.7	33.4	0.4
FL	767.5	57.2	1.5
GA	804.2	42.7	0.5
HI	807.1	28.0	0.1
IA	851.1	40.4	0.2
ID	465.6	27.6	0.4
IL	948.3	44.4	0.2
IN	835.7	38.9	0.2
KS	926.0	44.8	0.3
KY	781.9	36.9	0.2
LA	719.2	59.2	1.6
MA	550.4	47.0	1.4
MD	618.7	33.4	0.4
ME	550.4	47.0	1.4
MI	861.4	46.8	0.6
MN	851.1	40.4	0.2
MO	939.4	44.6	0.2
MS	709.8	48.3	1.0
MT	542.8	30.1	0.4
NC	616.6	30.5	0.2
ND	851.1	40.4	0.2
NE	851.1	40.4	0.2
NH	550.4	47.0	1.4
NJ	618.7	33.4	0.4
NM	778.5	55.3	1.3
NV	465.6	27.6	0.4
NY	480.7	32.3	0.8
OH	835.7	38.9	0.2
OK	904.8	63.9	1.4
OR	465.6	27.6	0.4
PA	672.9	34.7	0.4
RI	550.4	47.0	1.4
SC	616.6	30.5	0.2
SD	851.1	40.4	0.2
TN	781.9	36.9	0.2
TX	790.9	65.8	1.8
UT	465.6	27.6	0.4
VA	689.6	33.3	0.2
VT	550.4	47.0	1.4
WA	465.6	27.6	0.4
WI	860.7	44.1	0.4
WV	835.7	38.9	0.2
WY	623.7	36.4	0.5

B BIRDS Results by Building Type for the Nationwide Adoption of the LEC and *ASHRAE 90.1-2007* Designs

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
AK	-12.7	-31.2	-25.0	-1.7
AL	-35.2	-40.3	-42.9	-3.4
AR	-29.0	-36.6	-39.4	-1.8
AZ	-26.6	-31.1	-32.4	-1.6
CA	-16.1	-22.5	-19.8	0.2
CO	-21.9	-36.2	-37.9	-1.2
CT	-9.5	-18.5	-15.1	-0.1
DE	-10.4	-15.0	-16.0	-0.2
FL	-16.6	-17.7	-17.8	-0.3
GA	-14.3	-17.7	-18.8	0.4
HI	-20.4	-20.4	-20.4	-1.7
IA	-9.8	-15.8	-16.8	0.5
ID	-10.2	-14.8	-14.9	0.8
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
KY	-11.5	-15.6	-17.9	0.7
LA	-15.4	-17.6	-18.3	0.5
MA	-9.1	-16.8	-14.8	0.1
MD	-10.9	-17.1	-16.4	0.2
ME	-19.9	-32.9	-31.9	-2.6
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
MS	-35.7	-42.4	-42.6	-3.3
MT	-9.6	-15.2	-14.5	0.6
NC	-13.5	-17.0	-18.1	0.4
ND	-17.5	-30.8	-33.4	-1.0
NE	-9.8	-16.3	-17.2	0.7
NH	-9.5	-15.8	-14.7	-0.3
NJ	-10.3	-17.8	-16.0	0.4
NM	-13.6	-20.0	-20.0	0.5
NV	-14.5	-20.7	-18.8	-0.1
NY	-9.2	-17.5	-13.8	0.0
OH	-9.6	-16.0	-17.1	0.5
OK	-27.2	-35.1	-40.8	-1.3
OR	-10.0	-15.0	-15.4	1.1
PA	-9.5	-14.9	-16.0	0.6
RI	-9.2	-15.5	-15.1	0.2
SC	-18.0	-22.6	-23.2	-0.1
SD	-21.2	-34.1	-35.9	-1.7
TN	-16.1	-20.5	-21.3	-0.1
TX	-15.0	-18.6	-18.6	0.0
UT	-10.7	-17.6	-15.7	0.7
VA	-12.6	-17.0	-18.1	0.5
VT	-9.5	-15.5	-14.6	-0.2
WA	-8.8	-12.8	-14.0	1.2
WI	-9.5	-15.9	-16.4	0.4
WV	-25.3	-29.8	-38.9	-0.8
WY	-22.7	-36.6	-36.4	-1.4
Avg.	**-14.8**	**-21.2**	**-21.6**	**-0.1**

