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

Joshua Kneifel

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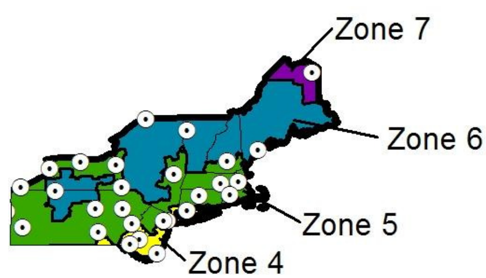
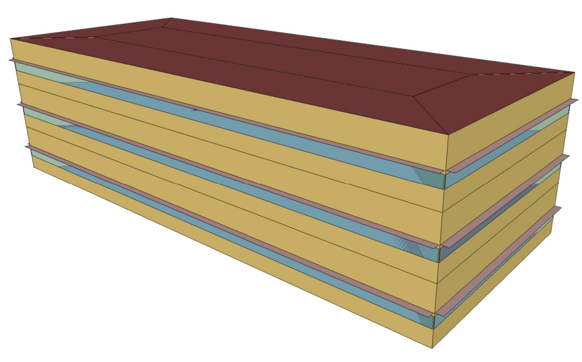


BIRDS
Building Industry Reporting and Design *for* Sustainability



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Joshua Kneifel
Applied Economics Office
Engineering Laboratory

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February 2013

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Rebecca Blank, Acting Secretary

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Abstract

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

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

Keywords

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

Preface

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

Disclaimer

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

Acknowledgements

The author wishes to thank all those who contributed ideas and suggestions for this report. They include Ms. Barbara Lippiatt and Dr. Robert Chapman of EL's Applied Economics Office, Dr. Harrison Skye 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 Building Industry Reporting and Design for Sustainability (BIRDS) database. Thanks to Mr. Nathaniel Soares for developing the initial version of the 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
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DOE	Department of Energy
EEFG	EnergyPlus Example File Generator
eGRID	Emissions and Generation Resource Integrated Database
EIA	Energy Information Administration
EL	Engineering Laboaratory
EPA	Environmental Protection Agency
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
HVAC	Heating, Ventilating, and Air Conditioning
I-P	Inch-Pounds (Customary Units)
IECC	International Energy Code Council
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
LCC	Life-Cycle Cost
LEC	Low Energy Case
MRR	Maintenance, Repair, and Replacement
N_2O	Nitrous Oxide
NIST	National Institute of Standards and Technology
PNNL	Pacific Northwest National Laboratory
ROI	Return On Investment
S-I	System International (Metric Units)
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SPV	Single Present Value

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

Executive Summary

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

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

Maine is the only state in the Northeast Census Region that has not yet adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. Maine would benefit from adopting either *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* as its state energy code. Adoption of *ASHRAE 90.1-2007* leads to greater reductions in energy use, energy costs, carbon emissions, and life-cycle costs than adoption of *ASHRAE 90.1-2004* relative to *ASHRAE 90.1-1999*.

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

The region-wide adoption of the LEC design as the commercial building energy code for all building types significantly decreases energy use (13.8 %), energy costs (20.1 %), and carbon emissions (19.0 %) while reducing life-cycle costs (1.2 %), on average, for a

10-year study period. Although the LEC design leads to reductions for all states, the magnitude of the reductions varies according to each state's adopted energy code. The state with no energy code, Maine, realizes the greatest percentage savings in energy use, energy costs, and carbon emissions.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 1 year to 10 years, the number of building types that are cost-effective increases from 7 to all 11. The study period length is an important determinant of cost-effectiveness and size of the percentage changes in life-cycle cost.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, and carbon emissions. After controlling for each state's energy code, cities located in warmer climates realize greater average percentage reductions in these measures. However, these same cities realize smaller percentage reductions in life-cycle costs because additional construction costs are required to obtain future energy cost savings.

Different building types realize different regional average percentage reductions in energy use, energy costs, and carbon emissions. High schools realize the smallest reductions while restaurants and 3- and 8-story office buildings realize the greatest reductions. The greatest percentage reductions in life-cycle costs also are realized by restaurants and 3- and 8-story office buildings while the smallest percentage reductions are realized by 4 and 6-story apartment buildings and 16-story office buildings.

The magnitude of a building type's average percentage change is not necessarily correlated with its changes in total energy use, energy costs, and energy-related carbon emissions relative to other building types. For example, high schools tend to realize some of the smallest percentage reductions, but some of the greatest total reductions in energy use, energy costs, and energy-related carbon emissions. Total reductions are driven largely by total new floor area constructed for the building type in a state. The adoption of the LEC design would lead to greater aggregate reductions in energy use in New York than in Vermont because the amount of newly constructed floor area for 2003 to 2007 was about 30 times greater in New York.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy prices, and carbon emissions rates. Maine realizes over twice the energy use reductions per unit of floor area than any other state in the Northeast because it has no state energy code, while the other eight states have adopted *ASHRAE 90.1-2007*. States with the highest electricity rates tend to realize the largest reductions in energy costs per unit of energy consumption reduced. Similarly, states with higher CO_2e emission rates per unit of electricity generated realize greater reductions in emissions per unit of energy consumption reduced.

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

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

1 Introduction

1.1 Background and Purpose

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

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

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

1.2 Literature Review

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

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

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

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

1.3 Approach

This study uses the BIRDS database to analyze the benefits and costs of increasing building energy efficiency for 26 cities located in the 9 states of the Northeast Census Region. BIRDS is a compilation of whole building energy simulations, building construction cost data, maintenance, repair, and replacement rates and costs, and energy-related carbon emissions data for 11 building types in 228 cities across all U.S. states. The present analysis compares energy performance of buildings designed to each state's current energy code for commercial buildings to the performance of more energy efficient building designs to determine the energy use savings, energy cost savings, and energy-related carbon emissions reductions, and the associated life-cycle costs, resulting from adopting stricter standards as the state's energy code.

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

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

2 Study Design

The BIRDS database used in this study was built following the framework developed in Kneifel (2010) and further expanded in Kneifel (2011a) and Kneifel (2013). This study analyzes whole building energy simulations, life-cycle costs, and life-cycle carbon emissions for 5 energy efficiency designs for 11 building types, 26 cities across the nine states in the Northeast Census Region of the United States, and 9 study period lengths.[1]

2.1 Building Types

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

Table 2-1 Building Characteristics

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

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

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

2.2 Building Designs

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

Table 2-2 shows that commercial building energy codes as of December 2011 are the same for 8 of 9 states in the Northeast Census Region. [3] Maine currently does not have a statewide energy code while the other 8 states have adopted *ASHRAE 90.1-2007*.

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

State	City	Zone	Code
CT	Bridgeport	5A	2007
	Hartford	5A	
MA	Boston	5A	2007
	Worcester	5A	
ME	Caribou	7	None
	Portland	6A	
NH	Concord	6A	2007
NJ	Atlantic City	4A	2007
	Newark	5A	
NY	Albany	5A	2007
	Binghamton	6A	
	Buffalo	6A	
	Massena	6A	
	New York	4A	
	Rochester	5A	
	Syracuse	5A	
PA	Allentown	5A	2007
	Bradford	5A	
	Erie	5A	
	Harrisburg	5A	
	Philadelphia	4A	
	Pittsburgh	5A	
	Wilkes-Barre	5A	
	Williamsport	5A	
RI	Providence	5A	2007
VT	Burlington	6A	2007

The 9 states, 26 cities, and *ASHRAE* climate zones listed in Table 2-2 are shown in Figure 2-1. States with more significant population centers have more cities included in the BIRDS database. For example, New York and Pennsylvania have 7 and 8 cities, respectively, while New Hampshire, Rhode Island, and Vermont each have one city. The climate zone(s) for each state vary across the Northeast Census Region from *ASHRAE* Climate Zone 4 in Atlantic City, New Jersey to Climate Zone 7 in Caribou, Maine.

[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] State energy codes as of December 2011.

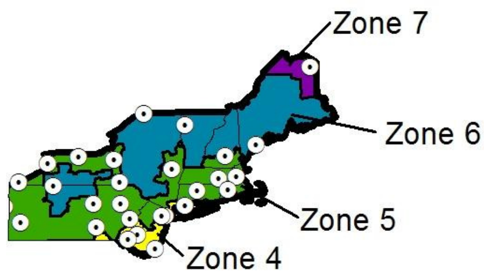

Figure 2-1 Cities and Climate Zones

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

3 Cost Data

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

3.1 First Costs

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

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

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

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

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

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

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

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

[6] First, incandescent lighting is replaced with compact fluorescent lighting while typical T-12 fluorescent tube lighting is replaced with more efficient T-8 fluorescent tube lighting to decrease the lighting density of the lighting system. Second, the number of fixtures is reduced to meet the remainder of the required reduction in watts per unit of floor area. Increasing the efficiency of the lighting increases the costs of construction. The first approach increases first costs while the second approach decreases first costs for the lighting system. This approach is based on Belzer et al. (2005) and Halverson et al. (2006).
[7] Overhang cost source is Winiarski et al. (2003)
[8] This study does not account for new HVAC efficiency requirements set by federal regulations.

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

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

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

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

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

3.2 Future Costs

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

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

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

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

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

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

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

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

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

4 Building Stock Data

Aggregating the savings for individual newly constructed commercial buildings to the state level requires new construction data for each building type within each state. This study uses the commercial building weighting factors reported in Jarnagin and Bandyopadhyay (2010) to estimate the total energy use savings, energy cost savings, life-cycle cost savings, and carbon emissions reduction resulting from adopting newer energy standard editions for each state. Jarnagin and Bandyopadhyay (2010) use two databases to generate the commercial building weighting factors: the 2003 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 include year of construction and location.

4.2 Weighting Factors

Jarnagin and Bandyopadhyay (2010) maps the more detailed McGraw-Hill dataset to the CBECS categories and subcategories shown in Table 4-1. The prototype commercial buildings analyzed in this study, shown in bold, represent 54.2 % of new commercial building stock floor area for 2003 through 2007 for the Northeast Census Region. The McGraw-Hill dataset is aggregated at the CBECS category-level. For this study, a prototype building is assumed to represent its entire CBECS category, which implies the prototypes together represent 64.0 % of the new commercial building stock.

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

Category	Subcategory	Conditioned Floor Area 1000 m^2 (1000 ft^2)	Percentage in Category	Percentage of Total
Office	**Large**	**2370 (25 514)**	**22.2 %**	**2.1%**
Office	**Medium**	**4314 (46 430)**	**40.4 %**	**3.9%**
Office	**Small**	**3993 (42 982)**	**37.4 %**	**3.6%**
Retail		**11 833 (127 372)**	**72.9 %**	**10.6%**
Strip Mall		4399 (47 349)	27.1 %	3.9%
School	Primary	4387 (47 223)	32.5 %	3.9%
School	**Secondary**	**9112 (98 078)**	**67.5 %**	**8.1%**
Hospital		2996 (32 251)	44.1 %	2.7%
Other Health Care		3798 (40 880)	55.9 %	3.4%
Restaurant	**Sit Down**	**511 (5503)**	**52.9 %**	**0.5%**
Restaurant	Fast Food	455 (4899)	47.1 %	0.4%
Hotel	**Large**	**5376 (57 863)**	**74.2 %**	**4.8%**
Hotel/Motel	Small	1869 (20 120)	25.8 %	1.7%
Warehouse		11 007 (118 479)		9.8 %
Public Assembly		5418 (58 321)		4.8 %
Apartment	**High-rise**	**12 709 (136 800)**	**55.1 %**	**11.4 %**
Apartment	**Mid-rise**	**10 356 (111 476)**	**44.9 %**	**9.2 %**
No Prototype		17 070 (183 742)		15.2 %
Total (2003 to 2007)		111 974 (1 205 281)		100.0 %

Note: Subcategory weighting is based on national construction data.

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

5 Analysis Approach

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

5.1 Energy Use

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

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

5.2 Life-Cycle Costing

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

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

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

5.3 Carbon Assessment

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

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

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

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

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

Table 5-1 Greenhouse Gas Global Warming Potentials

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

5.4 Analysis Metrics

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

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

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

6 Connecticut

Connecticut has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, and is located in the New England Census Division and Climate Zone 5A. Table 6-1 provides an overview of Connecticut's simulated energy use keyed to building types and energy codes. Average energy use varies across building type and energy standard edition. The 8-story office building uses the least amount of energy at 82 kWh/m^2 to 101 kWh/m^2 (26 kBtu/ft^2 to 32 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 223 kWh/m^2 to 236 kWh/m^2 (71 kBtu/ ft^2 to 75 kBtu/ ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	159	50	144	46
APART06	157	50	141	45
DORMI04	122	39	109	34
DORMI06	173	55	155	49
HOTEL15	165	52	144	46
HIGHS02	236	75	223	71
OFFIC03	109	35	89	28
OFFIC08	101	32	82	26
OFFIC16	156	49	132	42
RETAIL1	119	38	105	33
RSTRNT1	162	51	123	39

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

6.1 Percentage Savings

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

6.1.1 Statewide Building Comparison

Table 6-2 shows the percentage changes 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 -5.3 % to -24.1 % depending on the building type with an overall average of -13.4 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

Table 6-2 Average Percentage Changes in Energy Use from Adoption of the LEC Design, 10-Year, Connecticut

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.5	-18.5	-15.1	-0.1
APART06	-10.6	-21.8	-17.7	-0.4
DORMI04	-11.2	-18.9	-16.1	-1.6
DORMI06	-10.4	-21.2	-17.2	-0.7
HOTEL15	-12.7	-21.6	-18.3	-0.5
HIGHS02	-5.3	-17.9	-12.8	-1.9
OFFIC03	-17.9	-23.4	-21.8	-3.1
OFFIC08	-18.3	-21.3	-20.5	-2.7
OFFIC16	-15.2	-21.6	-19.6	-0.9
RETAIL1	-12.3	-16.9	-15.5	-1.7
RSTRNT1	-24.1	-33.6	-30.6	-4.4
Average	**-13.4**	**-21.5**	**-18.7**	**-1.6**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.9 % to -33.6 % depending on the building type, with an average of -21.5 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. In fact, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption for all building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 47.6 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is nearly three times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -12.8 % to -30.6 % with an average of -18.7 %. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for all 11 building types. The combination of the reduction in total energy

use and the shift in energy use from electricity consumption to natural gas consumption leads to greater reductions in carbon emissions than reductions in energy use.

The percentage change in life-cycle costs varies across building types, ranging from -4.4 % to -0.1 % for a 10-year study period. All 11 building types realize reductions in life-cycle costs. Therefore, the LEC design is cost-effective for the state to adopt as its state energy code for commercial buildings.

6.1.2 City Comparisons

Simulations are run for 2 cities located in Connecticut, both located in Zone 5A: Bridgeport and Hartford. While the two cities are located in the same climate zone, the results may still vary for two reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality.

Table 6-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for adoption of the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design do not vary significantly across cities, ranging from -12.9 % to -13.9 % with an overall average of -13.4 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 6-3 Average Percentage Changes from Adoption of the LEC Design by City, 10-Year, Connecticut

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Bridgeport	5A	-13.9	-21.8	-16.3	-1.6
Hartford	5A	-12.9	-21.3	-15.6	-1.6
Average		**-13.4**	**-21.5**	**-15.9**	**-1.6**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -21.3 % to -21.8 % for 10 years of operation. For both cities, reductions in energy costs are greater than energy use reductions 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 -15.6 % to -16.3 %. Reductions in life-cycle costs for all building types are constant across both cities, with a percentage change of -1.6 %. There is minimal variation in local construction costs throughout Connecticut.

6.2 Total Savings

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

6.2.1 Energy Use

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

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

Building Type	Standard Edition	
	LEC	
	kWh/m²	kBtu/ft²
APART04	-15.1	-4.8
APART06	-16.7	-5.3
DORMI04	-13.7	-4.3
DORMI06	-18.0	-5.7
HOTEL15	-20.9	-6.6
HIGHS02	-19.5	-6.2
OFFIC03	-12.4	-3.9
OFFIC08	-18.4	-5.8
OFFIC16	-23.6	-7.5
RETAIL1	-14.7	-4.7
RSTRNT1	-39.0	-12.4

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 13.6 GWh (46.3 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 58.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 23.2 GWh (79.2 GBtu) per year. These savings imply 232.0 GWh (792.2 GBtu) in energy use savings over the 10-year study period.

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

The change in energy use varies across the 9 building types with reported floor area data. The building types that have the greatest percentage reductions in energy use are not always the same buildings that lead to the greatest total reductions for the state. Instead, the building types that represent a greater amount of new floor area realize the largest changes in energy use. For example, the building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and high schools -- only rank 6th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 6-2.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	55.0	592	-829 089	-2 830 866
APART06	55.1 %	67.4	725	-1 121 166	-3 828 142
HOTEL15	100.0 %	97.7	1052	-2 047 501	-6 991 047
HIGHS02	100.0 %	238.9	2571	-2 952 006	-10 079 417
OFFIC03	37.4 %	46.3	498	-903 013	-3 083 275
OFFIC08	40.4 %	49.9	537	-916 556	-3 129 516
OFFIC16	22.2 %	27.4	295	-647 018	-2 209 198
RETAIL1	100.0 %	249.1	2681	-3 651 265	-12 466 988
RSTRNT1	100.0 %	13.0	140	-505 672	-1 726 582
Total		**844.5**	**9090**	**-13 573 285**	**-46 345 032**

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

6.2.2 Energy Costs

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

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

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	-$21.74	-$2.02
APART06	-$25.86	-$2.40
DORMI04	-$17.93	-$1.67
DORMI06	-$27.52	-$2.56
HOTEL15	-$27.38	-$2.54
HIGHS02	-$27.31	-$2.54
OFFIC03	-$27.62	-$2.57
OFFIC08	-$24.76	-$2.30
OFFIC16	-$33.18	-$3.08
RETAIL1	-$19.63	-$1.82
RSTRNT1	-$52.35	-$4.86

Table 6-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $21.2 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 58.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $35.1 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	55.0	592	-$1 195 290
APART06	55.1 %	67.4	725	-$1 741 254
HOTEL15	100.0 %	97.7	1052	-$2 676 789
HIGHS02	100.0 %	238.9	2571	-$6 596 069
OFFIC03	37.4 %	46.3	498	-$1 263 340
OFFIC08	40.4 %	49.9	537	-$1 234 909
OFFIC16	22.2 %	27.4	295	-$910 648
RETAIL1	100.0 %	249.1	2681	-$4 887 982
RSTRNT1	100.0 %	13.0	140	-$678 970
Total		**844.5**	**9090**	**-$21 185 251**

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

6.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition LEC	
	kg/m^2	lb/ft^2
APART04	-98.2	-20.1
APART06	-114.8	-23.5
DORMI04	-82.9	-17.0
DORMI06	-122.6	-25.1
HOTEL15	-126.6	-25.9
HIGHS02	-114.3	-23.4
OFFIC03	-124.2	-25.4
OFFIC08	-113.6	-23.3
OFFIC16	-150.7	-30.9
RETAIL1	-90.2	-18.5
RSTRNT1	-240.4	-49.2

Table 6-9 applies the Table 6-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The adoption of the LEC design decreases carbon emissions for all building types and results in total savings of 93 939 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the statewide reductions in carbon emissions of 160 579 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	55.0	592	-5,399
APART06	55.1 %	67.4	725	-7,731
HOTEL15	100.0 %	97.7	1052	-12,374
HIGHS02	100.0 %	238.9	2571	-27,297
OFFIC03	37.4 %	46.3	498	-5,746
OFFIC08	40.4 %	49.9	537	-5,668
OFFIC16	22.2 %	27.4	295	-4,129
RETAIL1	100.0 %	249.1	2681	-22,469
RSTRNT1	100.0 %	13.0	140	-3,127
Total		**844.5**	**9090**	**-93 939**

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

6.2.4 Life-Cycle Costs

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

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

Building Type	Standard Edition	
	LEC	
	$/m²	$/ft²
APART04	-$1.60	-$0.15
APART06	-$4.59	-$0.43
DORMI04	-$17.08	-$1.59
DORMI06	-$8.54	-$0.79
HOTEL15	-$5.41	-$0.50
HIGHS02	-$18.91	-$1.76
OFFIC03	-$29.46	-$2.74
OFFIC08	-$26.72	-$2.48
OFFIC16	-$8.04	-$0.75
RETAIL1	-$13.36	-$1.24
RSTRNT1	-$65.93	-$6.12

Table 6-11 applies the Table 6-10 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with all 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $12.5 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools and retail stores realize the greatest statewide decrease in life-cycle costs ($4.5 million and $3.3 million, respectively). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $19.7 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	55.0	592	-$87 885
APART06	55.1 %	67.4	725	-$309 268
HOTEL15	100.0 %	97.7	1052	-$529 147
HIGHS02	100.0 %	238.9	2571	-$4 516 248
OFFIC03	37.4 %	46.3	498	-$1 362 519
OFFIC08	40.4 %	49.9	537	-$1 332 949
OFFIC16	22.2 %	27.4	295	-$220 541
RETAIL1	100.0 %	249.1	2681	-$3 326 708
RSTRNT1	100.0 %	13.0	140	-$855 019
Total		**844.5**	**9090**	**-$12 540 284**

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

6.3 State Summary

Connecticut has adopted *ASHRAE 90.1-2007* as its state commercial building energy code. On average, adopting the LEC design reduces energy use, energy costs and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 232.0 GWh (792.2 GBtu), energy cost savings of $35.1 million, and carbon emissions reductions of 160 579 metric tons while decreasing life-cycle costs by $19.7 million for one year's worth of commercial building construction.

