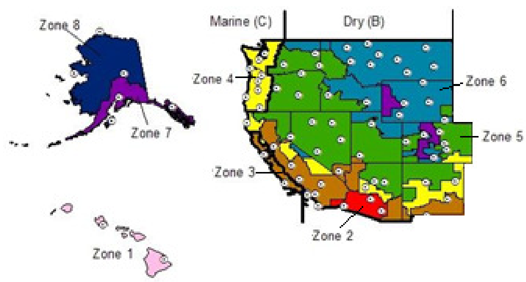
NIST Special Publication 1148-4

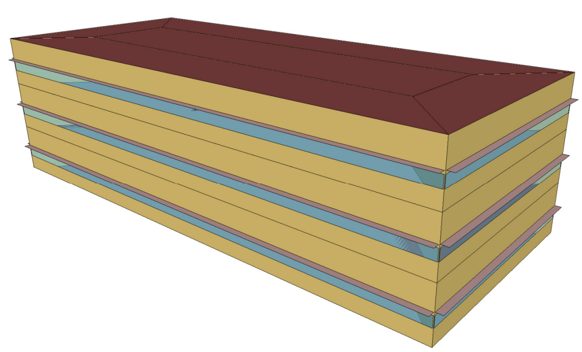
Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: West Census Region

Joshua Kneifel

http://dx.doi.org/10.6028/NIST.SP.1148-4



BIRDS
Building Industry Reporting and Design *for* Sustainability



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

NIST Special Publication 1148-4

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

Joshua Kneifel
Applied Economics Office
Engineering Laboratory

http://dx.doi.org/10.6028/NIST.SP.1148-4

February 2013

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

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

National Institute of Standards and Technology Special Publication 1148-4
Natl. Inst. Stand. Technol. Spec. Publ. 1148-4, 213 pages (February 2013)
http://dx.doi.org/10.6028/NIST.SP.1148-4
CODEN: NSPUE2

Abstract

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

The results of this report are based on analysis of the Building Industry Reporting and Design for Sustainability (BIRDS) database, which includes 12 540 whole building energy simulations covering eleven building types in 228 cities across all U.S. states for nine 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 West 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. Andrew Persily of EL's Energy and Environment Division, and Dr. Nicos S. Martys of EL's Materials and Structural Systems Division. A special thanks to Mr. Nicholas Long and the EnergyPlus Team for generating the initial energy simulations for this project. Thanks to Mr. Brian Presser for adapting the energy simulations to meet the study requirements and generating the final simulations used in the database. Thanks to Mr. Nathaniel Soares for developing the initial version of the Building Industry Reporting and Design for Sustainability (BIRDS) database, and to Ms. Priya Lavappa for enhancing the database for the current analysis. The author would like to thank the NIST Engineering Laboratory for its support of the project.

Author Information

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

Table of Contents

Abstract .... **ii**
Preface .... **iv**
Acknowledgements .... **vi**
Author Information .... **vi**
List of Figures .... **xiv**
List of Tables .... **xvi**
List of Acronyms .... **xxiv**
Executive Summary .... **xxvi**
1 Introduction **1**
1.1 Background and Purpose 1
1.2 Literature Review 1
1.3 Approach 3
2 Study Design **5**
2.1 Building Types 5
2.2 Building Designs 6
2.3 Study Period Lengths 8
3 Cost Data **9**
3.1 First Costs 9
3.2 Future Costs 12
4 Building Stock Data **15**
4.1 Databases 15
4.2 Weighting Factors 15
5 Analysis Approach **17**
5.1 Energy Use 17
5.2 Life-Cycle Costing 17
5.3 Carbon Assessment 18
5.4 Analysis Metrics 19
6 Alaska **21**
6.1 Percentage Savings 21
6.1.1 Energy Use 22
6.1.2 Energy Costs 23
6.1.3 Energy-related Carbon Emissions 24
6.1.4 Life-Cycle Costs 24
6.1.5 City Comparisons 25
6.2 Total Savings 28
6.2.1 Energy Use 28
6.2.2 Energy Costs 30
6.2.3 Energy-related Carbon Emissions 31
6.2.4 Life-Cycle Costs 33
6.3 State Summary 34
7 Arizona **37**
7.1 Percentage Savings 38

7.1.1 Energy Use ... 38
7.1.2 Energy Costs ... 39
7.1.3 Energy-related Carbon Emissions ... 40
7.1.4 Life-Cycle Costs ... 41
7.1.5 City Comparisons ... 41
7.2 Total Savings ... 44
7.2.1 Energy Use ... 44
7.2.2 Energy Costs ... 46
7.2.3 Energy-related Carbon Emissions ... 47
7.2.4 Life-Cycle Costs ... 49
7.3 State Summary ... 50
8 California ... 53
8.1 Percentage Savings ... 53
8.1.1 Statewide Building Comparison ... 54
8.1.2 City Comparisons ... 55
8.2 Total Savings ... 56
8.2.1 Energy Use ... 57
8.2.2 Energy Costs ... 58
8.2.3 Energy-related Carbon Emissions ... 60
8.2.4 Life-Cycle Costs ... 61
8.3 State Summary ... 62
9 Colorado ... 63
9.1 Percentage Savings ... 63
9.1.1 Energy Use ... 64
9.1.2 Energy Costs ... 65
9.1.3 Energy-related Carbon Emissions ... 65
9.1.4 Life-Cycle Costs ... 66
9.1.5 City Comparisons ... 67
9.2 Total Savings ... 69
9.2.1 Energy Use ... 70
9.2.2 Energy Costs ... 72
9.2.3 Energy-related Carbon Emissions ... 73
9.2.4 Life-Cycle Costs ... 74
9.3 State Summary ... 76
10 Hawaii ... 79
10.1 Percentage Savings ... 79
10.1.1 Energy Use ... 80
10.1.2 Energy Costs ... 80
10.1.3 Energy-related Carbon Emissions Reduction ... 81
10.1.4 Life-Cycle Costs ... 82
10.1.5 City Comparisons ... 83