Table B-2 6-Story Apartment Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-12.2	-31.1	-24.8	-1.5	MT	-9.5	-15.1	-14.4	0.6
AL	-35.6	-41.2	-44.1	-3.5	NC	-14.8	-19.2	-20.6	0.2
AR	-29.8	-37.9	-40.8	-1.9	ND	-17.2	-30.5	-33.1	-0.9
AZ	-27.1	-32.5	-34.0	-1.7	NE	-11.2	-19.5	-20.5	0.6
CA	-18.2	-26.1	-22.8	-0.1	NH	-9.3	-15.4	-14.4	-0.3
CO	-22.5	-37.7	-39.5	-1.2	NJ	-11.4	-20.6	-18.5	0.2
CT	-10.6	-21.8	-17.7	-0.4	NM	-15.1	-23.0	-23.0	0.3
DE	-11.2	-17.0	-18.2	-0.4	NV	-14.9	-22.9	-20.5	-0.1
FL	-17.5	-18.9	-19.0	-0.4	NY	-9.6	-19.4	-15.1	-0.1
GA	-15.5	-19.5	-20.9	0.3	OH	-10.6	-18.5	-19.9	0.4
HI	-20.7	-20.7	-20.7	-1.6	OK	-28.1	-36.5	-42.6	-1.5
IA	-10.6	-17.6	-18.7	0.5	OR	-10.9	-17.1	-17.7	1.0
ID	-11.1	-16.5	-16.5	0.8	PA	-10.4	-17.1	-18.5	0.5
IL	-10.5	-20.0	-20.1	0.1	RI	-10.0	-17.9	-17.4	0.0
IN	-11.3	-18.7	-20.1	0.5	SC	-18.9	-24.4	-25.1	-0.2
KS	-25.9	-37.4	-41.4	-1.8	SD	-20.6	-33.5	-35.4	-1.5
KY	-13.4	-18.6	-21.4	0.5	TN	-17.3	-22.9	-23.9	-0.3
LA	-16.5	-19.1	-20.0	0.4	TX	-16.3	-20.6	-20.6	-0.2
MA	-9.8	-19.5	-17.0	0.0	UT	-11.9	-20.5	-18.2	0.6
MD	-12.1	-19.9	-19.0	0.0	VA	-14.4	-20.0	-21.3	0.3
ME	-19.3	-32.3	-31.4	-2.4	VT	-9.2	-15.1	-14.2	-0.1
MI	-8.9	-16.7	-17.9	0.3	WA	-9.4	-14.4	-15.8	1.2
MN	-13.0	-17.3	-17.9	0.4	WI	-9.3	-15.5	-16.0	0.5
MO	-26.5	-35.2	-40.9	-1.1	WV	-26.2	-31.2	-41.0	-0.8
MS	-36.2	-43.3	-43.5	-3.4	WY	-22.5	-36.3	-36.2	-1.3
					Avg.	-9.5	-15.1	**-23.3**	**-0.2**

Table B-3 4-Story Dormitory Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-18.1	-34.8	-29.3	-2.4
AL	-36.7	-41.7	-44.2	-2.9
AR	-28.8	-37.1	-40.0	-4.9
AZ	-29.1	-32.1	-32.9	-1.6
CA	-18.2	-22.3	-20.6	-1.3
CO	-24.9	-36.6	-37.9	-4.2
CT	-11.2	-18.9	-16.1	-1.6
DE	-12.3	-16.3	-17.2	-0.5
FL	-17.4	-18.4	-18.5	-2.1
GA	-15.1	-18.1	-19.1	-1.2
HI	-22.1	-22.1	-22.1	-3.6
IA	-11.7	-16.7	-17.5	-0.2
ID	-12.7	-16.4	-16.5	-1.2
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
KY	-12.9	-16.4	-18.3	-1.0
LA	-15.5	-17.8	-18.5	-0.8
MA	-11.1	-17.8	-16.1	-1.3
MD	-12.5	-17.8	-17.2	-0.2
ME	-24.4	-35.6	-34.9	-1.6
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
MS	-39.0	-44.2	-44.4	-1.8
MT	-12.9	-17.1	-16.6	-1.2
NC	-14.8	-17.7	-18.5	-0.7
ND	-21.6	-33.7	-36.0	0.3
NE	-11.7	-17.2	-17.9	-0.2
NH	-12.2	-17.0	-16.2	-1.7
NJ	-12.3	-18.6	-17.2	-0.8
NM	-15.3	-19.8	-19.8	-1.6
NV	-17.1	-21.1	-19.9	-1.9
NY	-11.1	-18.2	-15.1	-1.5
OH	-11.2	-16.9	-17.8	-1.2
OK	-27.6	-36.1	-42.2	0.0
OR	-12.7	-16.7	-17.0	-1.0
PA	-11.1	-15.9	-16.8	-0.8
RI	-11.3	-16.7	-16.4	-1.4
SC	-16.9	-21.7	-22.3	-1.3
SD	-24.0	-35.7	-37.3	-1.4
TN	-17.3	-20.4	-20.9	-1.1
TX	-15.5	-18.6	-18.7	-0.9
UT	-12.8	-18.2	-16.8	-1.2
VA	-14.3	-17.9	-18.7	-0.7
VT	-11.9	-16.7	-15.9	-1.6
WA	-11.6	-15.0	-16.0	-0.5
WI	-12.0	-17.0	-17.4	-0.8
WV	-26.7	-31.0	-38.8	-3.3
WY	-26.9	-38.4	-38.3	-0.9
Avg.	**-16.9**	**-22.2**	**-22.6**	**-1.2**