7 Massachusetts

Massachusetts has adopted *ASHRAE 90.1-2007* as its state energy code, and is located in the New England Census Division and Climate Zone 5A. Table 7-1 provides an overview of Massachusetts's simulated energy use keyed to building types and energy codes. Average energy use varies across building type and energy standard edition. The 8-story office building uses the least amount of energy at 80 kWh/m^2 to 98 kWh/m^2 (25 kBtu/ft^2 to 31 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 232 kWh/m^2 to 244 kWh/m^2 (74 kBtu/ft^2 to 77 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	161	51	147	46
APART06	159	51	144	46
DORMI04	122	39	109	34
DORMI06	175	56	159	50
HOTEL15	168	53	149	47
HIGHS02	244	77	232	74
OFFIC03	107	34	88	28
OFFIC08	98	31	80	25
OFFIC16	156	49	134	42
RETAIL1	119	38	105	33
RSTRNT1	160	51	122	39

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

7.1 Percentage Savings

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

7.1.1 Statewide Building Comparison

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

ASHRAE 90.1-2007, ranging from -4.6 % to -23.8 % depending on the building type with an overall average of -12.9 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

Table 7-2 Average Percentage Changes from Adoption of the LEC Design, 10-Year, Massachusetts

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.1	-16.8	-14.8	0.1
APART06	-9.8	-19.5	-17.0	0.0
DORMI04	-11.1	-17.8	-16.1	-1.3
DORMI06	-9.5	-18.7	-16.4	-0.3
HOTEL15	-11.8	-19.3	-17.4	-0.1
HIGHS02	-4.6	-15.2	-12.3	-1.1
OFFIC03	-17.6	-22.8	-21.8	-2.6
OFFIC08	-18.3	-21.1	-20.6	-2.5
OFFIC16	-14.4	-20.2	-19.0	-0.3
RETAIL1	-11.8	-16.1	-15.2	0.1
RSTRNT1	-23.8	-32.5	-30.7	-3.7
Average	**-12.9**	**-20.0**	**-18.3**	**-1.1**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.2 % to -32.5 % depending on the building type with an average of -20.0 % 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, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption for all building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 53.0 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is three times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -12.3 % to -30.7 % with an average of -18.3 %. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for all 11 building types. The combination of the reduction in total energy

use and the shift in energy use from electricity consumption to natural gas consumption leads to greater reductions in carbon emissions than reductions in energy use.

The percentage change in life-cycle costs varies across building types, ranging from -3.7 % to 0.1 % for a 10-year study period. Eight of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -1.1 % in life-cycle costs, the LEC design is likely to be cost-effective if the state adopt it as its state energy code for commercial buildings.

7.1.2 City Comparisons

Simulations are run for 2 cities located in Massachusetts, both located in Zone 5A: Boston and Worcester. While the two 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 7-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design do not vary significantly across cities, ranging from -12.3 % to -13.5 % with an overall average of -12.9 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 7-3 Average Percentage Changes from Adoption of the LEC Design by City, 10-Year, Massachusetts

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Boston	5A	-13.5	-20.3	-18.8	-0.9
Worcester	5A	-12.3	-19.7	-18.0	-1.2
Average		**-12.9**	**-20.0**	**18.3**	**-1.1**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -19.7 % to -20.3 % for 10 years of operation. For both cities, percentage reductions in energy costs are greater than percentage 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 -18.0 % to -18.8 %. Reductions in life-cycle costs for all building types vary across cities, with the percentage change in life-cycle costs ranging from -1.2 % in Worcester to -0.9 % in Boston.

7.2 Total Savings

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

7.2.1 Energy Use

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

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

Building Type	Standard Edition	
	LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-14.6	-4.6
APART06	-15.6	-4.9
DORMI04	-13.5	-4.3
DORMI06	-16.7	-5.3
HOTEL15	-19.9	-6.3
HIGHS02	-18.8	-6.0
OFFIC03	-11.2	-3.5
OFFIC08	-18.0	-5.7
OFFIC16	-22.5	-7.1
RETAIL1	-14.1	-4.5
RSTRNT1	-37.9	-12.0

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 25.7 GWh (87.7 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 63.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to

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

be 40.4 GWh (137.9 GBtu) per year. These savings imply 403.8 GWh (1378.9 GBtu) in energy use savings over the 10-year study period.

The total change in energy use varies across building types. The building types that have the greatest percentage reductions in energy use are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest reductions in energy use. For example, the building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and 6-story apartments -- only rank 5th and 8th in percentage reduction, respectively, among the 11 building types, as reported in Table 7-2.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	266.0	2863	-3 877 165	-13 238 310
APART06	55.1 %	325.8	3507	-5 074 968	-17 328 124
HOTEL15	100.0 %	176.8	1903	-3 523 368	-12 030 293
HIGHS02	100.0 %	271.3	2920	-3 027 719	-10 337 935
OFFIC03	37.4 %	82.5	888	-1 554 979	-5 309 366
OFFIC08	40.4 %	89.0	958	-1 601 388	-5 467 828
OFFIC16	22.2 %	49.0	527	-1 101 807	-3 762 041
RETAIL1	100.0 %	354.5	3816	-5 003 557	-17 084 295
RSTRNT1	100.0 %	24.2	261	-919 678	-3 140 176
Total		**1639.3**	**17645**	**-25 684 629**	**-87 698 368**

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

7.2.2 Energy Costs

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

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

Building Type	Standard Edition LEC $/m^2	$/ft^2
APART04	-$19.07	-$1.77
APART06	-$22.12	-$2.06
DORMI04	-$15.98	-$1.48
DORMI06	-$23.31	-$2.17
HOTEL15	-$23.71	-$2.20
HIGHS02	-$24.12	-$2.24
OFFIC03	-$23.84	-$2.22
OFFIC08	-$22.08	-$2.05
OFFIC16	-$29.02	-$2.70
RETAIL1	-$17.32	-$1.61
RSTRNT1	-$46.46	-$4.32

Table 7-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $35.6 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 63.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $56.0 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	266.0	2863	-$5 074 238
APART06	55.1 %	325.8	3507	-$7 209 197
HOTEL15	100.0 %	176.8	1903	-$4 191 768
HIGHS02	100.0 %	271.3	2920	-$6 467 915
OFFIC03	37.4 %	82.5	888	-$1 991 071
OFFIC08	40.4 %	89.0	958	-$1 965 257
OFFIC16	22.2 %	49.0	527	-$1 421 337
RETAIL1	100.0 %	354.5	3816	-$6 138 432
RSTRNT1	100.0 %	24.2	261	-$1 127 430
Total		**1639.3**	**17645**	**-35 586 647**

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

7.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-95.4	-19.5
APART06	-109.3	-22.4
DORMI04	-81.2	-16.6
DORMI06	-115.4	-23.6
HOTEL15	-120.4	-24.7
HIGHS02	-112.1	-23.0
OFFIC03	-121.0	-24.8
OFFIC08	-111.6	-22.8
OFFIC16	-145.5	-29.8
RETAIL1	-87.5	-17.9
RSTRNT1	-234.8	-48.1

Table 7-9 applies the Table 7-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 176 424 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 277 396 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	266.0	2863	-25 374
APART06	55.1 %	325.8	3507	-35 610
HOTEL15	100.0 %	176.8	1903	-21 287
HIGHS02	100.0 %	271.3	2920	-30 399
OFFIC03	37.4 %	82.5	888	-9991
OFFIC08	40.4 %	89.0	958	-9929
OFFIC16	22.2 %	49.0	527	-7124
RETAIL1	100.0 %	354.5	3816	-31 014
RSTRNT1	100.0 %	24.2	261	-5697
Total		**1639.3**	**17 645**	**-176 424**

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

7.2.4 Life-Cycle Costs

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

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

Building Type	Standard Edition LEC $/$m^2$	Standard Edition LEC $/$ft^2$
APART04	$1.58	$0.15
APART06	-$0.28	-$0.03
DORMI04	-$14.49	-$1.35
DORMI06	-$3.80	-$0.35
HOTEL15	-$1.10	-$0.10
HIGHS02	-$10.87	-$1.01
OFFIC03	-$24.44	-$2.27
OFFIC08	-$24.28	-$2.26
OFFIC16	-$2.94	-$0.27
RETAIL1	$0.97	$0.09
RSTRNT1	-$55.65	-$5.17

Table 7-11 applies the Table 7-10 results to one year's worth of new building construction in the state to estimate changes in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 7 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $8.1 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools, 8-story office buildings, and 3-story office buildings realize the greatest statewide decreases in life-cycle costs ($2.9 million, $2.2 million, and $2.0 million, respectively) while 4-story apartment buildings and retail stores realize increases in life-cycle costs ($420 180 and $342 608, respectively). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $12.8 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	266.0	2863	$420 180
APART06	55.1 %	325.8	3507	-$91 074
HOTEL15	100.0 %	176.8	1903	-$194 373
HIGHS02	100.0 %	271.3	2920	-$2 947 480
OFFIC03	37.4 %	82.5	888	-$2 016 837
OFFIC08	40.4 %	89.0	958	-$2 161 502
OFFIC16	22.2 %	49.0	527	-$143 838
RETAIL1	100.0 %	354.5	3816	$342 608
RSTRNT1	100.0 %	24.2	261	-$1 350 337
Total		**1639.3**	**17 645**	**-$8 142 653**

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

7.3 State Summary

Massachusetts has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 403.8 GWh (1378.9 GBtu), energy cost savings of $56.0 million, and carbon emissions reductions of 277 396 metric tons while decreasing life-cycle costs by $12.8 million for one year's worth of commercial building construction.

8 Maine

Maine is located in the coldest climate zones in the Northeast Census Region (Zone 6 and Zone 7). The state does not have a commercial building energy code, and is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements. Table 8-1 provides an overview of Maine's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building type and energy standard edition. The 8-story office building uses the least amount of energy at 87 kWh/m^2 to 121 kWh/m^2 (28 kBtu/ft^2 to 38 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 286 kWh/m^2 to 320 kWh/m^2 (91 kBtu/ft^2 to 102 kBtu/ft^2) annually.

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

Building Type	Standard Edition									
	1999		2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	208	66	208	66	194	61	184	59	167	53
APART06	205	65	204	65	190	60	182	58	165	52
DORMI04	164	52	163	52	154	49	143	45	124	39
DORMI06	224	71	223	71	208	66	200	63	183	58
HOTEL15	203	64	202	64	189	60	193	61	174	55
HIGHS02	320	102	319	101	316	100	304	97	286	91
OFFIC03	136	43	134	43	127	40	116	37	93	30
OFFIC08	121	38	119	38	111	35	106	34	87	28
OFFIC16	178	56	177	56	169	54	174	55	153	49
RETAIL1	167	53	166	53	157	50	139	44	114	36
RSTRNT1	231	73	228	72	216	69	178	56	130	41

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

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 more energy efficient designs for the state of Maine.

8.1.1 Energy Use

Table 8-2 shows minimal change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types having energy use reductions of 1.6 % or less. There is a small decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from -1.5 % to -8.4 % with an average of -6.2 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -2.2 % to -22.8 %, with an overall average of -11.4 %.

Table 8-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Maine

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.3	-7.1	-11.5	-19.9
APART06	-0.3	-7.2	-11.2	-19.3
DORMI04	-0.8	-6.0	-13.1	-24.4
DORMI06	-0.4	-7.0	-10.7	-18.0
HOTEL15	-0.6	-7.1	-5.0	-14.0
HIGHS02	-0.3	-1.5	-4.9	-10.7
OFFIC03	-1.1	-6.1	-14.2	-31.1
OFFIC08	-1.6	-8.4	-12.8	-28.1
OFFIC16	-0.7	-4.8	-2.2	-13.9
RETAIL1	-0.6	-6.1	-16.7	-31.7
RSTRNT1	-1.2	-6.4	-22.8	-43.6
Average	**-0.7**	**-6.2**	**-11.4**	**-23.1**

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 -10.7 % to -43.6 % with an average of -23.1 %. Similar to the *ASHRAE 90.1-2007* design, the lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratio due to the stricter window SHGC requirement. Additionally, the high school realizes smaller reductions in energy use because of its unique occupant activity, significant occupancy during the school year and minimal occupancy during the summer.

8.1.2 Energy Costs

Table 8-3 shows a minimal percentage change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.5 % to -1.8 %), 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 -5.8 % to -18.5 % depending on the building type with an average of -13.8 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -4.2 % to -22.8 %, with an overall average of -16.4 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -15.9 % to -45.6 % with an average of -29.9 % overall.

Table 8-3 Average Percentage Change in Energy Costs, 10-Year, Maine

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.5	-18.4	-21.3	-32.9
APART06	-0.5	-18.5	-21.0	-32.3
DORMI04	-1.2	-18.5	-22.5	-35.6
DORMI06	-0.5	-18.1	-20.4	-30.6
HOTEL15	-0.8	-17.0	-13.6	-23.1
HIGHS02	-0.6	-5.8	-8.4	-18.9
OFFIC03	-1.4	-10.0	-13.8	-31.6
OFFIC08	-1.8	-11.6	-13.4	-29.2
OFFIC16	-0.9	-8.3	-4.2	-15.9
RETAIL1	-0.8	-12.4	-18.5	-33.2
RSTRNT1	-1.6	-13.4	-22.8	-45.6
Average	**-1.0**	**-13.8**	**-16.4**	**-29.9**

For all building designs, the average reductions in energy costs are greater than the reductions in energy use because not only is there a decrease in total energy consumption, there is a shift in energy use from electricity to natural gas. The buildings use electricity for all energy consumption except for the heating component of the HVAC system, which uses natural gas. The energy efficiency measures adopted lead to a decrease in energy use for both lighting and cooling the building, but an increase in heating loads. Since electricity is more expensive than natural gas on a per unit of energy basis, the shift in energy use from cooling to heating magnifies the decrease in energy costs for the building.

8.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small percentage reductions (less than 2 %) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 8-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -5.4 %

to -17.7 % with an average of -13.3 %. The *ASHRAE 90.1-2007* design leads to slightly greater reductions overall than *ASHRAE 90.1-2004*, with the average change in carbon emissions ranging from -4.1 % to -22.8 % with an overall average of -16.0 %. The LEC design leads to the greatest average changes in carbon emissions, ranging from -15.8 % to -45.5 %, depending on the building type, with an average of -29.4 % across all building types.

Table 8-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Maine

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.5	-17.6	-20.6	-31.9
APART06	-0.5	-17.7	-20.3	-31.4
DORMI04	-1.2	-17.7	-21.9	-34.9
DORMI06	-0.5	-17.3	-19.7	-29.7
HOTEL15	-0.8	-16.3	-13.0	-22.5
HIGHS02	-0.5	-5.4	-8.2	-18.3
OFFIC03	-1.3	-9.7	-13.8	-31.6
OFFIC08	-1.8	-11.4	-13.3	-29.1
OFFIC16	-0.9	-8.1	-4.1	-15.8
RETAIL1	-0.8	-12.0	-18.4	-33.1
RSTRNT1	-1.6	-13.0	-22.8	-45.5
Average	**-0.9**	**-13.3**	**-16.0**	**-29.4**

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 use and increase natural gas use. This shift towards natural gas use further decreases carbon emissions because electricity has a higher carbon emissions rate per unit of energy than natural gas in Maine.

8.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 8-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for 10 of 11 building types over a 10-year study period. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building designs for two and three building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* ranges from -3.1 % to 4.2 % depending on building type. The LEC design is the lowest cost building design for 6 building types and realizes a reduction in life-cycle costs for all 11 building types, with the percentage change in life-cycle costs ranging from -0.0 % to -3.1 %.

Table 8-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Maine

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.1	-2.2	**-2.8**	-2.6
APART06	0.0	-2.3	**-2.7**	-2.4
DORMI04	3.3	0.6	-0.2	**-1.6**
DORMI06	0.0	-2.7	**-3.1**	-3.1
HOTEL15	-0.1	**-2.9**	-2.4	-2.3
HIGHS02	0.7	-0.3	-0.8	**-1.9**
OFFIC03	4.8	2.2	1.6	**-0.7**
OFFIC08	4.7	2.1	1.7	**-0.0**
OFFIC16	0.0	**-1.3**	-0.7	-0.7
RETAIL1	2.7	-0.2	-0.9	**-1.2**
RSTRNT1	6.8	4.2	1.4	**-2.6**
Average	**2.1**	**-0.2**	**-0.8**	**-1.7**

8.1.5 City Comparisons

Simulations are run for two cities located in Maine: Portland in Climate Zone 6A and Caribou in Climate Zone 7. The results may vary across cities within Maine for two 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, construction material and labor costs vary by locality.

As can be seen in Table 8-6, average reductions in energy use for all building types from adopting newer energy standard editions varies minimally across climate zones. The adoption of *ASHRAE 90.1-2001* or *-2004* leads to greater reductions for Zone 6 than for Zone 7. The adoption of *ASHRAE 90.1-2007* and the LEC design leads to lower reductions for Zone 6 than for Zone 7. For the LEC design, Zone 7 realizes a change in average energy use of -24.2 % compared to -22.1 % for Zone 6.

Table 8-6 Average Percentage Changes in Energy Use from Adoption of Newer Standard Editions by City, Maine, 10-Year

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Caribou	7	-0.6	-5.2	-12.0	-24.2
Portland	6A	-0.8	-7.1	-10.8	-22.1
Average		**-0.7**	**-6.2**	**-11.4**	**-23.1**

The variations in energy costs across cities are a result of two factors, the reductions in energy use and the fuel source of the reductions. Table 8-7 shows that the climate zone with the greatest reduction in energy use realizes the greatest reduction in energy costs for each of the building designs. Both climate zones realize larger percentage reductions in energy costs than percentage reductions in energy use because energy use is shifted from electricity to natural gas consumption. Since electricity is more expensive than natural gas on a per unit basis, the shift in energy use leads to additional reductions in energy costs.

Table 8-7 Average Percentage Change in Energy Costs by City, 10-Year, Maine

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Caribou	7	-0.8	-13.0	-16.5	-30.0
Portland	6A	-1.1	-14.7	-16.2	-29.8
Average		**-1.0**	**-13.8**	**-16.4**	**-29.9**

Table 8-8 reports changes in energy-related carbon emissions by city for Maine. For both cities, the more stringent standard editions result in greater reductions in carbon emissions. For all building designs, the city that realizes the greatest reductions in energy use realizes the greatest reductions in carbon emissions.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Caribou	7	-0.7	-11.9	-15.9	-29.5
Portland	6A	-1.0	-13.6	-15.5	-29.1
Average		**-0.9**	**-12.7**	**-15.7**	**-29.3**

The data reported in Table 8-9 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*. Adoption of the *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* designs both result in average reductions in life-cycle costs for both cities relative to *ASHRAE 90.1-1999*. Adoption of the LEC design realizes the greatest average percentage reductions in life-cycle costs for cities in both Zone 6 and Zone 7. For the LEC design, the city in Zone 6 realizes slightly greater reductions in life-cycle costs than the city in Zone 7 (2.0 % versus 1.5 %).