Table B-4 6-Story Dormitory Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-11.1	-30.0	-23.7	-2.2
AL	-37.9	-43.7	-46.7	-4.9
AR	-30.8	-39.1	-42.1	-2.9
AZ	-28.3	-33.6	-35.1	-2.4
CA	-17.9	-26.3	-22.7	-0.4
CO	-20.7	-36.0	-37.9	-1.8
CT	-10.4	-21.2	-17.2	-0.7
DE	-11.3	-16.9	-18.0	-0.8
FL	-18.4	-20.0	-20.1	-0.9
GA	-15.5	-19.7	-21.2	-0.1
HI	-23.0	-23.0	-23.0	-2.5
IA	-10.0	-16.4	-17.4	0.2
ID	-10.6	-15.6	-15.7	0.5
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
KY	-12.9	-17.9	-20.6	0.2
LA	-16.7	-19.6	-20.6	0.0
MA	-9.5	-18.7	-16.4	-0.3
MD	-12.0	-19.7	-18.8	-0.4
ME	-18.0	-30.6	-29.7	-3.1
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
MS	-38.2	-45.6	-45.9	-4.7
MT	-8.6	-13.6	-12.9	0.3
NC	-14.7	-19.1	-20.4	-0.1
ND	-16.6	-28.8	-31.2	-1.6
NE	-10.9	-18.8	-19.8	0.3
NH	-8.4	-13.8	-12.9	-0.5
NJ	-11.4	-20.4	-18.3	-0.2
NM	-15.2	-22.8	-22.9	-0.1
NV	-14.1	-22.1	-19.6	-0.4
NY	-9.1	-18.3	-14.3	-0.4
OH	-10.3	-17.9	-19.2	0.1
OK	-29.9	-38.5	-44.8	-2.6
OR	-10.6	-16.7	-17.1	0.7
PA	-10.3	-16.8	-18.0	0.2
RI	-9.7	-17.2	-16.7	-0.3
SC	-20.2	-26.0	-26.8	-0.7
SD	-17.3	-30.6	-32.5	-2.0
TN	-16.1	-21.9	-22.9	-0.5
TX	-16.3	-20.9	-20.9	-0.6
UT	-12.0	-20.1	-18.0	0.3
VA	-14.2	-19.6	-20.8	0.0
VT	-8.2	-13.4	-12.6	-0.3
WA	-9.2	-14.1	-15.5	0.9
WI	-8.2	-13.7	-14.2	0.2
WV	-24.4	-29.6	-39.1	-1.4
WY	-19.1	-33.4	-33.2	-1.8
Avg.	**-15.2**	**-22.4**	**-22.8**	**-0.6**

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
AK	-6.9	-23.5	-18.0	-1.8
AL	-30.3	-36.2	-39.2	-3.0
AR	-21.5	-32.1	-36.0	-1.6
AZ	-23.1	-26.4	-27.3	-1.0
CA	-18.2	-24.5	-21.8	0.0
CO	-16.0	-28.8	-30.3	-1.1
CT	-12.7	-21.6	-18.3	-0.5
DE	-13.1	-17.6	-18.5	-0.6
FL	-16.7	-18.8	-19.0	-0.1
GA	-14.5	-18.5	-19.9	0.4
HI	-18.0	-18.1	-18.1	-0.6
IA	-11.0	-15.3	-16.0	0.5
ID	-12.3	-15.9	-15.9	0.7
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
KY	-13.7	-17.6	-19.8	0.6
LA	-14.5	-18.1	-19.3	0.6
MA	-11.8	-19.3	-17.4	-0.1
MD	-13.4	-19.4	-18.7	-0.1
ME	-14.0	-23.1	-22.5	-2.3
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
MS	-34.4	-37.0	-37.1	-2.8
MT	-9.4	-11.5	-11.3	0.4
NC	-14.9	-18.4	-19.4	0.3
ND	-10.0	-20.8	-22.8	-1.1
NE	-12.7	-18.9	-19.7	0.6
NH	-8.9	-11.2	-10.8	-0.2
NJ	-13.1	-20.2	-18.6	0.1
NM	-15.7	-21.1	-21.1	0.4
NV	-8.8	-14.7	-13.0	0.7
NY	-11.2	-18.0	-15.0	-0.2
OH	-11.8	-18.1	-19.2	0.4
OK	-19.7	-29.9	-37.5	-1.2
OR	-13.8	-18.4	-18.8	0.9
PA	-11.8	-17.1	-18.2	0.4
RI	-12.1	-18.1	-17.7	-0.1
SC	-8.5	-14.6	-15.4	0.9
SD	-11.8	-21.8	-23.2	-1.3
TN	-9.6	-13.6	-14.3	0.8
TX	-14.9	-19.6	-19.6	0.0
UT	-14.2	-20.2	-18.6	0.6
VA	-14.9	-18.8	-19.8	0.4
VT	-9.0	-11.3	-11.0	-0.1
WA	-12.3	-16.2	-17.2	1.1
WI	-8.9	-11.2	-11.4	0.4
WV	-18.9	-23.4	-32.3	-0.6
WY	-13.8	-24.7	-24.6	-1.3
Avg.	**-13.9**	**-19.6**	**-20.0**	**-0.1**

Table B-6 2-Story High School Summary Table for LEC and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-7.7	-17.8	-14.0	-1.6	MT	-9.7	-13.9	-13.3	-0.6
AL	-23.6	-29.4	-32.7	-3.3	NC	-10.5	-16.2	-18.1	-1.1
AR	-16.5	-25.0	-28.5	-1.8	ND	-11.1	-18.9	-20.8	-0.9
AZ	-21.5	-27.4	-29.2	-2.8	NE	-5.8	-15.0	-16.4	-0.6
CA	-13.7	-23.4	-19.2	-1.8	NH	-5.7	-12.3	-11.1	-1.5
CO	-10.6	-23.1	-25.0	-1.9	NJ	-6.6	-17.8	-15.0	-1.5
CT	-5.3	-17.9	-12.8	-1.9	NM	-9.6	-19.8	-19.9	-1.0
DE	-6.4	-13.3	-14.8	-1.8	NV	-9.5	-18.2	-15.4	-1.5
FL	-21.2	-23.4	-23.7	-1.9	NY	-6.2	-16.7	-11.8	-1.6
GA	-12.6	-18.2	-20.3	-1.6	OH	-5.6	-14.2	-15.8	-0.8
HI	-26.7	-26.7	-26.7	-4.2	OK	-15.0	-22.8	-29.7	-1.3
IA	-6.1	-13.8	-15.2	-0.8	OR	-4.9	-11.5	-12.1	0.0
ID	-6.0	-11.8	-11.9	-0.2	PA	-5.4	-12.7	-14.3	-0.6
IL	-5.6	-16.4	-16.5	-1.1	RI	-5.0	-13.7	-13.0	-0.9
IN	-6.4	-14.8	-16.6	-0.8	SC	-13.8	-19.8	-20.6	-1.3
KS	-13.7	-23.4	-27.7	-1.5	SD	-10.9	-20.0	-21.7	-1.8
KY	-8.0	-14.1	-17.8	-0.9	TN	-12.9	-19.9	-21.3	-1.7
LA	-15.4	-19.5	-21.0	-0.8	TX	-14.7	-21.0	-21.1	-1.7
MA	-4.6	-15.2	-12.3	-1.1	UT	-5.9	-15.6	-12.8	-0.8
MD	-7.2	-16.9	-15.6	-1.7	VA	-9.2	-16.4	-18.3	-0.6
ME	-10.7	-18.9	-18.3	-1.9	VT	-5.9	-12.1	-11.0	-1.4
MI	-4.6	-12.7	-14.2	-0.8	WA	-4.2	-9.4	-10.9	0.2
MN	-9.2	-14.1	-14.9	-1.1	WI	-5.9	-12.7	-13.4	-1.1
MO	-14.3	-21.7	-27.7	-1.4	WV	-13.3	-17.1	-26.4	-1.3
MS	-26.7	-33.1	-33.4	-3.4	WY	-11.5	-21.2	-21.1	-1.3
					Avg.	**-10.6**	**-18.0**	**-18.5**	**-1.3**

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
AK	-21.3	-25.8	-24.6	0.0
AL	-31.7	-32.2	-32.4	-0.7
AR	-30.0	-31.4	-31.9	-5.2
AZ	-28.1	-28.0	-28.0	-2.3
CA	-21.4	-21.9	-21.8	-2.8
CO	-28.3	-29.7	-29.9	-5.1
CT	-18.3	-21.3	-20.5	-2.7
DE	-19.7	-21.1	-21.3	-3.2
FL	-20.1	-20.2	-20.2	-2.6
GA	-19.5	-20.2	-20.4	-1.7
HI	-21.3	-21.3	-21.3	-3.6
IA	-17.3	-19.6	-19.8	-1.5
ID	-19.3	-20.4	-20.4	-2.4
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
KY	-19.5	-20.8	-21.4	-2.4
LA	-19.9	-20.2	-20.3	-1.8
MA	-18.3	-21.1	-20.6	-2.5
MD	-19.7	-21.4	-21.2	-2.9
ME	-28.1	-29.2	-29.1	0.0
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
MS	-32.4	-32.0	-31.9	1.1

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
MT	-16.9	-18.1	-18.0	-1.5
NC	-20.2	-20.9	-21.1	-1.9
ND	-26.0	-28.1	-28.4	1.3
NE	-18.5	-21.2	-21.5	-2.2
NH	-16.9	-18.2	-18.1	-2.2
NJ	-19.5	-21.4	-21.1	-2.5
NM	-21.4	-22.5	-22.5	-2.8
NV	-23.0	-23.4	-23.3	-3.6
NY	-17.0	-20.1	-19.0	-2.5
OH	-17.9	-20.6	-20.9	-2.2
OK	-31.2	-32.9	-34.0	0.9
OR	-20.9	-22.0	-22.0	-3.0
PA	-18.0	-20.3	-20.6	-2.4
RI	-18.9	-21.0	-20.9	-2.4
SC	-21.7	-21.9	-22.0	-2.2
SD	-26.8	-28.4	-28.6	-0.5
TN	-23.4	-22.7	-22.6	-3.0
TX	-19.9	-20.5	-20.5	-2.6
UT	-20.7	-22.5	-22.1	-2.6
VA	-20.8	-21.7	-21.9	-2.2
VT	-16.5	-18.0	-17.8	-2.0
WA	-20.0	-21.1	-21.3	-2.3
WI	-16.4	-18.0	-18.1	-1.2
WV	-30.1	-30.4	-30.3	-4.8
WY	-29.2	-30.1	-30.0	0.7
Avg.	**-21.5**	**-22.8**	**-22.8**	**-2.1**