Table 8-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Maine

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Caribou	7	2.2	-0.2	-0.6	-1.5
Portland	6A	1.9	-0.3	-1.1	-2.0
Average		**2.1**	**-0.2**	**-0.8**	**-1.7**

8.2 Total Savings

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

8.2.1 Energy Use

Table 8-10 reports the average per unit change in annual energy use by building type and building design in the state.[18] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 8-11 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.[19]

Table 8-10 Average Per Unit Change in Annual Energy Use, Maine

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-0.7	-0.2	-14.6	-4.6	-23.9	-7.6	-41.3	-13.1
APART06	-0.7	-0.2	-14.6	-4.6	-22.8	-7.3	-39.4	-12.5
DORMI04	-1.3	-0.4	-9.7	-3.1	-21.4	-6.8	-40.2	-12.7
DORMI06	-0.8	-0.3	-15.5	-4.9	-24.1	-7.7	-40.3	-12.8
HOTEL15	-1.1	-0.4	-14.2	-4.5	-10.3	-3.3	-28.6	-9.1
HIGHS02	-1.0	-0.3	-8.2	-2.6	-19.4	-6.2	-42.3	-13.4
OFFIC03	-1.5	-0.5	-4.6	-1.5	-15.8	-5.0	-34.4	-10.9
OFFIC08	-1.9	-0.6	-10.2	-3.2	-15.5	-4.9	-34.0	-10.8
OFFIC16	-1.2	-0.4	-8.4	-2.7	-4.18	-1.3	-24.9	-7.9
RETAIL1	-1.0	-0.3	-10.0	-3.2	-27.9	-8.9	-53.3	-16.9
RSTRNT1	-2.7	-0.8	-14.6	-4.6	-53.0	-16.8	-101.0	-32.1

The annual reduction in energy use shown in Table 8-11 ranges widely across building designs, but all building designs decrease overall energy use across the state relative to *ASHRAE 90.1-1999*. Adopting the *ASHRAE 90.1-2001, ASHRAE 90.1-2004*, and *ASHRAE 90.1-2007* designs result in annual decreases of 310 470 kWh (1.1 GBtu), 2.6 GWh (8.8 GBtu), and 5.8 GWh (19.8 GBtu), respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 11.9 GWh

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

(40.7 GBtu) of total energy use annually for one year's worth of new construction for these building types.

Table 8-11 Statewide Change in Annual Energy Use for One Year of Construction, Maine

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	5.8	62	-4	-13	-84	-287	-137	-469	-237	-810
APART06	55.1 %	7.1	76	-5	-17	-103	-350	-161	-548	-277	-946
HOTEL15	100.0 %	33.3	358	-37	-128	-473	-1616	-344	-1175	-952	-3250
HIGHS02	100.0 %	62.7	675	-63	-214	-289	-985	-991	-3383	-2156	-7360
OFFIC03	37.4 %	16.7	180	-25	-85	-137	-467	-325	-1111	-709	-2419
OFFIC08	40.4 %	18.1	195	-34	-117	-185	-631	-280	-956	-615	-2099
OFFIC16	22.2 %	9.9	107	-12	-42	-84	-287	-42	-142	-248	-845
RETAIL1	100.0 %	113.2	1218	-112	-383	-1	-3 860	-3158	-10 784	-6031	-20 594
RSTRNT1	100.0 %	6.9	74	-18	-62	-100	-341	-362	-1237	-691	-2359
Total		**273.5**	**2944**	**-310**	**-1 060**	**-2 584**	**-8 824**	**-5800**	**-19 805**	**-11 915**	**-40 683**

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

Assuming that the buildings considered in this study, which represent 55.0 % 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 from LEC adoption in new commercial buildings to be 21.7 GWh (74.0 GBtu) per year. These savings imply 216.6 GWh (740 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 10.5 GWh (36.0 GBtu) annually or 105.5 GWh (360.1 GBtu) over the 10-year study period.

The statewide change in energy use across the 9 building types with reported floor area data are consistent across building designs and vary within a building design. Building types that represent the greatest amount of new floor area realize the largest changes in aggregate energy use. The greatest reductions across all building designs are realized by retail stores followed by high schools and hotels. The smallest reductions are realized by the 4- and 6-story apartments and 16-story office buildings. 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 reduction in energy use for the LEC design -- retail stores and high schools -- rank 2nd and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 8-2.

8.2.2 Energy Costs

Table 8-12 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 8-12 Average Per Unit Change in Energy Costs, 10-Year, Maine

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	-$0.65	-$0.06	-$24.43	-$2.27	-$28.29	-$2.63	-$43.70	-$4.06
APART06	-$0.67	-$0.06	-$24.42	-$2.27	-$27.79	-$2.58	-$42.77	-$3.97
DORMI04	-$1.28	-$0.12	-$20.10	-$1.87	-$24.49	-$2.28	-$38.77	-$3.60
DORMI06	-$0.75	-$0.07	-$26.05	-$2.42	-$29.39	-$2.73	-$44.07	-$4.09
HOTEL15	-$1.08	-$0.10	-$22.60	-$2.10	-$18.08	-$1.68	-$30.82	-$2.86
HIGHS02	-$1.42	-$0.13	-$10.44	-$0.97	-$14.48	-$1.35	-$33.11	-$3.08
OFFIC03	-$0.96	-$0.09	-$10.17	-$0.94	-$14.90	-$1.38	-$33.41	-$3.10
OFFIC08	-$1.82	-$0.17	-$11.77	-$1.09	-$13.57	-$1.26	-$29.57	-$2.75
OFFIC16	-$1.18	-$0.11	-$10.97	-$1.02	-$5.69	-$0.53	-$21.12	-$1.96
RETAIL1	-$0.95	-$0.09	-$14.67	-$1.36	-$21.91	-$2.04	-$39.33	-$3.65
RSTRNT1	-$2.55	-$0.24	-$21.65	-$2.01	-$36.83	-$3.42	-$73.71	-$6.85

Table 8-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. All building types realize reductions in energy costs for all building designs. The *ASHRAE 90.1-2001* design realizes small reductions in energy costs ($298 613). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $4.0 million, $5.2 million, and $9.9 million respectively.

Assuming that the buildings considered in this study, which represent 55.0 % 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 *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 $542 933, $7.3 million, $9.4 million, and $18.0 million over the 10-year study period, respectively.

Table 8-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Maine

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	5.8	62	-$3718	-$140 176	-$162 334	-$250 720
APART06	55.1 %	7.1	76	-$4699	-$171 589	-$195 301	-$300 546
HOTEL15	100 %	33.3	358	-$36 049	-$752 086	-$601 543	-$1 025 661
HIGHS02	100 %	62.7	455	-$60 286	-$637 753	-$934 454	-$2 094 901
OFFIC03	37.4 %	16.7	180	-$23 875	-$175 007	-$242 750	-$555 088
OFFIC08	40.4 %	18.1	195	-$32 924	-$212 763	-$245 286	-$534 617
OFFIC16	22.2 %	9.9	107	-$11 711	-$109 175	-$56 561	-$210 098
RETAIL1	100 %	113.2	1218	-$107 882	-$1 658 926	-$2 478 426	-$4 448 912
RSTRNT1	100 %	6.9	74	-$17 468	-$148 017	-$251 822	-$503 982
Total		**273.5**	**2724**	**-$298 613**	**-$4 005 492**	**-$5 168 477**	**-$9 924 523**

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

8.2.3 Energy-related Carbon Emissions

Table 8-14 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 8-14 Average Per Unit Change in Carbon Emissions, 10-Year, Maine

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-4.0	-0.4	-149.1	-13.9	-174.7	-16.2	-271.1	-55.5
APART06	-4.2	-0.4	-149.0	-13.8	-171.4	-15.9	-265.0	-54.3
DORMI04	-8.0	-0.7	-122.0	-11.3	-151.4	-14.1	-241.5	-49.5
DORMI06	-4.7	-0.4	-158.9	-14.8	-181.3	-16.8	-272.9	-55.9
HOTEL15	-6.7	-0.6	-138.1	-12.8	-110.2	-10.2	-191.0	-39.1
HIGHS02	-6.0	-0.6	-61.6	-5.7	-92.9	-8.6	-208.0	-42.6
OFFIC03	-8.9	-0.8	-64.2	-6.0	-91.4	-8.5	-208.5	-42.7
OFFIC08	-11.3	-1.1	-72.7	-6.8	-84.9	-7.9	-185.1	-37.9
OFFIC16	-7.3	-0.7	-67.5	-6.3	-34.9	-3.2	-132.4	-27.1
RETAIL1	-5.9	-0.6	-89.8	-8.3	-138.0	-12.8	-248.6	-50.9
RSTRNT1	-15.9	-1.5	-132.6	-12.3	-233.7	-21.7	-466.2	-95.5

Table 8-15 applies the Table 8-14 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs decrease carbon emissions overall. The adoption of *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in savings of 24 498 metric tons and 32 322 metric tons over a 10-year study period, respectively. The adoption of the LEC design as the state's energy code decreases carbon emissions by 62 289 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types.

Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 44 541 metric tons, 58 767 metric tons, and 113 253 metric tons over the 10-year study period, respectively.

Table 8-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Maine – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	5.8	62	-23	-855	-1002	-1555
APART06	55.1 %	7.1	76	-29	-1047	-1204	-1862
HOTEL15	100.0 %	33.3	358	-225	-4596	-3666	-6357
HIGHS02	100.0 %	62.7	455	-376	-3865	-5827	-13 045
OFFIC03	37.4 %	16.7	180	-149	-1077	-1533	-3496
OFFIC08	40.4 %	18.1	195	-205	-1315	-1535	-3348
OFFIC16	22.2 %	9.9	107	-73	-672	-347	-1317
RETAIL1	100.0 %	113.2	1218	-672	-10 163	-15 608	-28 122
RSTRNT1	100.0 %	6.9	74	-109	-907	-1598	-3188
Total		**273.5**	**2724**	**-1860**	**-24 498**	**-32 322**	**-62 289**

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

8.2.4 Life-Cycle Costs

Table 8-16 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 8-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Maine

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	$0.57	$0.05	-$23.16	-$2.15	-$29.16	-$2.71	-$26.82	-$2.49
APART06	$0.01	$0.00	-$23.46	-$2.18	-$28.19	-$2.62	-$24.87	-$2.31
DORMI04	$31.77	$2.95	$6.16	$0.57	-$2.20	-$0.20	-$14.81	-$1.38
DORMI06	-$0.33	-$0.03	-$29.54	-$2.74	-$33.78	-$3.14	-$33.23	-$3.09
HOTEL15	-$0.64	-$0.06	-$29.47	-$2.74	-$24.96	-$2.32	-$23.69	-$2.20
HIGHS02	$6.18	$0.57	-$2.54	-$0.24	-$7.57	-$0.70	-$17.62	-$1.64
OFFIC03	$38.05	$3.53	$17.49	$1.63	$12.77	$1.19	-$5.23	-$0.49
OFFIC08	$38.94	$3.62	$17.00	$1.58	$13.95	$1.30	-$0.34	-$0.03
OFFIC16	-$0.30	-$0.03	-$10.23	-$0.95	-$5.33	-$0.50	-$5.90	-$0.55
RETAIL1	$18.28	$1.70	-$1.33	-$0.12	-$5.84	-$0.54	-$7.99	-$0.74
RSTRNT1	$86.19	$8.01	$53.80	$5.00	$18.24	$1.69	-$33.01	-$3.07

Table 8-17 applies the Table 8-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. Total changes in life-cycle costs over the 10-year study period vary across building designs. Adoption of the *ASHRAE 90.1-2001* design results in an increase in life-cycle costs for 7 of 9 building types. 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 $721 188 and $1.8 million, respectively. The LEC design decreases life-cycle costs for all 9 building types, and decreases total life-cycle costs by $3.5 million. For a 10-year study period, it is cost-effective to adopt *ASHRAE 90.1-2004* and *-2007* as well as 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 the adoption of the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC design can be extrapolated to estimate statewide changes in life-cycle costs of $7.9 million, -$1.3 million, -$3.3 million, and -$6.4 million over the 10-year study period, respectively.

Table 8-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Maine

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	5.8	62	$3249	-$132 899	-$167 289	-$153 907
APART06	55.1 %	7.1	76	$77	-$164 834	-$198 086	-$174 774
HOTEL15	100.0 %	33.3	358	-$21 333	-$980 723	-$830 455	-$788 514
HIGHS02	100.0 %	62.7	455	$387 645	-$159 483	-$474 430	-$1 104 770
OFFIC03	37.4 %	16.7	180	$637 962	$293 338	$214 066	-$87 658
OFFIC08	40.4 %	18.1	195	$704 131	$307 311	$252 233	-$6218
OFFIC16	22.2 %	9.9	107	-$2969	-$101 771	-$53 039	-$58 714
RETAIL1	100.0 %	113.2	1,218	$2 067 570	-$150 012	-$660 100	-$903 540
RSTRNT1	100.0 %	6.9	74	$589 358	$367 884	$124 730	-$225 704
Total		**273.5**	**2724**	**$4 365 691**	**-$721 188**	**-$1 792 369**	**-$3 503 798**

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

8.3 State Summary

Maine is the only state in the Northeast Census Region that has not yet adopted a state energy code for commercial buildings, and is located in the coldest climates in the region. On average, adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions at negative life-cycle costs. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 105.5 GWh (360.1 GBtu), energy cost savings of $9.4 million, and 58 767 metric tons of carbon emissions reductions while saving $3.3 million in life-cycle costs for one year's worth of commercial building construction.

The adoption of the LEC design leads to savings in total energy use, energy costs, and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design would lead to even greater impacts than adopting *ASHRAE 90.1-2007*, with savings of 216.6 GWh (739.7 GBtu), $18.0 million of energy costs, and 113 253 metric tons of carbon emissions while decreasing life-cycle cost by $6.4 million for one year's worth of commercial building construction.

9 New Hampshire

New Hampshire is located in the New England Census Division and has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. New Hampshire spans two climate zones with the southern portion of the state located in Zone 5A and the northern portion in Zone 6A. Only one city, Concord, is simulated for this study and is located in Zone 6A. Table 9-1 provides an overview of New Hampshire'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 87 kWh/m^2 to 105 kWh/m^2 (28 $kBtu/ft^2$ to 33 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 268 kWh/m^2 to 285 kWh/m^2 (85 $kBtu/ft^2$ to 90 $kBtu/ft^2$) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	177	56	160	51
APART06	175	56	159	50
DORMI04	138	44	121	38
DORMI06	196	62	180	57
HOTEL15	188	60	171	54
HIGHS02	285	90	268	85
OFFIC03	115	37	95	30
OFFIC08	105	33	87	28
OFFIC16	171	54	151	48
RETAIL1	135	43	114	36
RSTRNT1	178	57	135	43

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 (Concord).

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 the LEC design for the state of New Hampshire.

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 -5.7 % to -24.3 % with an average of -12.8 % relative to the *ASHRAE 90.1-2007* design. The greatest reduction in energy use for the LEC design occurs in the restaurant followed by the small and mid-sized office buildings. The smallest reductions occur in the high school followed by the 6-story dormitory and hotel.

Table 9-2 Average Percentage Changes from Adoption of a Newer of the LEC Design, 10 Year, New Hampshire

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.5	-15.8	-14.7	-0.3
APART06	-9.3	-15.4	-14.4	-0.3
DORMI04	-12.2	-17.0	-16.2	-1.7
DORMI06	-8.4	-13.8	-12.9	-0.5
HOTEL15	-8.9	-11.2	-10.8	-0.2
HIGHS02	-5.7	-12.3	-11.1	-1.5
OFFIC03	-18.1	-20.4	-20.1	-2.8
OFFIC08	-16.9	-18.2	-18.1	-2.2
OFFIC16	-11.3	-12.3	-12.2	-0.6
RETAIL1	-15.9	-17.8	-17.5	-0.9
RSTRNT1	-24.3	-29.0	-28.3	-4.6
Average	**-12.8**	**-16.7**	**-16.0**	**-1.4**

The LEC design realizes average changes in energy costs from -11.2 % to -29.0 % depending on the building type, with an average of -16.7 % overall over 10 years of 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 the most extreme case, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption for the high school. The increase in natural gas consumption offsets 19.2 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is twice the percentage reduction in energy use. The LEC design incorporates daylighting, which decreases the building's internal 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 -10.8 % to -28.3 % depending on the building type, with an average of -16.0 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. For the high school, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption, which leads to even greater reductions in carbon emissions.

The average change in life-cycle costs for the LEC design over a 10-year study period ranges from -0.3 % to -4.6 %. Four- and 6-story apartment buildings realize the smallest decrease in life-cycle costs while restaurants, 3-story office buildings, and 8-story office buildings are the building types that realize the greatest reductions in average life-cycle costs. Given that all 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 New Hampshire save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is necessary to estimate savings per unit of floor area for each building type in the state.