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
AK	-8.1	-14.9	-12.9	-0.2
AL	-23.3	-25.1	-26.0	-1.0
AR	-18.2	-23.8	-25.7	0.0
AZ	-19.6	-20.5	-20.8	0.0
CA	-19.8	-21.8	-21.0	-0.1
CO	-15.7	-21.2	-21.7	0.1
CT	-15.2	-21.6	-19.6	-0.9
DE	-16.0	-19.4	-19.9	-1.0
FL	-17.6	-18.5	-18.5	-0.2
GA	-16.5	-18.4	-19.1	0.5
HI	-16.4	-16.4	-16.4	-0.6
IA	-13.0	-16.2	-16.6	0.6
ID	-15.3	-17.7	-17.8	0.9
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
KY	-16.2	-19.3	-20.7	0.7
LA	-16.6	-18.3	-18.8	0.7
MA	-14.4	-20.2	-19.0	-0.3
MD	-16.0	-20.1	-19.7	-0.3
ME	-13.9	-15.9	-15.8	-0.7
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
MS	-27.3	-24.8	-24.7	-0.5
MT	-11.7	-12.5	-12.5	0.4
NC	-17.2	-19.1	-19.6	0.4
ND	-9.9	-13.5	-14.1	0.4
NE	-15.2	-20.2	-20.7	0.8
NH	-11.3	-12.3	-12.2	-0.6
NJ	-16.0	-21.0	-20.1	-0.1
NM	-18.9	-21.7	-21.7	0.3
NV	-12.5	-16.0	-15.1	0.7
NY	-13.9	-18.7	-16.9	-0.6
OH	-14.4	-19.5	-20.2	0.5
OK	-17.3	-23.0	-26.9	0.3
OR	-17.8	-20.9	-21.1	1.0
PA	-14.4	-18.9	-19.6	0.4
RI	-15.3	-20.0	-19.7	-0.3
SC	-12.1	-15.5	-15.9	1.0
SD	-10.1	-13.2	-13.6	0.2
TN	-12.3	-15.0	-15.4	0.8
TX	-16.8	-19.1	-19.1	-0.1
UT	-17.5	-21.7	-20.8	0.6
VA	-18.0	-20.6	-21.1	0.4
VT	-11.3	-12.3	-12.2	-0.4
WA	-16.2	-19.1	-19.8	1.4
WI	-10.9	-11.9	-12.0	0.3
WV	-16.9	-19.1	-23.0	0.9
WY	-12.8	-16.2	-16.1	0.1
Avg.	**-15.3**	**-18.3**	**-18.5**	**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
AK	-26.3	-27.3	-26.8	-0.2
AL	-35.1	-35.6	-35.9	-0.9
AR	-29.8	-31.8	-32.5	-1.7
AZ	-31.6	-32.4	-32.6	-1.8
CA	-16.1	-17.8	-17.1	0.0
CO	-28.4	-32.0	-32.4	-2.0
CT	-12.3	-16.9	-15.5	-1.7
DE	-14.2	-16.7	-17.1	-0.8
FL	-17.9	-18.2	-18.2	-0.7
GA	-15.5	-16.5	-16.8	0.5
HI	-22.3	-22.3	-22.3	-3.1
IA	-14.3	-17.2	-17.6	0.6
ID	-14.2	-16.3	-16.3	1.2
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
KY	-14.9	-17.2	-18.3	0.5
LA	-15.0	-15.5	-15.7	0.7
MA	-11.8	-16.1	-15.2	0.1
MD	-14.3	-17.3	-17.0	-0.1
ME	-31.7	-33.2	-33.1	-1.2
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
MS	-40.6	-38.8	-38.8	-0.3

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
MT	-16.0	-17.7	-17.5	0.1
NC	-15.8	-17.2	-17.6	0.1
ND	-31.8	-33.4	-33.7	0.6
NE	-12.5	-16.8	-17.2	0.8
NH	-15.9	-17.8	-17.5	-0.9
NJ	-13.9	-17.4	-16.7	0.1
NM	-15.6	-18.9	-18.9	0.1
NV	-21.0	-21.9	-21.7	-0.6
NY	-12.4	-16.4	-14.9	-0.6
OH	-12.5	-16.1	-16.6	-0.5
OK	-30.5	-32.6	-34.0	1.9
OR	-13.2	-15.3	-15.4	0.8
PA	-12.3	-15.4	-15.9	0.1
RI	-12.4	-15.8	-15.6	-1.5
SC	-20.2	-20.5	-20.5	0.2
SD	-29.9	-33.5	-34.0	-0.9
TN	-23.1	-22.6	-22.5	-0.4
TX	-15.3	-16.5	-16.5	0.0
UT	-13.0	-17.3	-16.3	1.2
VA	-16.1	-18.2	-18.7	0.5
VT	-15.7	-17.5	-17.3	-0.8
WA	-12.3	-13.9	-14.3	1.1
WI	-15.9	-18.0	-18.1	-1.1
WV	-30.7	-31.6	-32.9	-1.8
WY	-30.5	-34.0	-34.0	0.4
Avg.	**-18.9**	**-20.9**	**-21.0**	**-0.1**

Table B-10 1-Story Restaurant Summary Table for LEC and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-33.4	-40.1	-37.9	1.0	MT	-24.1	-28.9	-28.4	-1.4
AL	-43.9	-46.5	-47.7	-3.4	NC	-30.2	-33.0	-33.8	-4.8
AR	-39.8	-44.8	-46.5	-10.3	ND	-41.8	-44.2	-44.6	-0.2
AZ	-41.4	-43.6	-44.2	-5.2	NE	-24.2	-32.6	-33.5	-3.9
CA	-34.1	-37.5	-36.2	-5.2	NH	-24.3	-29.0	-28.3	-4.6
CO	-40.2	-46.3	-47.0	-7.4	NJ	-27.3	-34.1	-32.8	-6.3
CT	-24.1	-33.6	-30.6	-4.4	NM	-31.4	-36.6	-36.6	-4.3
DE	-27.7	-32.2	-33.0	-8.5	NV	-35.1	-38.6	-37.7	-6.0
FL	-30.5	-31.5	-31.6	-5.3	NY	-21.7	-31.5	-27.7	-4.3
GA	-30.0	-32.7	-33.6	-4.9	OH	-23.3	-31.4	-32.6	-3.4
HI	-34.8	-34.8	-34.8	-6.3	OK	-39.7	-45.1	-48.8	-3.1
IA	-23.7	-30.3	-31.2	-4.4	OR	-28.5	-33.0	-33.4	-4.5
ID	-26.0	-30.8	-30.9	-2.7	PA	-23.7	-30.4	-31.6	-3.4
IL	-23.3	-32.6	-32.6	-4.5	RI	-25.0	-31.8	-31.4	-3.8
IN	-24.8	-31.9	-33.1	-4.3	SC	-32.0	-34.7	-35.1	-4.2
KS	-40.8	-46.4	-48.3	-1.2	SD	-39.0	-43.6	-44.2	-3.0
KY	-27.9	-32.3	-34.3	-5.4	TN	-32.9	-35.6	-36.1	-7.7
LA	-29.3	-31.3	-31.9	-6.0	TX	-29.8	-33.2	-33.2	-5.9
MA	-23.8	-32.5	-30.7	-3.7	UT	-27.1	-34.7	-32.9	-3.8
MD	-27.7	-33.5	-32.9	-9.0	VA	-30.3	-34.0	-34.8	-5.4
ME	-43.6	-45.6	-45.5	-2.6	VT	-23.6	-28.5	-27.9	-4.3
MI	-22.1	-30.3	-31.4	-3.0	WA	-26.4	-30.6	-31.6	-3.9
MN	-37.9	-36.3	-36.1	-5.0	WI	-23.6	-28.7	-29.1	-3.3
MO	-39.1	-43.9	-46.8	-3.3	WV	-39.3	-41.8	-45.3	-6.4
MS	-46.0	-47.7	-47.7	-1.9	WY	-42.3	-46.2	-46.1	1.3
					Avg.	**-30.7**	**-35.4**	**-35.6**	**-4.2**

Table B-11 4-Story Apartment Building Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-5.6	-20.2	-15.3	-2.3	MS	-25.5	-29.7	-29.9	-3.6
AL	-24.3	-27.9	-29.8	-3.6	ND	-8.5	-18.8	-20.9	-1.6
AR	-18.7	-24.5	-26.6	-2.5	NV	-4.3	-3.7	-3.9	-0.4
AZ	-14.3	-15.9	-16.3	-1.8	OK	-17.4	-23.5	-28.0	-2.0
CO	-12.7	-22.0	-23.1	-1.9	SC	-4.7	-6.1	-6.3	-0.6
HI	-2.7	-2.7	-2.7	-0.5	SD	-12.5	-21.9	-23.3	-2.2
KS	-15.7	-23.0	-25.6	-2.2	TN	-3.7	-3.4	-3.3	-0.4
ME	-11.5	-21.3	-20.6	-2.8	WV	-15.9	-19.0	-25.3	-1.7
MN	-4.9	-3.5	-3.3	-0.5	WY	-13.7	-24.0	-23.9	-2.0
MO	-16.0	-21.6	-25.3	-1.8	**Avg.**	**-11.4**	**-16.7**	**-17.4**	**-1.7**

Table B-12 6-Story Apartment Building Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-5.5	-20.3	-15.4	-2.2	MS	-25.3	-29.5	-29.7	-3.6
AL	-23.7	-27.6	-29.5	-3.6	ND	-8.5	-18.8	-20.8	-1.6
AR	-18.4	-24.3	-26.4	-2.5	NV	-3.7	-3.2	-3.4	-0.3
AZ	-13.6	-15.3	-15.7	-1.7	OK	-17.0	-23.3	-27.9	-2.1
CO	-12.4	-21.7	-22.8	-1.8	SC	-4.1	-5.9	-6.1	-0.5
HI	-2.5	-2.5	-2.5	-0.4	SD	-12.1	-21.6	-22.9	-2.1
KS	-15.4	-22.7	-25.3	-2.3	TN	-3.1	-2.9	-2.8	-0.3
ME	-11.2	-21.0	-20.3	-2.7	WV	-15.4	-18.6	-24.8	-1.6
MN	-4.4	-3.1	-2.9	-0.4	WY	-13.3	-23.7	-23.6	-1.9
MO	-15.7	-21.2	-24.9	-1.8	**Avg.**	**-11.0**	**-16.3**	**-17.1**	**-1.6**