9.2.1 Energy Use

Table 9-3 reports the average per unit change in annual energy use by building type for the LEC design in the state.[20] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 9-4 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 office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[21]

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

Table 9-3 Average Per Unit Change in Annual Energy Use New Hampshire

Building Type	Standard Edition	
	LEC	
	kWh/m^2	kBtu/ft^2
APART04	-16.8	-5.3
APART06	-16.3	-5.2
DORMI04	-16.8	-5.3
DORMI06	-16.4	-5.2
HOTEL15	-16.8	-5.3
HIGHS02	-20.9	-6.6
OFFIC03	-16.4	-5.2
OFFIC08	-17.7	-5.6
OFFIC16	-19.4	-6.1
RETAIL1	-21.5	-6.8
RSTRNT1	-43.3	-13.8

The annual reduction in energy use shown in Table 9-4 ranges widely across building types with reported floor area data, but the LEC design decreases overall energy use across the state for all building types. The adoption of the LEC design as the state's energy code would save 6.9 GWh (23.4 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 63.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings to be 10.8 GWh (36.9 GBtu) per year. These savings imply 108.0 GWh (368.6 GBtu) in energy use savings over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				LEC	
				kWh	kBtu
APART04	44.9 %	12.7	137	-214 170	-731 267
APART06	55.1 %	15.6	168	-253 509	-865 590
HOTEL15	100.0 %	45.2	487	-759 456	-2 593 108
HIGHS02	100.0 %	82.1	884	-1 343 121	-4 585 993
OFFIC03	37.4 %	20.7	223	-431 979	-1 474 962
OFFIC08	40.4 %	22.3	240	-395 564	-1 350 627
OFFIC16	22.2 %	12.3	132	-237 481	-810 862
RETAIL1	100.0 %	129.5	1394	-2 778 392	-9 486 626
RSTRNT1	100.0 %	10.2	110	-441 331	-1 506 894
Total		**350.7**	**3775**	**-6 855 003**	**-23 405 928**

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

The reduction in energy use for the LEC design relative to *ASHRAE 90.1-2007* varies across the 9 building types with reported floor area data. The greatest reductions are realized by the retail store followed by the high school and hotel. The smallest reductions are realized by the apartment buildings and the 16-story office building. 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. The building types that lead to the greatest estimated reduction in energy use -- retail stores and high schools -- only rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 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, New Hampshire

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	-$18.42	-$1.71
APART06	-$17.99	-$1.67
DORMI04	-$16.03	-$1.49
DORMI06	-$17.80	-$1.65
HOTEL15	-$14.30	-$1.33
HIGHS02	-$21.23	-$1.97
OFFIC03	-$21.13	-$1.96
OFFIC08	-$18.54	-$1.72
OFFIC16	-$17.46	-$1.62
RETAIL1	-$19.50	-$1.81
RSTRNT1	-$41.76	-$3.88

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. Any variation is a result of the greater percentage reduction in electricity consumption relative to the reduction in natural gas consumption. Overall, reductions in energy costs total $6.9 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study, which represent 63.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total energy cost savings of $10.9 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	12.7	137	-$234 300
APART06	55.1 %	15.6	168	-$280 211
HOTEL15	100.0 %	45.2	487	-$647 483
HIGHS02	100.0 %	82.1	884	-$1 735 354
OFFIC03	37.4 %	20.7	223	-$438 997
OFFIC08	40.4 %	22.3	240	-$413 514
OFFIC16	22.2 %	12.3	132	-$214 308
RETAIL1	100.0 %	129.5	1394	-$2 525 037
RSTRNT1	100.0 %	10.2	110	-$425 202
Total		**350.7**	**3775**	**-$6 914 405**

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

9.2.3 Energy-related Carbon Emissions

Table 9-7 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, New Hampshire

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-99.2	-20.3
APART06	-96.7	-19.8
DORMI04	-87.7	-18.0
DORMI06	-95.9	-19.6
HOTEL15	-79.4	-16.3
HIGHS02	-111.9	-22.9
OFFIC03	-115.2	-23.6
OFFIC08	-100.3	-20.5
OFFIC16	-96.2	-19.7
RETAIL1	-107.3	-22.0
RSTRNT1	-228.2	-46.7

Table 9-8 applies the Table 9-7 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of the

LEC design. The total reduction in carbon emissions ranges widely across building types, and is correlated with each building's total reduction in energy use. However, there is not a perfect correlation because the magnitude of the offsetting natural gas increase varies across building types. The adoption of the LEC design as the state's energy code decreases carbon emissions by 37 573 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 59 169 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	12.7	137	-1262
APART06	55.1 %	15.6	168	-1507
HOTEL15	100.0 %	45.2	487	-3594
HIGHS02	100.0 %	82.1	884	-9189
OFFIC03	37.4 %	20.7	223	-2383
OFFIC08	40.4 %	22.3	240	-2238
OFFIC16	22.2 %	12.3	132	-1181
RETAIL1	100.0 %	129.5	1394	-13897
RSTRNT1	100.0 %	10.2	110	-2323
Total		**350.7**	**3775**	**-37 573**

Note: Dormitories are excluded because no such 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, New Hampshire

Building Type	Standard Edition LEC $/m²	$/ft²
APART04	-$3.55	-$0.33
APART06	-$2.59	-$0.24
DORMI04	-$16.35	-$1.52
DORMI06	-$4.89	-$0.45
HOTEL15	-$2.38	-$0.22
HIGHS02	-$14.00	-$1.30
OFFIC03	-$22.24	-$2.07
OFFIC08	-$18.22	-$1.69
OFFIC16	-$4.98	-$0.46
RETAIL1	-$6.30	-$0.59
RSTRNT1	-$59.95	-$5.57

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 the LEC design. The change in life-cycle costs varies widely across building types, but all building types realize a reduction in life-cycle costs. High schools realize the greatest decrease in life-cycle costs ($1.1 million) while 6- and 4-story apartment buildings realize the smallest reductions ($40 338 and $45 160). The LEC design leads to reductions in statewide life-cycle costs of $3.7 million relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total decrease in statewide life-cycle costs of $5.8 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC
APART04	44.9 %	12.7	137	-$45 160
APART06	55.1 %	15.6	168	-$40 338
HOTEL15	100.0 %	45.2	487	-$107 572
HIGHS02	67.5 %	82.1	884	-$1 149 857
OFFIC03	37.4 %	20.7	223	-$459 942
OFFIC08	40.4 %	22.3	240	-$406 478
OFFIC16	22.2 %	12.3	132	-$61 090
RETAIL1	100.0 %	129.5	1394	-$816 421
RSTRNT1	100.0 %	10.2	110	-$610 372
Total		**350.7**	**3775**	**-$3 697 228**

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

9.3 State Summary

New Hampshire has adopted *ASHRAE 90.1-2007* as its energy code for commercial buildings. The adoption of the LEC design, which goes beyond *ASHRAE 90.1-2007*, leads to reductions in energy use, energy costs, and energy-related carbon emissions in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code would lead to energy use savings of 108.0 GWh (368.6 GBtu), energy cost savings of $10.9 million, and carbon emissions reductions of 59 169 metric tons while decreasing life-cycle costs by $5.8 million for one year's worth of commercial building construction.

10 New Jersey

New Jersey has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, and is located in the Middle Atlantic Census Division and Climate Zone 4A. Table 10-1 provides an overview of New Jersey's simulated energy use keyed to building types and energy codes. Average energy use varies across building type and energy standard edition. The 8-story office building uses the least amount of energy at 79 kWh/m^2 to 98 kWh/m^2 (25 $kBtu/ft^2$ to 31 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 198 kWh/m^2 to 212 kWh/m^2 (63 kBtu/ ft^2 to 67 kBtu/ ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	151	48	135	43
APART06	150	47	133	42
DORMI04	112	36	98	31
DORMI06	164	52	145	46
HOTEL15	154	49	134	42
HIGHS02	212	67	198	63
OFFIC03	105	33	85	27
OFFIC08	98	31	79	25
OFFIC16	148	47	124	39
RETAIL1	113	36	97	31
RSTRNT1	158	50	115	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 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 the LEC design in the state of New Jersey.

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 change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -6.6 % to -27.3 % depending on the building type with an overall average of -14.7 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 10-2 Average Percentage Changes from Adoption of the LEC Design, 10-Year, New Jersey

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.3	-17.8	-16.0	0.4
APART06	-11.4	-20.6	-18.5	0.2
DORMI04	-12.3	-18.6	-17.2	-0.8
DORMI06	-11.4	-20.4	-18.3	-0.2
HOTEL15	-13.1	-20.2	-18.6	0.1
HIGHS02	-6.6	-17.8	-15.0	-1.5
OFFIC03	-19.6	-23.6	-22.9	-2.5
OFFIC08	-19.5	-21.4	-21.1	-2.5
OFFIC16	-16.0	-21.0	-20.1	-0.1
RETAIL1	-13.9	-17.4	-16.7	0.1
RSTRNT1	-27.3	-34.1	-32.8	-6.3
Average	**-14.7**	**-21.2**	**-19.7**	**-1.2**

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 -17.4 % to -34.1 % depending on the building type with an average of -21.2 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 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 43.2 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 2.7 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, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.0 % to -32.8 % with an average of -19.7 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 10 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -6.3 % to 0.4 % for a 10-year study period. Seven of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -1.2 % in life-cycle costs, the LEC design may be cost-effective if the state adopt it as its state energy code for commercial buildings.

10.1.2 City Comparisons

Simulations are run for two cities located in New Jersey, both located in Zone 4A: Atlantic City and Newark. While the two 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 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. The average percentage changes in energy use for all building types from adopting the LEC design do not vary significantly across cities, ranging from -14.5 % to -14.8 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 10-3 Average Percentage Changes from Adoption of the LEC Design by City, 10-Year, New Jersey

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Atlantic City	4A	-14.8	-21.4	-20.1	-1.2
Newark	4A	-14.5	-21.0	-19.7	-1.2
Average		**-14.7**	**-21.2**	**-19.9**	**-1.2**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -21.0 % to -21.4 % 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 -19.7 % to -20.1 %. Percentage changes in life-cycle costs for all building types are constant across cities, with percentage changes in life-cycle costs of -1.2 %.

10.2 Total Savings

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

10.2.1 Energy Use

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

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

Building Type	Standard Edition	
	LEC	
	kWh/m^2	kBtu/ft^2
APART04	-15.6	-4.9
APART06	-17.1	-5.4
DORMI04	-13.8	-4.4
DORMI06	-18.7	-5.9
HOTEL15	-20.2	-6.4
HIGHS02	-20.6	-6.5
OFFIC03	-13.9	-4.4
OFFIC08	-19.1	-6.1
OFFIC16	-23.7	-7.5
RETAIL1	-15.7	-5.0
RSTRNT1	-43.2	-13.7

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 34.2 GWh (116.8 GBtu) of total energy use

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

annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 58.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 58.2 GWh (198.6 GBtu) per year. These savings imply 581.6 GWh (1985.7 GBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest changes in energy use. For example, the building types that lead to the greatest estimated energy use reductions for the LEC design -- retail stores and high schools -- only rank 5th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 10-2.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	252.3	2716	-3 924 198	-13 398 900
APART06	55.1 %	309.0	3326	-5 272 009	-18 000 905
HOTEL15	100.0 %	188.5	2029	-3 798 052	-12 968 181
HIGHS02	100.0 %	525.5	5656	-7 312 848	-24 969 207
OFFIC03	37.4 %	92.4	995	-1 905 016	-6 504 545
OFFIC08	40.4 %	99.7	1073	-1 902 346	-6 495 426
OFFIC16	22.2 %	54.9	591	-1 299 367	-4 436 598
RETAIL1	100.0 %	498.7	5368	-7 810 630	-26 668 850
RSTRNT1	100.0 %	22.5	242	-971 785	-3 318 092
Total		**2043.5**	**21 996**	**-34 196 250**	**-116 760 704**

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

10.2.2 Energy Costs

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

Building Type	Standard Edition LEC $/m²	$/ft²
APART04	-$18.37	-$1.71
APART06	-$21.46	-$1.99
DORMI04	-$14.96	-$1.39
DORMI06	-$23.25	-$2.16
HOTEL15	-$21.96	-$2.04
HIGHS02	-$23.05	-$2.14
OFFIC03	-$23.22	-$2.16
OFFIC08	-$20.81	-$1.93
OFFIC16	-$27.23	-$2.53
RETAIL1	-$16.88	-$1.57
RSTRNT1	-$45.38	-$4.22

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. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $42.7 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 58.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $72.7 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC
APART04	44.9 %	252.3	2716	-$4 634 161
APART06	55.1 %	309.0	3326	-$6 630 982
HOTEL15	100.0 %	188.5	2029	-$4 139 036
HIGHS02	100.0 %	525.5	5656	-$12 199 834
OFFIC03	37.4 %	92.4	995	-$2 130 809
OFFIC08	40.4 %	99.7	1073	-$2 075 083
OFFIC16	22.2 %	54.9	591	-$1 493 769
RETAIL1	100.0 %	498.7	5368	-$8 417 123
RSTRNT1	100.0 %	22.5	242	-$1 020 178
Total		**2043.5**	**21996**	**-42 740 975**

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

10.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-111.3	-22.8
APART06	-128.8	-26.4
DORMI04	-91.8	-18.8
DORMI06	-139.8	-28.6
HOTEL15	-134.7	-27.6
HIGHS02	-134.6	-27.6
OFFIC03	-140.8	-28.8
OFFIC08	-127.6	-26.1
OFFIC16	-165.6	-33.9
RETAIL1	-103.7	-21.2
RSTRNT1	-280.0	-57.3

Table 10-9 applies the Table 10-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 256 832 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the statewide reduction in carbon emissions of 436 789 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	252.3	2716	-28 076
APART06	55.1 %	309.0	3326	-39 811
HOTEL15	100.0 %	188.5	2029	-25 386
HIGHS02	100.0 %	525.5	5656	-70 721
OFFIC03	37.4 %	92.4	995	-13 016
OFFIC08	40.4 %	99.7	1073	-12 725
OFFIC16	22.2 %	54.9	591	-9086
RETAIL1	100.0 %	498.7	5368	-51 717
RSTRNT1	100.0 %	22.5	242	-6295
Total		**2043.5**	**21 996**	**-256 832**

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

10.2.4 Life-Cycle Costs

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

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

Building Type	Standard Edition LEC $/m²	Standard Edition LEC $/ft²
APART04	$5.05	$0.47
APART06	$2.43	$0.23
DORMI04	-$9.43	-$0.88
DORMI06	-$2.46	-$0.23
HOTEL15	$1.20	$0.11
HIGHS02	-$14.69	-$1.36
OFFIC03	-$24.88	-$2.31
OFFIC08	-$25.80	-$2.40
OFFIC16	-$1.04	-$0.10
RETAIL1	$1.20	$0.11
RSTRNT1	-$107.29	-$9.97

Table 10-11 applies the Table 10-10 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 5 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $12.2 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools realize the greatest statewide decreases in life-cycle costs ($7.7 million) followed by 8-story office buildings ($2.6 million), restaurants ($2.4 million), and 3-story office buildings ($2.3 million). Four-story apartment buildings realize the greatest increase in life-cycle costs ($1.3 million) followed by 6-story apartment buildings ($749 397) and retail stores ($600 809). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $20.8 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	252.3	2716	$1 273 611
APART06	55.1 %	309.0	3326	$749 397
HOTEL15	100.0 %	188.5	2029	$225 953
HIGHS02	100.0 %	525.5	5656	-$7 718 061
OFFIC03	37.4 %	92.4	995	-$2 300 821
OFFIC08	40.4 %	99.7	1073	-$2 572 238
OFFIC16	22.2 %	54.9	591	-$57 286
RETAIL1	100.0 %	498.7	5368	$600 809
RSTRNT1	100.0 %	22.5	242	-$2 412 045
Total		**2043.5**	**21 996**	**-$12 210 682**

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

10.3 State Summary

New Jersey has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs and energy-related carbon emissions, and does so in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 581.6 GWh (1985.7 GBtu), energy cost savings of $72.7 million, and carbon emissions reductions of 436 789 metric tons while decreasing life-cycle costs by $20.8 million for one year's worth of commercial building construction.

11 New York

New York has adopted *ASHRAE 90.1-2007* as its state energy code, is located in the Middle Atlantic Census Division, and spans three climate zones (Zone 4A, Zone 5A, and Zone 6A). Table 11-1 provides an overview of New York's simulated energy use keyed to building types and energy codes. Average energy use varies across building type and energy standard edition. The 8-story office building uses the least amount of energy at 88 kWh/m^2 to 107 kWh/m^2 (28 $kBtu/ft^2$ to 34 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 244 kWh/m^2 to 258 kWh/m^2 (77 $kBtu/ft^2$ to 82 $kBtu/ft^2$) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	172	55	156	50
APART06	168	53	152	48
DORMI04	136	43	121	38
DORMI06	185	59	169	54
HOTEL15	181	57	161	51
HIGHS02	258	82	244	77
OFFIC03	119	38	99	31
OFFIC08	107	34	88	28
OFFIC16	167	53	144	46
RETAIL1	136	43	119	38
RSTRNT1	190	60	150	47

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

11.1 Percentage Savings

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

11.1.1 Statewide Building Comparison

Table 11-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*.

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -6.2 % to -21.7 % depending on the building type with an overall average of -12.6 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 11-2 Average Percentage Changes from Adoption of the LEC Design, 10-Year, New York

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.2	-17.5	-13.8	0.0
APART06	-9.6	-19.4	-15.1	-0.1
DORMI04	-11.1	-18.2	-15.1	-1.5
DORMI06	-9.1	-18.3	-14.3	-0.4
HOTEL15	-11.2	-18.0	-15.0	-0.2
HIGHS02	-6.2	-16.7	-11.8	-1.6
OFFIC03	-16.9	-22.0	-20.2	-3.0
OFFIC08	-17.0	-20.1	-19.0	-2.5
OFFIC16	-13.9	-18.7	-16.9	-0.6
RETAIL1	-12.4	-16.4	-14.9	-0.6
RSTRNT1	-21.7	-31.5	-27.7	-4.3
Average	**-12.6**	**-19.7**	**-16.7**	**-1.3**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.4 % to -31.5 % depending on the building type with an average of -19.7 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 10 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 37.2 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 2.7 times greater than the percentage reduction in energy use. The LEC design incorporates daylighting in all climate zones and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -11.8 % to -27.7 % with an average of -16.7 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 10 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -4.3 % to 0.0 % for a 10-year study period. Ten of the 11 building types realize reductions in life-cycle costs with restaurants realizing the greatest percentage reduction in life-cycle costs while 4-story apartment buildings realize a slight increase in life-cycle costs (0.004 %). Based on the overall average percentage change of -1.3 % in life-cycle costs, the LEC design is likely to be cost-effective for the state to adopt as its state energy code.

11.1.2 City Comparisons

Simulations are run for 7 cities located in New York located across three climate zones: New York City in Zone 4A, Albany, Buffalo, Rochester, and Syracuse in Zone 5A, and Binghamton and Massena in Zone 6A. The results may vary across cities within New York for several reasons. First, the state is covered by three climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 11-3 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 -12.0 % to -13.9 % with an overall average of -12.6 %. The city in Zone 4 realizes slightly greater reductions in energy use than the cities in Zone 5 and Zone 6.

Table 11-3 Average Percentage Changes from Adoption of the LEC Design by City, 10-Year, New York

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
New York City	4A	-13.9	-21.4	-18.6	-1.2
Albany	5A	-12.0	-20.1	-16.7	-1.5
Buffalo	5A	-12.4	-20.5	-17.1	-1.3
Rochester	5A	-12.5	-20.5	-17.2	-1.6
Syracuse	5A	-12.0	-20.3	-16.8	-1.5
Binghamton	6A	-13.1	-18.1	-16.0	-1.2
Massena	6A	-12.2	-17.2	-15.0	-1.2
Average		**-12.6**	**-19.7**	**-16.8**	**-1.3**

The average percentage change in energy costs for all building types varies across cities, ranging from -17.2 % to -21.4 % for 10 years of operation. The warmer the climate zone in which a city is located, the greater the reduction in energy costs. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies across cities, ranging from -15.0 % to -18.6 % with cities in warmer climate zones realizing greater reductions in carbon emissions. Changes in life-cycle costs for all building types vary minimally across cities, with the percentage change in life-cycle costs ranging from -1.2 % to -1.6 %. There are no distinct trends across cities within different climate zones.

11.2 Total Savings

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

11.2.1 Energy Use

Table 11-4 reports the average per unit change in annual energy use by building type and building design in the state.[24] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 11-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy

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

use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[25]

Table 11-4 Average Per Unit Change in Annual Energy Use, New York

Building Type	Standard Edition	
	LEC	
	kWh/m^2	kBtu/ft^2
APART04	-15.7	-5.0
APART06	-16.1	-5.1
DORMI04	-15.1	-4.8
DORMI06	-16.7	-5.3
HOTEL15	-19.9	-6.3
HIGHS02	-20.1	-6.4
OFFIC03	-14.9	-4.7
OFFIC08	-18.1	-5.7
OFFIC16	-22.9	-7.3
RETAIL1	-16.8	-5.3
RSTRNT1	-40.4	-12.8

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 78.7 GWh (268.5 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 75.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 103.8 GWh (354.3 GBtu) per year. These savings imply 1.0 TWh (3.5 TBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest changes in energy use. For example, the building types that lead to the greatest estimated total reductions in energy use for the LEC design – 4- and 6-story apartments -- only rank 8th and 9th in percentage reduction, respectively, among the 11 building types, as reported in Table 11-2.

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

Table 11-5 Statewide Change in Annual Energy Use for One Year of Construction, New York

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	1044.7	11 245	-16 389 178	-55 959 701
APART06	55.1 %	1279.6	13 774	-20 572 024	-70 241 736
HOTEL15	100.0 %	391.8	4217	-7 808 261	-26 660 760
HIGHS02	100.0 %	449.4	4837	-6 703 561	-22 888 839
OFFIC03	37.4 %	249.3	2683	-5 008 588	-17 101 472
OFFIC08	40.4 %	268.8	2893	-4 859 177	-16 591 319
OFFIC16	22.2 %	147.9	1592	-3 391 199	-11 579 010
RETAIL1	100.0 %	726.6	7821	-12 222 052	-41 731 341
RSTRNT1	100.0 %	42.0	452	-1 697 056	-5 794 479
Total		**4600.0**	**49 514**	**-78 651 094**	**-268 548 656**

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

11.2.2 Energy Costs

Table 11-6 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 11-6 Average Per Unit Change in Energy Costs, 10-Year, New York

Building Type	Standard Edition LEC $/m²	Standard Edition LEC $/ft²
APART04	-$19.65	-$1.83
APART06	-$21.78	-$2.02
DORMI04	-$16.66	-$1.55
DORMI06	-$22.50	-$2.09
HOTEL15	-$22.42	-$2.08
HIGHS02	-$24.55	-$2.28
OFFIC03	-$25.79	-$2.40
OFFIC08	-$22.00	-$2.04
OFFIC16	-$27.30	-$2.54
RETAIL1	-$18.64	-$1.73
RSTRNT1	-$48.52	-$4.51

Table 11-7 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 $100.4 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 75.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $132.5 million over the 10-year study period.