Table B-13 4-Story Dormitory Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-6.5	-21.1	-16.3	-1.8	MS	-29.2	-32.0	-32.1	-1.0
AL	-25.6	-29.4	-31.2	-1.2	ND	-9.3	-20.2	-22.2	1.2
AR	-17.7	-24.5	-26.9	-5.1	NV	-5.0	-3.5	-3.9	-0.7
AZ	-16.4	-16.9	-17.0	-0.1	OK	-16.8	-24.2	-29.4	-0.3
CO	-13.4	-21.8	-22.8	-2.9	SC	-2.0	-4.4	-4.7	-0.5
HI	-2.9	-2.9	-2.9	-0.8	SD	-13.1	-22.7	-24.0	-1.2
KS	-17.2	-24.4	-26.9	0.3	TN	-3.6	-2.8	-2.7	-0.7
ME	-13.1	-22.5	-21.9	-0.2	WV	-16.2	-19.4	-25.1	-2.2
MN	-7.3	-4.7	-4.3	-0.7	WY	-14.9	-24.6	-24.5	0.4
MO	-16.9	-22.6	-26.3	-0.1	**Avg.**	**-12.3**	**-17.2**	**-17.9**	**-0.9**

Table B-14 6-Story Dormitory Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change Energy Use	Energy Cost	Carbon	LCC	State	Percentage Change Energy Use	Energy Cost	Carbon	LCC
AK	-5.1	-19.9	-14.9	-2.6	MS	-27.7	-32.2	-32.4	-4.5
AL	-26.5	-30.5	-32.5	-4.6	ND	-9.0	-18.3	-20.2	-2.1
AR	-19.5	-25.6	-27.8	-3.2	NV	-2.7	-2.6	-2.6	-0.2
AZ	-15.2	-16.7	-17.1	-2.2	OK	-19.3	-25.8	-30.5	-2.9
CO	-10.6	-20.6	-21.8	-2.1	SC	-5.9	-8.0	-8.2	-0.7
HI	-2.3	-2.3	-2.3	-0.4	SD	-9.6	-19.8	-21.3	-2.3
KS	-14.3	-21.9	-24.7	-2.7	TN	-2.1	-2.3	-2.3	-0.2
ME	-10.7	-20.4	-19.7	-3.1	WV	-13.8	-17.2	-23.5	-1.9
MN	-3.6	-2.5	-2.3	-0.3	WY	-10.6	-21.8	-21.7	-2.2
MO	-15.4	-21.3	-25.2	-2.3	**Avg.**	**-10.7**	**-16.3**	**-17.1**	**-2.0**

Table B-15 15-Story Hotel Building Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change Energy Use	Energy Cost	Carbon	LCC	State	Percentage Change Energy Use	Energy Cost	Carbon	LCC
AK	2.7	-12.9	-7.7	-2.1	MS	-25.0	-22.9	-22.8	-3.1
AL	-18.6	-22.4	-24.3	-3.2	ND	-0.4	-10.9	-12.9	-1.6
AR	-9.1	-17.8	-21.0	-2.2	NV	6.0	6.8	6.5	0.6
AZ	-9.2	-8.9	-8.8	-1.3	OK	-7.9	-16.3	-22.5	-1.8
CO	-3.4	-12.8	-13.9	-1.6	SC	7.4	5.0	4.7	0.6
HI	2.1	2.1	2.2	0.3	SD	-3.0	-12.1	-13.4	-1.8
KS	-7.0	-13.6	-15.9	-2.0	TN	5.8	6.7	6.9	0.6
ME	-5.0	-13.6	-13.0	-2.4	WV	-6.7	-9.7	-15.8	-1.4
MN	2.7	4.7	5.0	0.3	WY	-4.0	-14.3	-14.2	-1.8
MO	-7.3	-12.4	-15.8	-1.6	**Avg.**	**-3.2**	**-8.1**	**-8.8**	**-1.2**

Table B-16 2-Story High School Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change Energy Use	Energy Cost	Carbon	LCC	State	Percentage Change Energy Use	Energy Cost	Carbon	LCC
AK	-2.4	-7.1	-5.3	-0.7	MS	-16.8	-17.4	-17.4	-2.3
AL	-12.3	-14.4	-15.6	-1.7	ND	-4.9	-8.1	-8.9	-0.4
AR	-6.4	-10.5	-12.1	-0.7	NV	-3.4	-2.7	-3.0	-0.4
AZ	-10.8	-11.4	-11.6	-1.5	OK	-6.0	-9.8	-13.1	-0.3
CO	-5.0	-8.8	-9.3	-1.1	SC	-1.7	-2.0	-2.1	0.2
HI	-1.0	-1.0	-1.0	-0.1	SD	-5.0	-8.7	-9.4	-0.9
KS	-7.1	-10.3	-11.6	-0.8	TN	-3.1	-2.5	-2.3	-0.4
ME	-4.9	-8.4	-8.2	-0.8	WV	-6.7	-7.9	-10.7	-1.0
MN	-3.4	-2.6	-2.4	-0.5	WY	-5.2	-9.4	-9.3	-0.6
MO	-7.1	-9.4	-11.2	-0.9	**Avg.**	**-5.8**	**-7.7**	**-8.2**	**-0.8**