Table 11-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, New York

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	1044.7	11 245	-$20 525 366
APART06	55.1 %	1279.6	13 774	-$27 876 096
HOTEL15	100.0 %	391.8	4217	-$8 784 147
HIGHS02	100.0 %	449.4	4837	-$11 591 182
OFFIC03	37.4 %	249.3	2683	-$6 120 208
OFFIC08	40.4 %	268.8	2893	-$5 913 718
OFFIC16	22.2 %	147.9	1592	-$4 038 014
RETAIL1	100.0 %	726.6	7821	-$13 544 435
RSTRNT1	100.0 %	42.0	452	-$2 036 423
Total		**4600.0**	**49 514**	**-$100 429 589**

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

11.2.3 Energy-related Carbon Emissions

Table 11-8 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 11-8 Average Per Unit Change in Carbon Emissions, 10-Year, New York

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-83.6	-17.1
APART06	-90.7	-18.6
DORMI04	-73.7	-15.1
DORMI06	-93.8	-19.2
HOTEL15	-98.7	-20.2
HIGHS02	-100.8	-20.6
OFFIC03	-105.3	-21.6
OFFIC08	-94.5	-19.3
OFFIC16	-118.0	-24.2
RETAIL1	-82.4	-16.9
RSTRNT1	-209.2	-42.9

Table 11-9 applies the Table 11-8 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of the LEC design. The total reductions in carbon emissions ranges widely across building designs and is highly correlated with total energy use reduction. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 425 099 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 560 817 metric tons over the 10-year study period.

Table 11-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, New York – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	1044.7	11 245	-87 376
APART06	55.1 %	1279.6	13 774	-116 002
HOTEL15	100.0 %	391.8	4217	-38 658
HIGHS02	100.0 %	449.4	4837	-45 299
OFFIC03	37.4 %	249.3	2683	-26 247
OFFIC08	40.4 %	268.8	2893	-25 390
OFFIC16	22.2 %	147.9	1592	-17 455
RETAIL1	100.0 %	726.6	7821	-59 887
RSTRNT1	100.0 %	42.0	452	-8786
Total		**4600.0**	**49 514**	**-425 099**

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

11.2.4 Life-Cycle Costs

Table 11-10 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 11-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, New York

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$0.32	$0.03
APART06	-$0.99	-$0.09
DORMI04	-$15.61	-$1.45
DORMI06	-$4.35	-$0.40
HOTEL15	-$2.64	-$0.25
HIGHS02	-$15.10	-$1.40
OFFIC03	-$26.86	-$2.50
OFFIC08	-$23.55	-$2.19
OFFIC16	-$4.94	-$0.46
RETAIL1	-$4.16	-$0.39
RSTRNT1	-$62.34	-$5.79

Table 11-11 applies the Table 11-10 results to one year's worth of new building construction in the state to estimate changes in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 8 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $28.1 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools, 3-story office buildings, and 8-story office buildings realize the greatest statewide decrease in life-cycle costs ($6.8 million, $6.7 million and $6.3 million, respectively) while 4-story apartment buildings realize an increase in life-cycle costs of $330 672. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $37.1 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	1044.7	11 245	$330 672
APART06	55.1 %	1279.6	13 774	-$1 262 978
HOTEL15	100.0 %	391.8	4217	-$1 034 590
HIGHS02	100.0 %	449.4	4837	-$6 784 657
OFFIC03	37.4 %	249.3	2683	-$6 694 703
OFFIC08	40.4 %	268.8	2893	-$6 330 184
OFFIC16	22.2 %	147.9	1592	-$730 229
RETAIL1	100.0 %	726.6	7821	-$3 024 418
RSTRNT1	100.0 %	42.0	452	-$2 616 648
Total		**4600.0**	**49 514**	**-$28 147 734**

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

11.3 State Summary

New York has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 1.0 TWh (3.5 TBtu), energy cost savings of $132.5 million, and carbon emissions reductions of 560 817 metric tons while decreasing life-cycle costs by $37.1 million for one year's worth of commercial building construction.

12 Pennsylvania

Pennsylvania has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the Middle Atlantic Census Division, and spans three climate zones (Zone 4A, Zone 5A, and Zone 6A). Table 12-1 provides an overview of Pennsylvania's simulated energy use keyed to building types and energy codes. Average energy use varies across building type and energy standard edition. The 8-story office building uses the least amount of energy at 83 kWh/m^2 to 101 kWh/m^2 (26 kBtu/ft^2 to 32 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 231 kWh/m^2 to 244 kWh/m^2 (73 kBtu/ ft^2 to 77 kBtu/ ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	163	52	148	47
APART06	162	51	145	46
DORMI04	127	40	113	36
DORMI06	178	56	160	51
HOTEL15	170	54	150	47
HIGHS02	244	77	231	73
OFFIC03	112	35	92	29
OFFIC08	101	32	83	26
OFFIC16	159	50	136	43
RETAIL1	123	39	108	34
RSTRNT1	167	53	128	41

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

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 the LEC design in the state of Pennsylvania.

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 -5.4 % to -23.7 % depending on the building type with an overall average of -13.1 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 12-2 Average Percentage Changes from Adoption of the LEC Design, 10-Year, Pennsylvania

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.5	-14.9	-16.0	0.6
APART06	-10.4	-17.1	-18.5	0.5
DORMI04	-11.1	-15.9	-16.8	-0.8
DORMI06	-10.3	-16.8	-18.0	0.2
HOTEL15	-11.8	-17.1	-18.2	0.4
HIGHS02	-5.4	-12.7	-14.3	-0.6
OFFIC03	-17.5	-21.5	-22.1	-2.7
OFFIC08	-18.0	-20.3	-20.6	-2.4
OFFIC16	-14.4	-18.9	-19.6	0.4
RETAIL1	-12.3	-15.4	-15.9	0.1
RSTRNT1	-23.7	-30.4	-31.6	-3.4
Average	**-13.1**	**-18.3**	**-19.2**	**-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 -12.7 % to -30.4 % depending on the building type with an average of -18.3 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. In fact, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption for all building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 46.3 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 2.4 times greater than the percentage reduction in energy use. The LEC design incorporates daylighting in all climate zones and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -14.3 % to -31.6 % with an average of -19.2 %. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for all 11 building types. The combination of the reduction in total energy

use and the shift in energy use from electricity consumption to natural gas consumption leads to greater reductions in carbon emissions than reductions in energy use.

The percentage change in life-cycle costs varies across building types, ranging from -3.4 % to 0.6 % for a 10-year study period. Only 5 of the 11 building types realize reductions in life-cycle costs. Yet 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 8 cities located in Pennsylvania located across three climate zones: Philadelphia located in Zone 4A, Allentown, Erie, Harrisburg, Pittsburgh, Wilkes-Barre, and Williamsport located in Zone 5A, and Bradford located in Zone 6A. The results may vary across cities within Pennsylvania for several reasons. First, the state is covered by three climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 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 -11.0 % to -14.6 % with an overall average of -13.1 %. The warmer the climate zone in which a city is located, the greater the reduction in energy use.

Table 12-3 Average Percentage Changes from Adoption of the LEC Design by City, 10-Year, Pennsylvania

Cities	Zone	LEC			
		Energy Use	**Energy Cost**	**Carbon**	**LCC**
Philadelphia	4A	-14.6	-19.2	-20.2	-0.3
Allentown	5A	-13.6	-18.7	-19.8	-0.5
Erie	5A	-12.4	-17.8	-19.0	-0.7
Harrisburg	5A	-14.0	-18.9	-20.0	-0.7
Pittsburgh	5A	-13.7	-18.8	-19.9	-0.9
Wilkes-Barre	5A	-12.4	-17.8	-19.0	-0.8
Williamsport	5A	-13.1	-18.3	-19.4	-0.9
Bradford	6A	-11.0	-16.8	-18.1	-0.8
Average		**-13.1**	**-18.3**	**-19.4**	**-0.7**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -16.8 % to -19.2 % for 10 years of operation. Similar to energy use, cities in warmer climate zones realize greater reductions in energy costs. 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 -18.1 % to -20.2 %. Similar to energy use and energy costs, cities in warmer climate zones realize greater reductions in carbon emissions. Changes in life-cycle costs vary across cities ranging from -0.3 % to -0.9 %. Philadelphia, the only city in Zone 4, realizes smaller reductions in life-cycle costs than all other cities in the state.

12.2 Total Savings

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

12.2.1 Energy Use

Table 12-4 reports the average per unit change in annual energy use by building type and building design in the state.[26] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 12-5 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.[27]

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

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

Building Type	Standard Edition LEC	
	kWh/m^2	kBtu/ft^2
APART04	-15.4	-4.9
APART06	-16.7	-5.3
DORMI04	-14.0	-4.4
DORMI06	-18.2	-5.8
HOTEL15	-19.9	-6.3
HIGHS02	-19.5	-6.2
OFFIC03	-13.0	-4.1
OFFIC08	-18.2	-5.8
OFFIC16	-22.9	-7.3
RETAIL1	-15.1	-4.8
RSTRNT1	-39.5	-12.5

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 42.6 GWh (145.5 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 55.7 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 76.5 GWh (261.2 GBtu) per year. These savings imply 764.9 GWh (2611.5 GBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent the greatest 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 5th 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, Pennsylvania

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	135.1	1454	-2 080 259	-7 102 899
APART06	55.1 %	165.5	1781	-2 767 241	-9 448 551
HOTEL15	100.0 %	281.2	3027	-5 607 223	-19 145 471
HIGHS02	100.0 %	732.0	7879	-9 500 680	-32 439 407
OFFIC03	37.4 %	181.4	1953	-3 530 608	-12 055 015
OFFIC08	40.4 %	195.7	2107	-3 562 784	-12 164 877
OFFIC16	22.2 %	107.7	1159	-2 466 001	-8 419 989
RETAIL1	100.0 %	752.3	8098	-11 354 259	-38 768 324
RSTRNT1	100.0 %	43.9	472	-1 733 418	-5 918 635
Total		**2594.9**	**27 931**	**-42 602 475**	**-145 463 169**

Note: Dormitories are excluded because no such 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, Pennsylvania

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$12.12	-$1.13
APART06	-$13.90	-$1.29
DORMI04	-$10.23	-$0.95
DORMI06	-$14.93	-$1.39
HOTEL15	-$14.68	-$1.36
HIGHS02	-$15.10	-$1.40
OFFIC03	-$14.27	-$1.33
OFFIC08	-$13.78	-$1.28
OFFIC16	-$17.89	-$1.66
RETAIL1	-$11.17	-$1.04
RSTRNT1	-$29.69	-$2.76

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 a statewide reduction in energy costs of $35.6 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 55.7 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $63.9 million over the 10-year study period.

Table 12-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Pennsylvania

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	135.1	1454	-$1 636 842
APART06	55.1 %	165.5	1781	-$2 300 575
HOTEL15	100.0 %	281.2	3027	-$4 126 921
HIGHS02	100.0 %	732.0	7879	-$10 447 069
OFFIC03	37.4 %	181.4	1953	-$2 741 178
OFFIC08	40.4 %	195.7	2107	-$2 696 047
OFFIC16	22.2 %	107.7	1159	-$1 926 308
RETAIL1	100.0 %	752.3	8098	-$8 402 848
RSTRNT1	100.0 %	43.9	472	-$1 302 380
Total		**2594.9**	**27 931**	**-35 580 171**

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

12.2.3 Energy-related Carbon Emissions

Table 12-8 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, Pennsylvania

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-118.5	-24.3
APART06	-136.8	-28.0
DORMI04	-99.1	-20.3
DORMI06	-146.7	-30.1
HOTEL15	-142.3	-29.2
HIGHS02	-144.2	-29.5
OFFIC03	-147.5	-30.2
OFFIC08	-134.1	-27.5
OFFIC16	-174.8	-35.8
RETAIL1	-108.4	-22.2
RSTRNT1	-288.7	-59.1

Table 12-9 applies the Table 12-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 350 304 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 628 913 metric tons over the 10-year study period.

Table 12-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Pennsylvania – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	135.1	1454	-16 006
APART06	55.1 %	165.5	1781	-22 639
HOTEL15	100.0 %	281.2	3027	-40 028
HIGHS02	100.0 %	732.0	7879	-105 585
OFFIC03	37.4 %	181.4	1953	-26 763
OFFIC08	40.4 %	195.7	2107	-26 240
OFFIC16	22.2 %	107.7	1159	-18 821
RETAIL1	100.0 %	752.3	8098	-81 558
RSTRNT1	100.0 %	43.9	472	-12 665
Total		**2594.9**	**27 931**	**-350 304**

Note: Dormitories are excluded because no such 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 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 12-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Pennsylvania

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$6.11	$0.57
APART06	$5.19	$0.48
DORMI04	-$7.83	-$0.73
DORMI06	$1.92	$0.18
HOTEL15	$4.19	$0.39
HIGHS02	-$5.01	-$0.47
OFFIC03	-$22.68	-$2.11
OFFIC08	-$20.67	-$1.92
OFFIC16	$3.72	$0.35
RETAIL1	$0.67	$0.06
RSTRNT1	-$47.53	-$4.42

Table 12-11 applies the Table 12-10 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $10.1 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Three-story office buildings, 8-story office buildings, and high schools realize the greatest statewide decreases in life-cycle costs ($4.1 million, $4.0 million, and $3.7 million, respectively) while hotels, 6-story apartment buildings, and 4-story office buildings realize the greatest increases in life-cycle costs ($1.2 million, $859 590, and $826 125 million, respectively). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a decrease in statewide life-cycle costs of $18.2 million over the 10-year study period.

Table 12-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Pennsylvania

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	135.1	1454	$826 125
APART06	55.1 %	165.5	1781	$859 590
HOTEL15	100.0 %	281.2	3027	$1 178 384
HIGHS02	100.0 %	732.0	7879	-$3 670 171
OFFIC03	37.4 %	181.4	1953	-$4 116 820
OFFIC08	40.4 %	195.7	2107	-$4 045 870
OFFIC16	22.2 %	107.7	1159	$400 381
RETAIL1	100.0 %	752.3	8098	$504 961
RSTRNT1	100.0 %	43.9	472	-$2 085 209
Total		**2594.9**	**27 931**	**-$10 148 630**

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

12.3 State Summary

Pennsylvania has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 764.9 GWh (2611.5 GBtu), energy cost savings of $63.9 million, and carbon emissions reductions of 628 913 metric tons while decreasing life-cycle costs by $18.2 million for one year's worth of commercial building construction.

13 Rhode Island

Rhode Island has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, and is located in the New England Census Division. Only one city, Providence, is simulated for this study, and is located in Zone 5A. Table 13-1 provides an overview of Rhode Island'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 79 kWh/m^2 to 97 kWh/m^2 (25 kBtu/ft^2 to 31 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 219 kWh/m^2 to 230 kWh/m^2 (69 kBtu/ft^2 to 73 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	154	49	140	44
APART06	152	48	137	43
DORMI04	116	37	103	33
DORMI06	168	53	152	48
HOTEL15	161	51	142	45
HIGHS02	230	73	219	69
OFFIC03	105	33	85	27
OFFIC08	97	31	79	25
OFFIC16	152	48	129	41
RETAIL1	115	37	101	32
RSTRNT1	155	49	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 (Providence).

13.1 Percentage Savings

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

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

The LEC design realizes changes in energy use ranging from -5.0 % to -25.0 % with an average of -13.4 % relative to the *ASHRAE 90.1-2007* design. The greatest reduction in energy use for the LEC design occurs in the restaurant followed by the small and mid-sized office buildings. The smallest reduction occurs in the high school followed by the 4-story apartment and 6-story dormitory.

Table 13-2 Average Percentage Changes from Adoption of the LEC Design, 10 Year, Rhode Island

Building Type	LEC			
	Energy Use	**Energy Cost**	**Carbon**	**LCC**
APART04	-9.2	-15.5	-15.1	0.2
APART06	-10.0	-17.9	-17.4	0.0
DORMI04	-11.3	-16.7	-16.4	-1.4
DORMI06	-9.7	-17.2	-16.7	-0.3
HOTEL15	-12.1	-18.1	-17.7	-0.1
HIGHS02	-5.0	-13.7	-13.0	-0.9
OFFIC03	-18.5	-22.5	-22.3	-2.8
OFFIC08	-18.9	-21.0	-20.9	-2.4
OFFIC16	-15.3	-20.0	-19.7	-0.3
RETAIL1	-12.4	-15.8	-15.6	-1.5
RSTRNT1	-25.0	-31.8	-31.4	-3.8
Average	**-13.4**	**-19.1**	**-18.7**	**-1.2**

The LEC design realizes average percentage changes in energy costs ranging from -13.7 % to -31.8 % depending on the building type, with an average of -19.1 % over 10 years of operation. The high school and 4-story apartment building realize the smallest average percentage reduction in energy costs while the restaurant realizes the greatest average reduction in energy costs. 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, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption for all building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 52.5 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 2.7 times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

The LEC design leads to average changes in carbon emissions ranging from -13.0 % to -31.4 % depending on the building type, with an average of -18.7 % across all building types. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for all 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to greater reductions in carbon emissions than reductions in energy use.

The average change in life-cycle costs for the LEC design over a 10-year study period ranges from -3.8 % to 0.2 %. Four- and 6-story apartment buildings realize increases 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 9 of 11 buildings types realize an average percentage decrease in life-cycle costs, it is likely that the LEC design is cost-effective for the state to adopt as its state energy code for commercial buildings.

13.2 Total Savings

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

13.2.1 Energy Use

Table 13-3 reports the average per unit change in annual energy use by building type for the LEC design in the state.[28] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 13-4 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 office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[29]

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

Table 13-3 Average Per Unit Change in Annual Energy Use, Rhode Island

Building Type	Standard Edition LEC	
	kWh/m^2	kBtu/ft^2
APART04	-14.2	-4.5
APART06	-15.2	-4.8
DORMI04	-13.1	-4.2
DORMI06	-16.3	-5.2
HOTEL15	-19.5	-6.2
HIGHS02	-19.4	-6.2
OFFIC03	-11.5	-3.7
OFFIC08	-18.4	-5.9
OFFIC16	-23.36	-7.4
RETAIL1	-14.3	-4.5
RSTRNT1	-38.8	-12.3

The annual reduction in energy use shown in Table 13-4 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 3.9 GWh (13.3 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 70.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings to be 5.5 GWh (18.9 GBtu) annually. These savings imply 55.3 GWh (188.7 GBtu) in energy use savings over the 10-year study period.

Table 13-4 Statewide Change in Annual Energy Use for One Year of Construction, Rhode Island

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	21.4	230	-302 916	-1 034 287
APART06	55.1 %	26.2	282	-397 811	-1 358 299
HOTEL15	100.0 %	38.5	414	-751 212	-2 564 962
HIGHS02	100.0 %	39.5	425	-454 826	-1 552 973
OFFIC03	37.4 %	18.9	203	-365 071	-1 246 510
OFFIC08	40.4 %	20.3	219	-374 200	-1 277 681
OFFIC16	22.2 %	11.1	120	-260 937	-890 951
RETAIL1	100.0 %	55.6	598	-793 686	-2 709 987
RSTRNT1	100.0 %	5.2	56	-200 551	-684 766
Total		**236.5**	**2546**	**-3 901 212**	**-13 320 416**

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

The relative reduction in energy use varies across the 9 building types with reported floor area data for the LEC design relative to *ASHRAE 90.1-2007*. The greatest reductions are realized by retail stores, hotels, and high schools. The smallest reductions are for restaurants and the 16-story office 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 reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. The building types that lead to the greatest total reductions in energy use -- retail stores and hotels -- only rank 5th and 6th in percentage reduction, respectively, among the 11 building types, as reported in Table 13-2.

13.2.2 Energy Costs

Table 13-5 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 13-5 Average Per Unit Change in Energy Costs, 10-Year, Rhode Island

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	-$16.67	-$1.55
APART06	-$19.26	-$1.79
DORMI04	-$14.10	-$1.31
DORMI06	-$20.35	-$1.89
HOTEL15	-$21.02	-$1.95
HIGHS02	-$21.65	-$2.01
OFFIC03	-$20.48	-$1.90
OFFIC08	-$19.89	-$1.85
OFFIC16	-$26.36	-$2.45
RETAIL1	-$15.54	-$1.44
RSTRNT1	-$41.88	-$3.89

Table 13-6 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. Any variation is a result of the greater percentage reduction in electricity consumption relative to the reduction in natural gas consumption. Overall, reductions in energy costs total $4.7 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study, which represent 70.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total energy cost savings of $6.6 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	21.4	230	-$356 182
APART06	55.1 %	26.2	282	-$504 219
HOTEL15	100.0 %	38.5	414	-$807 997
HIGHS02	100.0 %	39.5	425	-$808 470
OFFIC03	37.4 %	18.9	203	-$407 656
OFFIC08	40.4 %	20.3	219	-$403 745
OFFIC16	22.2 %	11.1	120	-$294 422
RETAIL1	100.0 %	55.6	598	-$863 071
RSTRNT1	100.0 %	5.2	56	-$216 324
Total		**236.5**	**2546**	**-4 662 086**

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

13.2.3 Energy-related Carbon Emissions

Table 13-7 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 13-7 Average Per Unit Change in Carbon Emissions, 10-Year, Rhode Island

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-94.8	-19.4
APART06	-109.2	-22.4
DORMI04	-80.6	-16.5
DORMI06	-115.4	-23.6
HOTEL15	-120.1	-24.6
HIGHS02	-114.7	-23.5
OFFIC03	-123.5	-25.3
OFFIC08	-113.6	-23.3
OFFIC16	-150.2	-30.8
RETAIL1	-88.7	-18.2
RSTRNT1	-239.2	-49.0

Table 13-8 applies the Table 13-7 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building types, and is correlated with each building's total reduction in energy use. However, there is not a perfect correlation because the magnitude of the offsetting natural gas increase varies across building types. The adoption of the LEC design as the state's energy code decreases carbon emissions by 26 501 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 37 536 metric tons over the 10-year study period.

Table 13-8 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Rhode Island – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	21.4	230	-2026
APART06	55.1 %	26.2	282	-2859
HOTEL15	100 %	38.5	414	-4615
HIGHS02	100.0 %	39.5	425	-4529
OFFIC03	37.4 %	18.9	203	-2324
OFFIC08	40.4 %	20.3	219	-2306
OFFIC16	22.2 %	11.1	120	-1678
RETAIL1	100.0 %	55.6	598	-4927
RSTRNT1	100.0 %	5.2	56	-1235
Total		**236.5**	**2546**	**-26 501**

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

13.2.4 Life-Cycle Costs

Table 13-9 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 13-9 Average Per Unit Change in Life-Cycle Costs, 10-Year, Rhode Island

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$1.79	$0.17
APART06	$0.28	$0.03
DORMI03	-$13.97	-$1.30
DORMI06	-$2.84	-$0.26
HOTEL15	-$0.63	-$0.06
HIGHS02	-$8.52	-$0.79
OFFIC03	-$25.09	-$2.33
OFFIC08	-$22.01	-$2.04
OFFIC16	-$2.89	-$0.27
RETAIL1	-$11.00	-$1.02
RSTRNT1	-$53.61	-$4.98

Table 13-10 applies the Table 13-9 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 the LEC design. The change in life-cycle costs varies widely across building types, with life-cycle costs decreasing for 7 of 9 building types. Four- and 6-story apartment buildings realize increases in life-cycle costs of less than $40 000. Meanwhile, retail stores realize a reduction in life-cycle costs of greater than $600 000 overall. The LEC design leads to statewide decreases in life-cycle costs of $2.2 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 decrease in life-cycle costs of $3.1 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	21.4	230	$38 199
APART06	55.1 %	26.2	282	$7265
HOTEL15	100.0 %	38.5	414	-$24 041
HIGHS02	67.5 %	39.5	425	-$336 461
OFFIC03	37.4 %	18.9	203	-$472 398
OFFIC08	40.4 %	20.3	219	-$446 840
OFFIC16	22.2 %	11.1	120	-$32 315
RETAIL1	100.0 %	55.6	598	-$611 038
RSTRNT1	100.0 %	5.2	56	-$276 929
Total		**236.5**	**2546**	**-$2 154 557**

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

13.3 State Summary

Rhode Island has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. The adoption of the LEC design, which goes beyond *ASHRAE 90.1-2007*, leads to energy use, energy cost, and energy-related carbon emissions reductions, and does so in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code would lead to energy use savings of 55.3 GWh (188.7 GBtu), energy cost savings of $6.6 million, and carbon emissions reductions of 37 536 metric tons while decreasing life-cycle costs by $3.1 million for one year's worth of commercial building construction.

14 Vermont

Vermont has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, and is located in the Northeast Census Division. Only one city, Burlington, is simulated for this study, and is located in Climate Zone 6A.

Table 14-1 provides an overview of Vermont'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 91 kWh/m^2 to 109 kWh/m^2 (29 kBtu/ft^2 to 35 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 281 kWh/m^2 to 298 kWh/m^2 (89 kBtu/ft^2 to 95 kBtu/ ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	185	59	167	53
APART06	183	58	166	53
DORMI04	148	47	130	41
DORMI06	204	65	187	59
HOTEL15	197	62	179	57
HIGHS02	298	95	281	89
OFFIC03	122	39	101	32
OFFIC08	109	35	91	29
OFFIC16	179	57	159	50
RETAIL1	140	45	118	38
RSTRNT1	187	59	143	45

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 (Burlington).

14.1 Percentage Savings

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

Table 14-2 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 -5.9 % to -23.6 % with an average of -12.6 % relative to the *ASHRAE 90.1-2007* design. The greatest reduction in energy use for the LEC design occurs in the restaurants followed by the small and mid-sized office buildings. The smallest reductions occur in the high school followed by the 6-story dormitory and hotel.

Table 14-2 Average Percentage Changes from Adoption of the LEC Design, 10 Year, Vermont

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.5	-15.5	-14.6	-0.2
APART06	-9.2	-15.1	-14.2	-0.1
DORMI04	-11.9	-16.7	-15.9	-1.6
DORMI06	-8.2	-13.4	-12.6	-0.3
HOTEL15	-9.0	-11.3	-11.0	-0.1
HIGHS02	-5.9	-12.1	-11.0	-1.4
OFFIC03	-17.6	-20.1	-19.8	-2.6
OFFIC08	-16.5	-18.0	-17.8	-2.0
OFFIC16	-11.3	-12.3	-12.2	-0.4
RETAIL1	-15.7	-17.5	-17.3	-0.8
RSTRNT1	-23.6	-28.5	-27.9	-4.3
Average	**-12.6**	**-16.4**	**-15.8**	**-1.2**

The LEC design realizes average changes in energy costs from -11.3 % to -28.5 % depending on the building type, with an average of -16.4 % overall over 10 years of operation. The hotel and high school realize the smallest average reduction in energy costs while the restaurant realizes the greatest average reduction 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. In the most extreme case, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption for the high school. The increase in natural gas consumption offsets 13.3 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is twice the percentage reduction in energy use. The LEC design incorporates daylighting in Zone 6, which decreases the building's internal 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 -11.0 % to -27.9 % depending on the building type, with an average of -15.8 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. For the high school, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption, which leads to even greater reductions in carbon emissions.

The average change in life-cycle costs for the LEC design ranges from -4.3 % to -0.1 % for a 10-year study period. 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 all 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.

14.2 Total Savings

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

14.2.1 Energy Use

Table 14-3 reports the average per unit change in annual energy use by building type for the LEC design in the state.[30] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 14-4 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 office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[31]

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

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

Table 14-3 Average Per Unit Change in Annual Energy Use, Vermont

Building Type	Standard Edition LEC	
	kWh/m²	kBtu/ft²
APART04	-17.5	-5.5
APART06	-16.8	-5.3
DORMI04	-17.6	-5.6
DORMI06	-16.7	-5.3
HOTEL15	-17.8	-5.6
HIGHS02	-21.6	-6.9
OFFIC03	-17.5	-5.6
OFFIC08	-18.0	-5.7
OFFIC16	-20.2	-6.4
RETAIL1	-22.0	-7.0
RSTRNT1	-44.0	-14.0

The annual reduction in energy use shown in Table 14-4 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 2.1 GWh (7.3 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 57.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings to be 3.7 GWh (12.7 GBtu) annually. These savings imply 37.3 GWh (127.3 GBtu) in energy use savings over the 10-year study period.

Table 14-4 Statewide Change in Annual Energy Use for One Year of Construction, Vermont

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	14.5	156	-253 220	-864 600
APART06	55.1 %	17.7	191	-298 851	-1 020 405
HOTEL15	100.0 %	19.1	206	-339 888	-1 160 525
HIGHS02	100.0 %	27.2	293	-476 793	-1 627 977
OFFIC03	37.4 %	8.5	91	-182 453	-622 974
OFFIC08	40.4 %	9.1	98	-164 270	-560 888
OFFIC16	22.2 %	5.0	54	-101 073	-345 107
RETAIL1	100.0 %	12.5	135	-275 921	-942 113
RSTRNT1	100.0 %	1.3	14	-55 647	-190 003
Total		**114.9**	**1237**	**-2 148 116**	**-7 334 592**

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

The size of the reduction in energy use varies across the 9 building types with reported floor area data. The greatest reductions are realized by high schools and hotels. The smallest reductions are realized by restaurants followed by the 16-story office 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 reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. The building types that lead to the greatest estimated reductions in energy use -- hotels and high schools -- only rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 14-2.

14.2.2 Energy Costs

Table 14-5 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 14-5 Average Per Unit Change in Energy Costs, 10-Year, Vermont

Building Type	Standard Edition	
	LEC	
	$\$/m^2$	$\$/ft^2$
APART04	-$16.54	-$1.54
APART06	-$16.09	-$1.50
DORMI04	-$14.50	-$1.35
DORMI06	-$15.80	-$1.47
HOTEL15	-$13.11	-$1.22
HIGHS02	-$19.08	-$1.77
OFFIC03	-$19.15	-$1.78
OFFIC08	-$16.54	-$1.54
OFFIC16	-$15.77	-$1.47
RETAIL1	-$17.39	-$1.62
RSTRNT1	-$37.23	-$3.46

Table 14-6 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. Any variation is a result of the greater percentage reduction in electricity consumption relative to the reduction in natural gas consumption. Overall, reductions in energy costs total $2.0 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study, which represent 57.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total energy cost savings of $3.4 million over the 10-year study period.

Table 14-6 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Vermont

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	14.5	156	-$239 854
APART06	55.1 %	17.7	191	-$285 765
HOTEL15	100.0 %	19.1	206	-$250 866
HIGHS02	100.0 %	27.2	293	-$520 486
OFFIC03	37.4 %	8.5	91	-$161 052
OFFIC08	40.4 %	9.1	98	-$150 574
OFFIC16	22.2 %	5.0	54	-$78 997
RETAIL1	100.0 %	12.5	135	-$217 782
RSTRNT1	100.0 %	1.3	14	-$47 041
Total		**114.9**	**1237**	**-$1 952 418**

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

14.2.3 Energy-related Carbon Emissions

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

Building Type	Standard Edition LEC	
	kg/m^2	lb/ft^2
APART04	-100.5	-20.6
APART06	-97.7	-20.0
DORMI04	-89.5	-18.3
DORMI06	-96.0	-19.7
HOTEL15	-82.0	-16.8
HIGHS02	-114.7	-23.5
OFFIC03	-116.8	-23.9
OFFIC08	-100.8	-20.6
OFFIC16	-97.9	-20.1
RETAIL1	-107.8	-22.1
RSTRNT1	-229.0	-46.9

Table 14-8 applies the Table 14-7 results to one year’s worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building types, and is correlated with each building’s total reduction in energy use. However, there is not a perfect correlation because the magnitude of the offsetting natural gas increase varies across building types. The adoption of the LEC design as the state's energy code decreases carbon emissions by 11 912 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 20 681 metric tons over the 10-year study period.

Table 14-8 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Vermont – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	14.5	156	-1457
APART06	55.1 %	17.7	191	-1734
HOTEL15	100 %	19.1	206	-1569
HIGHS02	100.0 %	27.2	293	-3118
OFFIC03	37.4 %	8.5	91	-986
OFFIC08	40.4 %	9.1	98	-918
OFFIC16	22.2 %	5.0	54	-490
RETAIL1	100.0 %	12.5	135	-1351
RSTRNT1	100.0 %	1.3	14	-289
Total		**114.9**	**1237**	**-11 912**

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

14.2.4 Life-Cycle Costs

Table 14-9 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 14-9 Average Per Unit Change in Life-Cycle Costs, 10-Year, Vermont

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	-$1.60	-$0.15
APART06	-$0.65	-$0.06
DORMI04	-$14.04	-$1.30
DORMI06	-$2.91	-$0.27
HOTEL15	-$1.19	-$0.11
HIGHS02	-$11.98	-$1.11
OFFIC03	-$19.39	-$1.80
OFFIC08	-$15.62	-$1.45
OFFIC16	-$3.28	-$0.31
RETAIL1	-$4.74	-$0.44
RSTRNT1	-$52.47	-$4.87

Table 14-10 applies the Table 14-9 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 the LEC design. The change in life-cycle costs varies widely across building types, but all 9 building types realize reductions in life-cycle costs. High schools realize the greatest reductions ($325 561). The LEC design leads to a statewide decrease in life-cycle costs of $831 158 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 decrease in life-cycle costs of $1.4 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	14.5	156	-$23 164
APART06	55.1 %	17.7	191	-$11 626
HOTEL15	100.0 %	19.1	206	-$22 806
HIGHS02	67.5 %	27.2	293	-$325 561
OFFIC03	37.4 %	8.5	91	-$163 714
OFFIC08	40.4 %	9.1	98	-$142 225
OFFIC16	22.2 %	5.0	54	-$16 455
RETAIL1	100.0 %	12.5	135	-$59 311
RSTRNT1	100.0 %	1.3	14	-$66 297
Total		**114.9**	**1237**	**-$831 158**

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

14.3 State Summary

Vermont has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. The adoption of the LEC design, which goes beyond *ASHRAE 90.1-2007*, leads to reductions in energy use, energy cost, and energy-related carbon emissions, and does so in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code would lead to energy use savings of 37.3 GWh (127.3 GBtu), energy cost savings of $3.4 million, and carbon emissions reductions of 20 681 metric tons while decreasing life-cycle costs by $1.4 million for one year's worth of commercial building construction.

15 State Comparisons for the Adoption of the Low Energy Case Design

One purpose of this study is to determine which states could benefit the most from adopting a more stringent state energy code. This chapter analyzes benefits from the region-wide adoption of the LEC design relative to the current collection of state energy codes. The aggregate benefits and costs are compared for each of the states in the Northeast Census Region. Benefits and costs on a percentage basis are also evaluated across several dimensions: geography (state and climate zone), time, and building type. As in the state-by-state analysis for analyzing benefits from adopting the LEC design, it is necessary to assume a particular study period length because energy costs and life-cycle costs fluctuate on an annual basis. A 10-year study period is used as the baseline because it is the most realistic investor time frame of the nine study period length options in BIRDS. The significance of the study period length will be tested below.

It would be expected that the state with no state energy code, Maine, would realize greater benefits from adopting the LEC design relative to the other eight states in the Northeast Census Region that have adopted the more energy efficient *ASHRAE 90.1-2007*.

15.1 Total Savings Comparison

By comparing the aggregate results from the detailed state-by-state analysis, some interesting trends emerge. Table 15-1 shows the total savings in energy use, energy costs, carbon emissions, and life-cycle costs from adopting the LEC design as the commercial building energy code for each of the states in the Northeast Census Region for a 10-year study period. In general, there is a strong correlation between energy use with both energy costs and carbon emissions. However, there are a number of factors that lead to significant variation in relative savings, including current state energy code requirements, newly constructed building stock mix and size, climate zone, electricity costs, and electricity production fuel mix.

Table 15-1 Total Reductions by State for Adoption of the LEC Design, 10-Year

State	Code	Average Annual New Floor Area 1000 m^2 (1000 ft^2)	Energy Use (GWh)	Energy Costs ($million)	Carbon (1000 tCO_2e)	LCC ($million)
CT	2007	1445 (15 549)	232.0	35.1	160.6	19.7
MA	2007	2579 (27 760)	403.8	56.0	277.4	12.8
ME	None	497 (5349)	216.6	18.0	113.3	6.4
NH	2007	553 (5948)	108.0	10.9	59.2	5.8
NJ	2007	3476 (37 421)	581.6	72.7	436.8	20.8
NY	2007	6071 (65 346)	1037.6	132.5	560.8	37.1
PA	2007	4661 (50 170)	764.9	63.9	628.9	18.2
RI	2007	335 (3604)	55.3	6.6	37.5	3.1
VT	2007	200 (2147)	37.3	3.4	20.7	1.4
Total		**22 395 (241 056)**	**3437.1**	**399.1**	**2331.5**	**125.3**

Total energy use savings varies across states for a number of reasons. First, states with more newly constructed commercial floor area realize greater reductions in energy use. Second, states located in warmer climate zones realize greater reductions in energy use than the states located in colder climate zones because the buildings in warmer climates benefit more from the overhangs and daylighting installed in the LEC design. Third, a state's current state energy code for commercial buildings drives the variation in energy use. Consider the reductions in energy use for two states with similar amounts of new floor area, Maine and New Hampshire. Even though New Hampshire has slightly more new floor area construction and a warmer climate, Maine realizes twice the total reductions in energy use. Maine has not adopted a state energy code for commercial buildings while New Hampshire has adopted *ASHRAE 90.1-2007*.

Table 15-2 shows the reduction in energy use per unit of newly constructed floor area by state. Maine realizes over twice the reduction in energy use per unit of floor area relative to all other states in the Northeast. The two states with the greatest total new floor area, New York and Pennsylvania, are 4th and 7th out of the 9 states considered in this study, respectively. These results vary significantly from the total reductions in energy use, where New York is 1st (1038 GWh), Pennsylvania a distant 2nd (765 GWh), and Maine 6th (217 GWh).

Table 15-2 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC Design by State, 10-Year

State	Code	Floor Area Ranking	Average Annual New Floor Area 1000 m² (1000 ft²)	Energy Use Reduction		
				GWh	kWh/m²	kBtu/ft²
ME	None	41	497 (5349)	216.6	436	138
NH	2007	39	553 (5948)	107.9	195	62
VT	2007	50	200 (2147)	37.3	187	59
NY	2007	6	6071 (65346)	1037.6	171	54
NJ	2007	15	3476 (37421)	581.6	167	53
RI	2007	44	335 (3604)	55.3	165	52
PA	2007	9	4661 (50170)	764.9	164	52
CT	2007	32	1445 (15549)	232.0	161	51
MA	2007	21	2579 (27760)	403.8	157	50

In general, the states that realize the greatest reductions in energy use also realize the greatest reductions in energy costs. However, reductions in energy costs are also impacted by the per unit energy costs of electricity and natural gas, and the fuel mix of the reductions in energy use in a state. Table 15-3 shows each state's reduction in energy costs per unit of reduction in energy use, natural gas rate, electricity rate, and the weighted average fraction of electricity consumption offset by a change in natural gas consumption. [32] States with the highest electricity rates tend to realize the greatest reductions in energy costs per unit of reduction in energy use. Relative to electricity prices, natural gas prices are fairly constant across states ($0.03/kWh or $0.04/kWh) and are always cheaper per unit of energy.