Table B-17 8-Story Office Building Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-6.0	-10.8	-9.5	1.1	MS	-15.8	-14.5	-14.5	3.1
AL	-15.3	-15.3	-15.3	1.1	ND	-10.7	-12.5	-12.8	2.5
AR	-13.8	-14.5	-14.7	-3.9	NV	-3.2	-1.3	-1.8	-0.4
AZ	-8.8	-7.8	-7.6	1.4	OK	-16.0	-16.9	-17.4	2.4
CO	-10.7	-10.6	-10.6	-2.6	SC	-2.6	-2.1	-2.1	-0.7
HI	-1.4	-1.4	-1.4	-0.3	SD	-12.4	-12.9	-12.9	0.7
KS	-16.0	-14.9	-14.6	3.0	TN	-4.0	-1.8	-1.5	-0.8
ME	-12.8	-13.4	-13.3	1.7	WV	-13.3	-12.8	-11.8	-2.8
MN	-5.6	-2.2	-1.9	-0.3	WY	-13.7	-14.0	-14.0	2.2
MO	-16.1	-14.8	-14.1	2.4	**Avg.**	**-9.8**	**-9.5**	**-9.3**	**0.5**

Table B-18 16-Story Office Building Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	4.0	-3.2	-1.0	-0.4	MS	-14.1	-7.9	-7.6	-0.9
AL	-9.1	-9.4	-9.6	-1.3	ND	2.2	-1.8	-2.4	-0.2
AR	-3.5	-7.9	-9.4	-1.0	NV	5.8	7.0	6.7	0.8
AZ	-1.9	-0.4	0.0	0.0	OK	-2.9	-7.3	-10.4	-0.6
CO	0.3	-2.4	-2.7	-0.3	SC	5.6	3.7	3.5	0.5
HI	3.1	3.1	3.1	0.6	SD	1.2	-1.5	-1.8	-0.2
KS	-1.0	-2.2	-2.7	-0.2	TN	6.4	6.8	6.8	0.8
ME	-2.2	-4.2	-4.1	-0.7	WV	-0.8	-1.5	-2.7	-0.2
MN	3.0	4.7	4.9	0.4	WY	-0.4	-3.8	-3.7	-0.4
MO	-0.7	-1.7	-2.3	-0.1	**Avg.**	**0.5**	**-0.8**	**-0.9**	**-0.1**

Table B-19 1-Story Retail Store Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-8.4	-13.9	-12.1	-0.7	MS	-30.5	-27.3	-27.2	-1.3
AL	-23.7	-23.6	-23.5	-1.2	ND	-15.7	-18.0	-18.4	-0.3
AR	-17.5	-18.7	-19.1	-2.6	NV	-10.0	-6.4	-7.4	-1.2
AZ	-19.9	-18.6	-18.3	-1.7	OK	-19.1	-20.3	-21.1	1.4
CO	-17.1	-17.3	-17.3	-2.9	SC	-5.9	-4.9	-4.8	-0.1
HI	-0.5	-0.5	-0.5	0.0	SD	-16.1	-18.4	-18.7	-1.1
KS	-19.4	-20.2	-20.5	0.2	TN	-8.4	-5.3	-4.9	-0.4
ME	-16.7	-18.5	-18.4	-0.9	WV	-19.5	-19.4	-19.0	-2.6
MN	-11.7	-6.9	-6.3	-0.3	WY	-16.9	-18.9	-18.9	-0.9
MO	-19.5	-19.9	-20.1	0.5	**Avg.**	**-15.2**	**-15.1**	**-15.0**	**-0.9**

Table B-20 1-Story Restaurant Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period

State	Percentage Change				State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC		Energy Use	Energy Cost	Carbon	LCC
AK	-12.4	-17.0	-15.4	2.4	MS	-24.8	-23.1	-23.0	3.6
AL	-21.0	-22.1	-22.6	1.5	ND	-20.6	-20.8	-20.9	2.9
AR	-16.2	-19.6	-20.7	-3.1	NV	-11.3	-6.7	-8.1	-1.7
AZ	-16.1	-14.6	-14.2	0.8	OK	-17.3	-21.0	-23.6	4.2
CO	-18.6	-18.8	-18.8	-4.5	SC	-2.8	-2.8	-2.8	-0.5
HI	-2.6	-2.6	-2.6	-0.6	SD	-19.9	-20.9	-21.0	0.3
KS	-18.5	-20.1	-20.6	4.9	TN	-4.4	-2.9	-2.6	-0.9
ME	-22.8	-22.8	-22.8	1.4	WV	-17.2	-17.8	-18.3	-3.5
MN	-17.0	-10.1	-9.2	-2.2	WY	-22.4	-22.9	-22.9	1.6
MO	-16.3	-18.2	-19.3	4.6	**Avg.**	**-15.6**	**-15.5**	**-15.6**	**0.4**