There is some fluctuation in the results due to the fuel source mix of the reductions in energy use. For example, New Hampshire has a higher electricity rate than Rhode Island. However, Rhode Island realizes a greater average energy cost savings per unit of energy use savings ($0.12) than New Hampshire ($0.10) because Rhode Island realizes a shift in fuel consumption from electricity to natural gas, magnifying the savings from the reduction in total energy use alone. Meanwhile, New Hampshire realizes reductions in both electricity and natural gas consumption, which dampens its savings per unit of reduction in energy use.

[32] 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 15-3 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)
CT	2007	18.5	16.9	2.9	0.15
MA	2007	18.0	15.4	3.8	0.14
NY	2007	7.6	15.5	3.1	0.13
NJ	2007	17.4	13.8	3.0	0.13
RI	2007	16.8	13.7	4.4	0.12
NH	2007	-20.4	14.6	4.2	0.10
VT	2007	-18.6	12.9	3.8	0.09
PA	2007	17.2	9.5	3.5	0.08
ME	None	-27.5	12.6	4.1	0.08

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

Table 15-4 shows the weighted average fraction of electricity consumption offset by a change in natural gas consumption, the average CO_2e emission rate for electricity and natural gas, and the reduction in cradle-to-grave energy-related carbon emissions per unit of reduction in energy use. There is a direct correlation between the carbon emissions rate for electricity generation in a state and the reduction in carbon emissions per unit of reduction in energy use. However, the fuel source mix of reductions in energy use leads to additional variation. For example, six states have the same average emissions rate for electricity generation. The states with a greater offset in the reduction of electricity due to a change in natural gas realize a greater average reduction in carbon emissions. Additionally, New York realizes greater average reductions in carbon emissions than Maine even though its emissions rate for electricity is smaller, because Maine's offset reflects an increase in natural gas consumption while New York's reflects a decrease.

Table 15-4 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)
PA	2007	17.2	708	241	822
NJ	2007	17.4	653	241	751
CT	2007	18.5	599	241	692
MA	2007	18.0	599	241	687
RI	2007	16.8	599	241	678
VT	2007	-18.6	599	241	555
NH	2007	-20.4	599	241	548
NY	2007	7.6	514	241	540
ME	None	-27.5	599	241	523

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

The relative change in life-cycle costs per unit of new floor area is shown in Table 15-5. There is some correlation between the energy cost savings (Table 15-3) and the life-cycle cost-effectiveness of adopting the LEC design. However, it is not a strong correlation because additional construction costs are required to obtain future energy cost savings. All Northeast states realize an average decrease in life-cycle costs, ranging from $3.90/m^2 to $13.63/m^2 ($0.36/ft^2 to $1.27/ft^2).

Table 15-5 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
CT	2007	32	161	$19.7	$13.63	$1.27
ME	None	41	436	$6.4	$12.88	$1.20
NH	2007	39	195	$5.8	$10.49	$0.98
RI	2007	44	165	$3.1	$9.25	$0.86
VT	2007	50	187	$1.4	$7.00	$0.65
NY	2007	6	171	$37.1	$6.11	$0.57
NJ	2007	15	167	$20.8	$5.98	$0.56
MA	2007	21	157	$12.8	$4.96	$0.46
PA	2007	9	164	$18.2	$3.90	$0.36

15.2 Percentage Savings Comparison

State 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, carbon emissions, and life-cycle costs are analyzed for the most common existing building type, small office buildings. Summary results for the other 10 building types are reported in Table B-1 through Table B-10 in Appendix B.

15.2.1 3-Story Office Building

Table 15-6 summarizes the percentage changes in energy use, energy costs, carbon emissions, and life-cycle costs 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 18 % each while reducing life-cycle costs by 2.6 %.

Table 15-6 Average Percentage Change by State, 3-Story Office Building, 10-Year

State	Percentage Change			
	Energy Use	Energy Cost	Carbon Emissions	LCC
CT	-17.9	-23.4	-21.8	-3.1
MA	-17.6	-22.8	-21.8	-2.6
ME	-31.1	-31.6	-31.6	-0.7
NH	-18.1	-20.4	-20.1	-2.8
NJ	-19.6	-23.6	-22.9	-2.5
NY	-16.9	-22.0	-20.2	-3.0
PA	-17.5	-21.5	-22.1	-2.7
RI	-18.5	-22.5	-22.3	-2.8
VT	-17.6	-20.1	-19.8	-2.6
Avg.	**-18.7**	**-22.8**	**-22.2**	**-2.6**

These detailed results can be readily analyzed in mappings of the Northeast Census Region. Figure 15-1, Figure 15-2, Figure 15-3, and Figure 15-4 display the average percentage energy use savings, energy cost savings, carbon emissions reduction, and life-cycle cost savings by state, respectively. The state with no state energy code is shown with cross hatching and a bolded state border.

The state energy code is the primary driver of the reductions in energy use. Figure 15-1 shows that Maine, the only state without a state energy code, realizes energy use savings greater than 30 % by adopting the LEC design. The other 8 Northeastern states, which

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

have all adopted *ASHRAE 90.1-2007*, realize much lower energy use savings (less than 20 %).

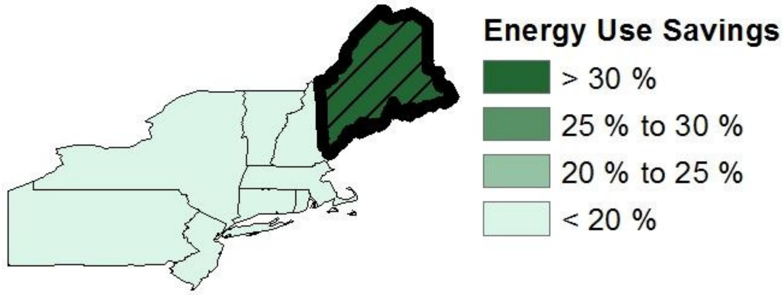

Figure 15-1 Average Energy Use Savings by State, 3-Story Office Building, 10-year

Figure 15-2 shows the average energy cost savings over 10 years by state from adopting the LEC design. Every state reduces energy costs by at least 20 %. Similar to energy use, Maine realizes the greatest energy cost savings. None of the other eight states have cost savings greater than 25 %. The reductions in energy costs are larger than the reductions in energy use for all states.

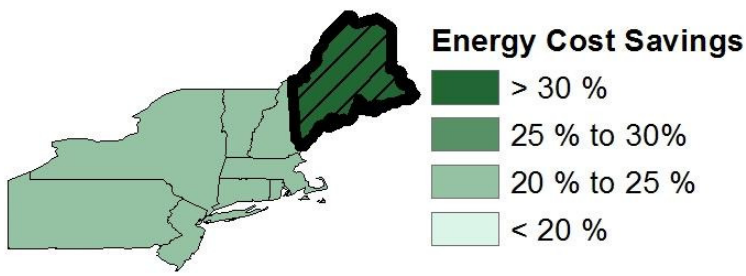

Figure 15-2 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year

Figure 15-3 shows the average reductions in energy-related carbon emissions by state from adopting the LEC design. The results for carbon emissions are similar to those for energy use and energy costs. Maine realizes the greatest reduction in carbon emissions (33 %). Seven of the other eight states realize reductions between 20 % and 25 %. Vermont realizes the smallest reductions in carbon emissions (19.8 %) because natural gas accounts for a greater fraction of the reduction in total energy use for Vermont than for any other state.

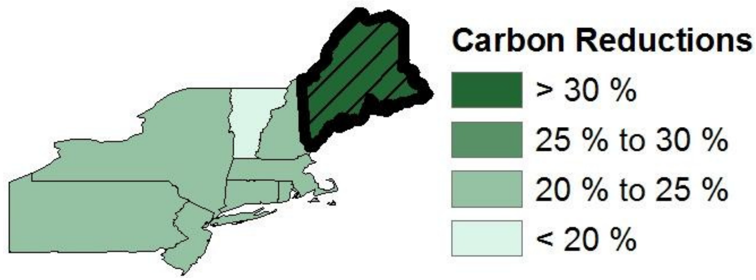

Figure 15-3 Average Energy-related Carbon Emissions Reduction by State, 3-Story Office Building, 10-year

Figure 15-4 shows the average life-cycle cost savings over 10 years by state from adopting the LEC design. Maine realizes the smallest reduction in life-cycle costs (0.7 %), which may be driven by the higher investment costs required to obtain the more efficient building design. The other 8 states realize reductions in life-cycle costs between 2 % and 4 %.

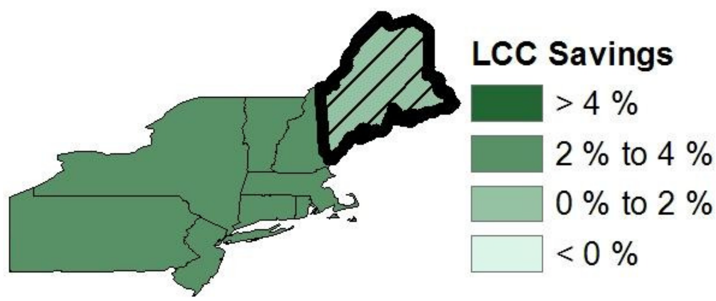

Figure 15-4 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year

For a 3-story office building, as expected, Maine has the most to gain in percentage terms in energy use, energy cost, and carbon emissions savings from adopting the LEC design. However, Maine realizes the smallest life-cycle cost reductions. The other eight states would also realize significant benefits from the adoption of the LEC design for 3-story office buildings, and do so while realizing greater life-cycle cost savings.

15.2.2 Region-wide Results by Study Period Length

The percentage change comparisons up to this point have focused on 3-story office buildings over a 10-year study period. It is important to consider how the study period length – representing the time horizon of the investor -- impacts energy use, energy costs, energy-related carbon emissions, and life-cycle costs. Nine study period lengths are analyzed: 1 year, 5 years, 10 years, 15 years, 20 years, 25 years, 30 years, 35 years, and 40 years. All building types are included in this analysis.

Average reductions in energy use from adoption of the LEC design are constant over all study period lengths because energy efficiency is assumed to be constant over time. The regional reduction in average energy use across all 26 cities in the study ranges from 6.1 % to 25.1 %, depending on the building type, with an overall regional average of 13.8 %. Table 15-7 shows these results.

Table 15-7 Northeast Region Average Percentage Change in Energy Use by Building Type

Building Type	Percentage Change
APART04	-10.2
APART06	-10.8
DORMI04	-12.3
DORMI06	-10.4
HOTEL15	-11.8
HIGHS02	-6.1
OFFIC03	-18.7
OFFIC08	-18.6
OFFIC16	-14.2
RETAIL1	-14.2
RSTRNT1	-25.1
Average	**-13.8**

As shown in Table 15-8, savings in energy costs vary slightly, in percentage terms, over increasing study period lengths. The regional average reduction in energy costs across all location-building type combinations is constant at 20.1 % for all study periods. The minor variation within a building type is a result of the escalation rates used to adjust future energy prices. The regional average reduction ranges from 15.1 % to 32.6 %, depending on the building type, over all study periods.

Table 15-8 Northeast Region Average Percentage Change in Energy Costs by Building Type and Study Period Length

Building Type	Study Period Length								
	1	5	10	15	20	25	30	35	40
APART04	-17.8	-17.7	-17.7	-17.8	-17.8	-17.8	-17.8	-17.7	-17.7
APART06	-19.7	-19.5	-19.6	-19.7	-19.7	-19.7	-19.7	-19.6	-19.6
DORMI04	-18.8	-18.6	-18.7	-18.8	-18.8	-18.8	-18.7	-18.7	-18.7
DORMI06	-18.9	-18.7	-18.8	-18.8	-18.9	-18.9	-18.8	-18.8	-18.8
HOTEL15	-18.2	-18.1	-18.2	-18.2	-18.2	-18.2	-18.2	-18.2	-18.1
HIGHS02	-15.3	-15.1	-15.2	-15.3	-15.3	-15.3	-15.3	-15.2	-15.2
OFFIC03	-22.8	-22.7	-22.8	-22.8	-22.8	-22.8	-22.8	-22.8	-22.8
OFFIC08	-21.0	-21.0	-21.0	-21.0	-21.0	-21.0	-21.0	-21.0	-21.0
OFFIC16	-18.6	-18.6	-18.6	-18.6	-18.6	-18.6	-18.6	-18.6	-18.6
RETAIL1	-17.6	-17.5	-17.6	-17.6	-17.6	-17.6	-17.6	-17.6	-17.6
RSTRNT1	-32.6	-32.4	-32.5	-32.5	-32.6	-32.6	-32.5	-32.5	-32.5
Average	**-20.1**	**-20.0**	**-20.1**	**-20.1**	**-20.1**	**-20.1**	**-20.1**	**-20.1**	**-20.1**

Since the regional average reduction in energy use is constant over all study periods, the average energy-related carbon emissions are also constant at 19.0 %. The regional average reduction in carbon emissions ranges from 13.4 % to 31.3 % depending on the building type, as shown in Table 15-9.

Table 15-9 Northeast Region Average Percentage Change in Carbon Emissions by Building Type

Building Type	Percentage Change
APART04	-16.3
APART06	-18.0
DORMI04	-17.6
DORMI06	-17.3
HOTEL15	-17.1
HIGHS02	-13.4
OFFIC03	-22.2
OFFIC08	-20.7
OFFIC16	-18.0
RETAIL1	-17.0
RSTRNT1	-31.3
Average	**-19.0**

Table 15-10 shows that the percentage changes in life-cycle costs vary significantly over increasing study period lengths, but on average decrease for all study period lengths. Seven of the 11 building types realize reductions in life-cycle costs for all study periods.

Table 15-10 Northeast Region Average Percentage Change in Life-Cycle Costs by Building Type and Study Period Length

Building Type	Study Period Length								
	1	5	10	15	20	25	30	35	40
APART04	-2.0	-0.0	-0.0	-0.3	-0.2	-0.3	-0.5	-0.7	-0.6
APART06	0.1	0.2	-0.1	-0.6	-0.5	-0.7	-0.8	-1.0	-1.0
DORMI04	-7.0	-1.6	-1.2	-1.5	-1.2	-1.3	-1.4	-1.5	-1.4
DORMI06	1.2	0.0	-0.4	-0.9	-0.9	-1.1	-1.2	-1.4	-1.4
HOTEL15	1.7	0.3	-0.2	-0.9	-0.9	-1.2	-1.4	-1.7	-1.7
HIGHS02	-1.5	-1.1	-1.2	-1.6	-1.6	-1.8	-2.0	-2.2	-2.2
OFFIC03	-10.7	-3.1	-2.6	-3.0	-2.6	-2.7	-2.9	-3.0	-2.9
OFFIC08	-4.6	-2.4	-2.3	-2.7	-2.4	-2.5	-2.6	-2.8	-2.7
OFFIC16	2.5	0.5	-0.2	-1.1	-1.2	-1.5	-1.7	-2.1	-2.1
RETAIL1	-9.1	-0.6	-0.5	-1.1	-0.7	-0.9	-1.1	-1.4	-1.3
RSTRNT1	-10.9	-4.7	-4.0	-4.9	-4.4	-4.5	-4.8	-5.0	-5.0
Average	**-3.7**	**-1.1**	**-1.2**	**-1.7**	**-1.5**	**-1.7**	**-1.9**	**-2.1**	**-2.0**

Figure 15-5 shows that four building types – the 6-story apartment building, 6-story dormitory, hotel, and 16-story office building – are not cost-effective for a 1-year study period, with an average change in life-cycle costs ranging from 0.1 % to 2.5 %. By a 10-year study period, these four building types become cost-effective.

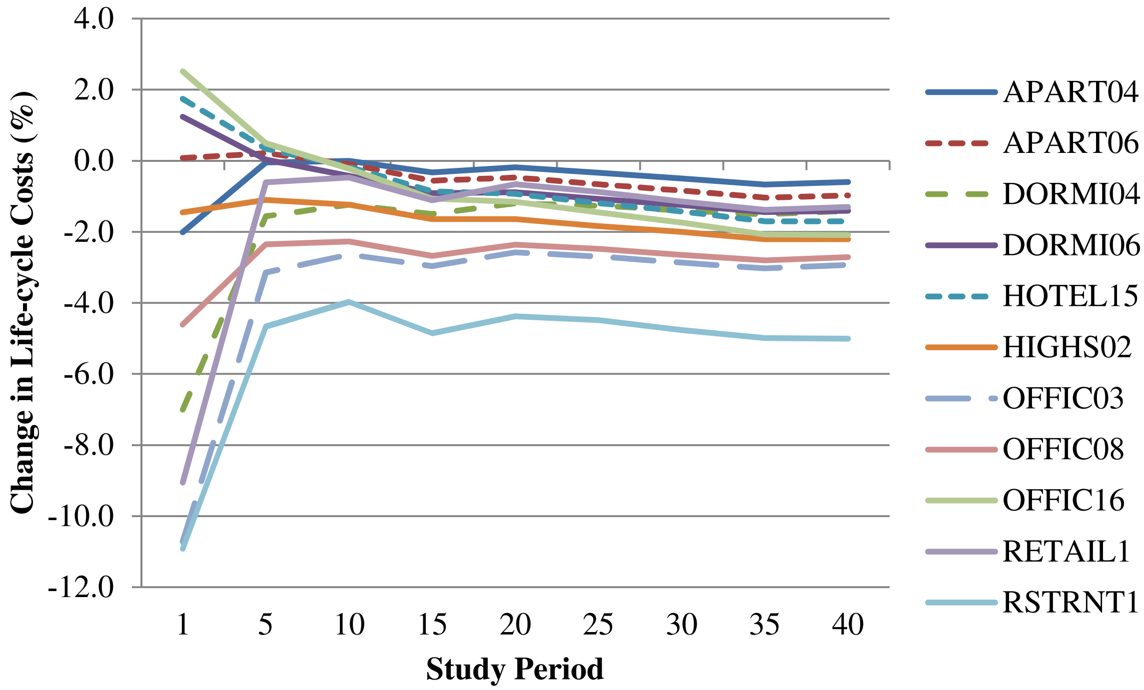

Figure 15-5 Average Life-Cycle Cost Savings by Building Type and Study Period Length

15.2.3 Region-wide Results by Building Type

For a 10-year study period length, Table 15-11 shows the simple average changes across all 26 cities in the Northeast Census Region, in percentage terms, from adopting the LEC design. The building type that realizes the smallest percentage reductions in energy use, energy costs, and energy-related carbon emissions is the high school while the greatest reductions are realized by the restaurant followed by the 3- and 8-story office buildings.

The occupant activity is the primary driver of the results for the high school, which is heavily occupied during the school year and lightly occupied during the summer months. Some of the energy efficiency measures (e.g., lighting) decrease heat gains, which lead to lower cooling loads during warmer months and greater heating loads during the colder months. A significant portion of the reductions in electricity consumption during these colder months is offset by increases in natural gas consumption required to meet the increased heating loads. Thus, a greater portion of the high school's energy use occurs during the colder months relative to other building types. The combination of more energy use occurring during the colder months and the offsetting increase in natural gas consumption during those months leads to a smaller overall percentage reduction in energy use for high schools.

One of the reasons that the restaurant realizes the greatest reductions in energy use is that the restaurant has the smallest plug and process loads in terms of watts per unit of floor area. Since the plug and process load is the only electricity use not impacted by the energy efficiency measures adopted in this study, a greater fraction of energy use can be decreased for restaurants relative to the other building types.

For all types, the percentage changes in energy costs and carbon emissions are greater than the percentage changes in energy use. This result is most significant for the high school, for which the percentage reduction in energy costs is over twice the percentage reduction in energy use. High schools realize such a dramatic difference due to the significant shift in energy use from electricity to cheaper and cleaner natural gas.

All 11 building types realize reductions in life-cycle costs. The restaurant, 3-story office building, and 8-story office building realize the greatest percentage reductions in life-cycle costs. The 4- and 6-story apartment buildings realize the smallest reductions in life-cycle costs.

Table 15-11 Northeast Region Percentage Change for LEC by Building Type, 10-Year

Building Type	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.2	-17.7	-16.3	-0.0
APART06	-10.8	-19.6	-18.0	-0.1
DORMI04	-12.3	-18.7	-17.6	-1.2
DORMI06	-10.4	-18.8	-17.3	-0.4
HOTEL15	-11.8	-18.2	-17.1	-0.2
HIGHS02	-6.1	-15.2	-13.4	-1.2
OFFIC03	-18.7	-22.8	-22.2	-2.6
OFFIC08	-18.6	-21.0	-20.7	-2.3
OFFIC16	-14.2	-18.6	-18.0	-0.2
RETAIL1	-14.2	-17.6	-17.0	-0.5
RSTRNT1	-25.1	-32.5	-31.3	-4.0
Average	**-13.8**	**-20.1**	**-19.0**	**-1.2**

15.2.4 Region-wide Results by Climate Zone

Table 15-12 shows the region-wide average percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs by *ASHRAE* climate zone. These changes are for the adoption of the LEC design relative to current state energy codes for all building types combined. However, it is necessary to control for state energy codes to properly analyze these results.

Table 15-12 Average Percentage Change for LEC by Climate Zone

Climate Zone	Energy Use	Energy Cost	Carbon Emissions	LCC
4A	-14.4	-20.8	-19.7	-1.0
5A	-12.9	-19.6	-18.5	-1.1
6A	-14.0	-19.2	-18.4	-1.2
7	-24.2	-30.1	-29.5	-2.0
Average	**-13.8**	**-20.1**	**-19.1**	**-1.2**

Table 15-13 shows the average percentage reduction in energy use for all cities located in a climate zone while controlling for state energy codes. The region-wide average reduction in energy use is -13.8 % with Zone 7 realizing the greatest reduction (-24.2 %) and Zone 5 the smallest (-12.9 %). Controlling for state energy codes, the warmer the climate the greater the reduction in energy use, which is a result of the energy efficiency improvement options considered in the LEC design. In general, 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.

Table 15-13 Average Percentage Change in Energy Use for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change		
	1999	2007	All
4A		-14.4	-14.4
5A		-12.9	-12.9
6A	-22.1	-12.3	-14.0
7	-24.2		-24.2
Grand Total	**-23.1**	**-13.1**	**-13.8**

Table 15-14 shows the average percentage reduction in energy costs for all cities located in a climate zone while controlling for state energy codes. The region-wide average reduction in energy costs is -20.1 % with Zone 7 realizing the greatest average reduction. Similar to energy use, controlling for state energy codes, cities located in warmer climates realize greater reductions in energy costs.

Table 15-14 Average Percentage Change in Energy Costs for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change		
	1999	2007	All
4A		-20.7	-20.8
5A		-19.6	-19.6
6A	-29.8	-17.0	-19.2
7	-30.0		-30.1
Grand Total	**-29.9**	**-19.2**	**-20.1**

Table 15-15 shows the average percentage reduction in energy-related carbon emissions for all cities located in a climate zone. Similar to energy use and energy costs, while controlling for state energy codes, cities located in warmer climates realize greater reductions in the carbon emissions.

Table 15-15 Average Percentage Change in Carbon Emissions for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change		
	1999	2007	All
4A		-19.7	-19.7
5A		-18.5	-18.5
6A	-29.1	-16.3	-18.4
7	-29.5		-29.5
Grand Total	**-29.3**	**-18.3**	**-19.1**

Table 15-16 shows the average percentage change in life-cycle costs for all cities located in a climate zone while controlling for state energy codes. For both state energy codes, cities in warmer climate zones realize smaller percentage reductions in life-cycle costs. For the adoption of the *ASHRAE 90.1-2007* design, cities in Zone 4 realize reductions of 1.0 % and cities in Zone 6 realize 1.2 %.

Table 15-16 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change		
	1999	2007	All
4A		-1.0	-1.0
5A		-1.1	-1.1
6A	-1.5	-1.2	-1.2
7	-2.0		-2.0
Grand Total	**-1.7**	**-1.1**	**-1.2**

16 Discussion

This study analyzes the impacts of adopting new, more stringent state energy codes for 26 cities located across the Northeast Census Region. Results are summarized at the regional level as well as the state level for all 9 Northeastern states. This section will discuss the key findings, limitations of the research, and recommended directions for future research.

16.1 Key Findings

Maine is the only state in the Northeast Census Region that has not yet adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. Maine would benefit from adopting either *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* as its state energy code. Adoption of *ASHRAE 90.1-2007* leads to greater reductions in energy use, energy costs, carbon emissions, and life-cycle costs than adoption of *ASHRAE 90.1-2004* relative to *ASHRAE 90.1-1999*.

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

The region-wide adoption of the LEC design as the commercial building energy code for all building types significantly decreases energy use (13.8 %), energy costs (20.1 %), and carbon emissions (19.0 %) while reducing life-cycle costs (1.2 %), on average, for a 10-year study period. Although the LEC design leads to reductions for all states, the magnitude of the reductions varies according to each state's adopted energy code. The state with no energy code, Maine, realizes the greatest percentage savings in energy use, energy costs, and carbon emissions.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 1 year to 10 years, the number of building types that are cost-effective increases from 7 to all 11. Setting the study period is an important determinant of cost-effectiveness and size of the percentage changes in life-cycle cost.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, and carbon emissions. After controlling for each state's energy code, cities located in warmer climates realize greater average percentage reductions in these measures. However, these same cities realize smaller percentage reductions in life-cycle costs because additional construction costs are required to obtain future energy cost savings.

Different building types realize different regional average percentage reductions in energy use, energy costs, and carbon emissions. High schools realize the smallest reductions while restaurants and 3- and 8-story office buildings realize the greatest reductions. The greatest percentage reductions in life-cycle costs also are realized by restaurants and 3- and 8-story office buildings while the smallest percentage reductions are realized by 4 and 6-story apartment buildings and 16-story office buildings.

The magnitude of a building type's average percentage change is not necessarily correlated with its changes in total energy use, energy costs, and energy-related carbon emissions relative to other building types. For example, high schools tend to realize some of the smallest percentage reductions, but some of the greatest total reductions in energy use, energy costs, and energy-related carbon emissions. Total reductions are driven largely by total new floor area constructed for the building type in a state. The adoption of the LEC design would lead to greater aggregate reductions in energy use in New York than in Vermont because the amount of newly constructed floor area for 2003 to 2007 was about 30 times greater in New York.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy prices, and emissions rates. Maine realizes over twice the energy use reductions per unit of floor area than any other state in the Northeast because it has no state energy code, while the other eight states have adopted *ASHRAE 90.1-2007*. States with the highest electricity rates tend to realize the largest reductions in energy costs per unit of energy consumption reduced. Similarly, states with higher emission rates per unit of electricity generated realize greater reductions in emissions per unit of energy consumption reduced.

16.2 Limitations and Future Research

The use of building prototypes in this study is meant to reveal general trends in the benefits and costs of energy standard adoption at the city, state, and regional levels. The study is not appropriate for analysis of individual buildings because each building has specific characteristics that may differ from the prototype. The analysis in this study is limited in scope and would be strengthened by analyzing more states, including sensitivity analysis, expanding the BIRDS database and metrics, and enabling public access to all the results.

This study only analyzes 9 of the 50 states in detail, and cannot be extrapolated to estimate the magnitude of nationwide savings. Combining the results in this study with detailed analysis of the remaining 41 states will allow for estimation of nationwide impacts. Also, analysis across census regions may show some additional variation in results revealing insights not captured in this study.

Sensitivity analysis is needed for at least two assumptions in the analysis. First, consider the assumed discount rate used in life-cycle costing. Although 3 % is a reasonable discount rate, in real terms, for federal government investment decisions, it may be too low of a value for an expected real return on an alternative investment in the private sector. A higher discount rate would decrease the value of future energy cost savings, which could impact the cost-effectiveness of adopting more energy efficient building designs. Sensitivity analysis on the assumed discount rate is needed to determine the robustness of the cost results. Second, the current analysis assumes that the cooling load is met by equipment running on electricity while heating loads are met with equipment running on natural gas, which is not the typical fuel mix for some areas of the nation. The database should be expanded to include alternative fuel sources for heating.

Additional data are needed to refine and expand the BIRDS database. First, the study uses simple statewide averages of constructed floor area to summarize energy use, energy cost, carbon emissions, and life-cycle cost changes. However, the amount of total floor area constructed will vary significantly from city to city. Future research could develop a weighted average of savings in a state based on the fraction of newly constructed floor area by city. Second, the 11 prototypical buildings analyzed in this study are likely not representative of the entire building stock for each building type. For example, all high-rise buildings are not 100 % glazed, as assumed here. For this reason, the results should be considered as general magnitudes instead of hard numbers. Future research should include additional prototypes, such as the DOE Benchmark Buildings (NREL, 2011), in the database. Additionally, since existing buildings account for nearly the entire building stock, prototypes for retrofitting buildings should be incorporated into the BIRDS database as well. Another addition to expand the database is the inclusion of building designs to meet the newest edition of *ASHRAE 90.1* (*-2010*) as well as *ASHRAE*'s green building standard (*ASHRAE 189.1-2011*). The state average energy cost rates and energy-related carbon emissions rates do not control for local variation in energy tariffs or electricity fuel mixes. By using utility-level energy cost and emissions rate data, the accuracy of the estimates in BIRDS could be improved. Additionally, the fuel mix used for electricity generation across the United States will change over time as economic and regulatory conditions change. A range of potential emissions rates could be included to allow for potential changes in emissions rates in the future.

The analysis in this study ignores the impacts that plug and process loads have on the reductions in energy use. Buildings with greater plug and process loads will realize smaller percentage changes in energy use because the energy efficiency measures considered in this study focus on the building envelope and HVAC equipment, holding constant the energy use from other equipment used in the building. As building energy efficiency improves, the plug and process loads become a larger fraction of the overall energy load. Future research should consider the impact changes in plug and process loads have on the overall energy use savings realized by energy efficiency improvements to buildings.

This study only compares the current state energy code to newer, more stringent standard editions for states in the Midwest Census Region. The BIRDS database is much more expansive, allowing researchers to compare any of the editions of *ASHRAE 90.1* with any other edition of *ASHRAE 90.1* or the LEC design for any state in the country. The BIRDS database should be made available to the public through a simple-to-use software tool that allows other researchers to use the database for their own research on building energy efficiency.

Finally, a more comprehensive sustainability assessment of the benefits and costs of building energy efficiency would strengthen the impact of this work. This study applies environmental life cycle assessment methods to evaluate the global warming potentials attributable to building energy efficiency improvements. In a parallel effort, the BIRDS database is being expanded to include a full range of 11 life-cycle environmental impacts covering human health effects, ecological health effects, and resource depletion. The sustainability assessment is also being expanded beyond building energy efficiency to cover the materials used in construction, MRR, and waste management. The BIRDS software tool in development will provide the results of this more comprehensive sustainability assessment alongside the results summarized in this report.

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A Building and Energy Characteristics

Table A-1 CBECS Categories and Subcategories

Category	Subcategory
Education	elementary or middle school high school college or university preschool or daycare adult education career or vocational training religious education
Food Sales	grocery store or food market gas station with a convenience store; convenience store
Food Service	fast food restaurant or cafeteria
Health Care Inpatient	hospital inpatient rehabilitation
Health Care Outpatient	medical office (see previous column) clinic or other outpatient health care outpatient rehabilitation veterinarian
Lodging	motel or inn hotel dormitory, fraternity, or sorority retirement home nursing home, assisted living, etc. convent or monastery shelter, orphanage, halfway house
Mercantile Non-Mall	retail store beer, wine, or liquor store rental center dealership or showroom for vehicles or boats studio/gallery
Mercantile Malls	enclosed mall strip shopping center
Office	administrative or professional office government office mixed-use office bank or other financial institution medical office (see previous column) sales office contractor's office non-profit or social services research and development city hall or city center religious office call center

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
Warehouse and Storage	refrigerated warehouse non-refrigerated warehouse distribution or shipping center
Other	airplane hangar crematorium laboratory telephone switching agricultural with some retail space manufacturing or industrial with some retail space data center or server farm
Vacant	None

Table A-2 New Commercial Building Construction Floor Area for 2003 through 2007 by State and Building Type

	Building Construction Floor Area in 1000 m^2 (1,000 ft^2)										
State	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total
CT	611 (6582)	403 (4333)	489 (5261)	618 (6651)	510 (5485)	65 (698)	1245 (13 403)	1194 (12 856)	817 (8798)	1271 (13 679)	7223 (77 746)
MA	2959 (31 854)	728 (7832)	884 (9516)	1103 (11 868)	632 (6808)	121 (1306)	1772 (19 079)	1356 (14 599)	854 (9197)	2484 (26 742)	12 895 (138 802)
ME	64 (687)	209 (2245)	166 (1791)	224 (2411)	134 (1441)	34 (368)	566 (6088)	313 (3374)	281 (3021)	494 (5320)	2485 (26 745)
NH	141 (1523)	227 (2440)	226 (2437)	276 (2974)	154 (1653)	51 (548)	648 (6970)	411 (4421)	191 (2059)	438 (4717)	2763 (29 741)
NJ	2807 (30 209)	796 (8563)	943 (10 145)	1235 (13 295)	774 (8335)	112 (1210)	2494 (26 842)	2627 (28 280)	3008 (32 383)	2587 (27 841)	17 382 (187 103)
NY	11 622 (125 095)	1639 (17 639)	1959 (21 083)	3330 (35 842)	1075 (11 572)	210 (2259)	3633 (39 107)	2247 (24 186)	1286 (13 845)	3354 (36 104)	30 354 (326 732)
PA	1503 (16 177)	1908 (20 535)	1406 (15 135)	2424 (26 096)	1354 (14 577)	219 (2361)	3762 (40 489)	3660 (39 397)	3512 (37 805)	3556 (38 280)	23 305 (250 852)
RI	238 (2559)	60 (649)	192 (2069)	251 (2707)	81 (877)	26 (278)	278 (2990)	197 (2125)	114 (1228)	236 (2540)	1674 (18 021)
VT	161 (1736)	99 (1063)	96 (1030)	113 (1214)	71 (765)	6 (68)	63 (674)	136 (1463)	88 (946)	165 (1777)	998 (10 737)
Total	20 106 (216 422)	6069 (65 299)	6361 (68 467)	9574 (103 058)	4785 (51 513)	844 (9096)	14461 (155 642)	12 141 (130 701)	10 151 (109 282)	14585 (157 000)	99 079 (1 066 479)

Table A-3 New Commercial Building Construction Share by State and Building Type

	Percentage of Building Construction Floor Area											
State	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total	Rep. by Study
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 %
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 %
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 %
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 %
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 %
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 %
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 %

Table A-4 Electricity Generation CO_2, CH_4, and N_2O Emissions Rates by State

State	CO_2 (t/GWh)	CH4 (t/GWh)	N2O (t/GWh)
CT	550.4	47.0	1.4
MA	550.4	47.0	1.4
ME	550.4	47.0	1.4
NH	550.4	47.0	1.4
NJ	618.7	33.4	0.4
NY	480.7	32.3	0.8
PA	672.9	34.7	0.4
RI	550.4	47.0	1.4
VT	550.4	47.0	1.4

B Additional BIRDS Database Results

Table B-1 4-Story Apartment Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
CT	-9.5	-18.5	-15.1	-0.1
MA	-9.1	-16.8	-14.8	0.1
ME	-19.9	-32.9	-31.9	-2.6
NH	-9.5	-15.8	-14.7	-0.3
NJ	-10.3	-17.8	-16.0	0.4
NY	-9.2	-17.5	-13.8	0.0
PA	-9.5	-14.9	-16.0	0.6
RI	-9.2	-15.5	-15.1	0.2
VT	-9.5	-15.5	-14.6	-0.2

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
CT	-10.6	-21.8	-17.7	-0.4
MA	-9.8	-19.5	-17.0	0.0
ME	-19.3	-32.3	-31.4	-2.4
NH	-9.3	-15.4	-14.4	-0.3
NJ	-11.4	-20.6	-18.5	0.2
NY	-9.6	-19.4	-15.1	-0.1
PA	-10.4	-17.1	-18.5	0.5
RI	-10.0	-17.9	-17.4	0.0
VT	-9.2	-15.1	-14.2	-0.1

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
CT	-11.2	-18.9	-16.1	-1.6
MA	-11.1	-17.8	-16.1	-1.3
ME	-24.4	-35.6	-34.9	-1.6
NH	-12.2	-17.0	-16.2	-1.7
NJ	-12.3	-18.6	-17.2	-0.8
NY	-11.1	-18.2	-15.1	-1.5
PA	-11.1	-15.9	-16.8	-0.8
RI	-11.3	-16.7	-16.4	-1.4
VT	-11.9	-16.7	-15.9	-1.6

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
CT	-10.4	-21.2	-17.2	-0.7
MA	-9.5	-18.7	-16.4	-0.3
ME	-18.0	-30.6	-29.7	-3.1
NH	-8.4	-13.8	-12.9	-0.5
NJ	-11.4	-20.4	-18.3	-0.2
NY	-9.1	-18.3	-14.3	-0.4
PA	-10.3	-16.8	-18.0	0.2
RI	-9.7	-17.2	-16.7	-0.3
VT	-8.2	-13.4	-12.6	-0.3

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
CT	-12.7	-21.6	-18.3	-0.5
MA	-11.8	-19.3	-17.4	-0.1
ME	-14.0	-23.1	-22.5	-2.3
NH	-8.9	-11.2	-10.8	-0.2
NJ	-13.1	-20.2	-18.6	0.1
NY	-11.2	-18.0	-15.0	-0.2
PA	-11.8	-17.1	-18.2	0.4
RI	-12.1	-18.1	-17.7	-0.1
VT	-9.0	-11.3	-11.0	-0.1

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
CT	-5.3	-17.9	-12.8	-1.9
MA	-4.6	-15.2	-12.3	-1.1
ME	-10.7	-18.9	-18.3	-1.9
NH	-5.7	-12.3	-11.1	-1.5
NJ	-6.6	-17.8	-15.0	-1.5
NY	-6.2	-16.7	-11.8	-1.6
PA	-5.4	-12.7	-14.3	-0.6
RI	-5.0	-13.7	-13.0	-0.9
VT	-5.9	-12.1	-11.0	-1.4

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
CT	-18.3	-21.3	-20.5	-2.7
MA	-18.3	-21.1	-20.6	-2.5
ME	-28.1	-29.2	-29.1	0.0
NH	-16.9	-18.2	-18.1	-2.2
NJ	-19.5	-21.4	-21.1	-2.5
NY	-17.0	-20.1	-19.0	-2.5
PA	-18.0	-20.3	-20.6	-2.4
RI	-18.9	-21.0	-20.9	-2.4
VT	-16.5	-18.0	-17.8	-2.0

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
CT	-15.2	-21.6	-19.6	-0.9
MA	-14.4	-20.2	-19.0	-0.3
ME	-13.9	-15.9	-15.8	-0.7
NH	-11.3	-12.3	-12.2	-0.6
NJ	-16.0	-21.0	-20.1	-0.1
NY	-13.9	-18.7	-16.9	-0.6
PA	-14.4	-18.9	-19.6	0.4
RI	-15.3	-20.0	-19.7	-0.3
VT	-11.3	-12.3	-12.2	-0.4

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
CT	-12.3	-16.9	-15.5	-1.7
MA	-11.8	-16.1	-15.2	0.1
ME	-31.7	-33.2	-33.1	-1.2
NH	-15.9	-17.8	-17.5	-0.9
NJ	-13.9	-17.4	-16.7	0.1
NY	-12.4	-16.4	-14.9	-0.6
PA	-12.3	-15.4	-15.9	0.1
RI	-12.4	-15.8	-15.6	-1.5
VT	-15.7	-17.5	-17.3	-0.8

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
CT	-24.1	-33.6	-30.6	-4.4
MA	-23.8	-32.5	-30.7	-3.7
ME	-43.6	-45.6	-45.5	-2.6
NH	-24.3	-29.0	-28.3	-4.6
NJ	-27.3	-34.1	-32.8	-6.3
NY	-21.7	-31.5	-27.7	-4.3
PA	-23.7	-30.4	-31.6	-3.4
RI	-25.0	-31.8	-31.4	-3.8
VT	-23.6	-28.5	-27.9	-4.3