10.2 Total Savings ... 84
10.2.1 Energy Use ... 84
10.2.2 Energy Costs ... 86
10.2.3 Energy-related Carbon Emissions ... 87
10.2.4 Life-Cycle Costs ... 89
10.3 State Summary ... 90
11 Idaho ... 91
11.1 Percentage Savings ... 91
11.1.1 Statewide Building Comparison ... 91
11.1.2 City Comparisons ... 93
11.2 Total Savings ... 94
11.2.1 Energy Use ... 94
11.2.2 Energy Costs ... 96
11.2.3 Energy-related Carbon Emissions ... 97
11.2.4 Life-Cycle Costs ... 98
11.3 State Summary ... 100
12 Montana ... 101
12.1 Percentage Savings ... 101
12.1.1 Statewide Building Comparison ... 101
12.1.2 City Comparisons ... 103
12.2 Total Savings ... 104
12.2.1 Energy Use ... 104
12.2.2 Energy Costs ... 105
12.2.3 Energy-related Carbon Emissions ... 107
12.2.4 Life-Cycle Costs ... 108
12.3 State Summary ... 109
13 Nevada ... 111
13.1 Percentage Savings ... 111
13.1.1 Energy Use ... 112
13.1.2 Energy Costs ... 112
13.1.3 Energy-related Carbon Emissions Reduction ... 113
13.1.4 Life-Cycle Costs ... 114
13.1.5 City Comparisons ... 115
13.2 Total Savings ... 117
13.2.1 Energy Use ... 118
13.2.2 Energy Costs ... 119
13.2.3 Energy-related Carbon Emissions ... 121
13.2.4 Life-Cycle Costs ... 122
13.3 State Summary ... 124
14 New Mexico ... 125
14.1 Percentage Savings ... 125

14.1.1 Statewide Building Comparison 125
14.1.2 City Comparisons 127
14.2 Total Savings 128
14.2.1 Energy Use 128
14.2.2 Energy Costs 129
14.2.3 Energy-related Carbon Emissions 131
14.2.4 Life-Cycle Costs 132
14.3 State Summary 133
15 Oregon 135
15.1 Percentage Savings 135
15.1.1 Statewide Building Comparison 135
15.1.2 City Comparisons 137
15.2 Total Savings 138
15.2.1 Energy Use 138
15.2.2 Energy Costs 140
15.2.3 Energy-related Carbon Emissions 141
15.2.4 Life-Cycle Costs 142
15.3 State Summary 144
16 Utah 145
16.1 Percentage Savings 145
16.1.1 Statewide Building Comparison 145
16.1.2 City Comparisons 147
16.2 Total Savings 148
16.2.1 Energy Use 148
16.2.2 Energy Costs 149
16.2.3 Energy-related Carbon Emissions 151
16.2.4 Life-Cycle Costs 152
16.3 State Summary 153
17 Washington 155
17.1 Percentage Savings 155
17.1.1 Statewide Building Comparison 156
17.1.2 City Comparisons 157
17.2 Total Savings 158
17.2.1 Energy Use 158
17.2.2 Energy Costs 160
17.2.3 Energy-related Carbon Emissions 162
17.2.4 Life-Cycle Costs 163
17.3 State Summary 164
18 Wyoming 165
18.1 Percentage Savings 165
18.1.1 Energy Use 166

18.1.2 Energy Costs 167
18.1.3 Energy-related Carbon Emissions 167
18.1.4 Life-Cycle Costs 168
18.1.5 City Comparisons 169
18.2 Total Savings 171
18.2.1 Energy Use 171
18.2.2 Energy Costs 173
18.2.3 Energy-related Carbon Emissions 174
18.2.4 Life-Cycle Costs 176
18.3 State Summary 177
19 State Comparisons for the Adoption of the Low Energy Case Design 179
19.1 Total Savings Comparison 179
19.2 Percentage Change Comparison 184
19.2.1 3-Story Office Building 184
19.2.2 Region-wide Results by Study Period Length 187
19.2.3 Region-wide Results by Building Type 190
19.2.4 Region-wide Results by Climate Zone 191
20 Discussion 195
20.1 Key Findings 195
20.2 Limitations and Future Research 197
References 201
A Building and Energy Characteristics 205
B Additional BIRDS Database Results 209

List of Figures

Figure 2-1 Cities and Climate Zones 8
Figure 19-1 Average Energy Use Savings by State, 3-Story Office Building, 10-Year 185
Figure 19-2 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year 186
Figure 19-3 Average Energy-related Carbon Emissions Reduction by State, 3-Story Office Building, 10-Year 186
Figure 19-4 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year 187
Figure 19-5 Average Change in Life-Cycle Costs by Building Type and Study Period Length 190

List of Tables

Table 2-1 Building Characteristics ... 5
Table 2-2 Energy Code by State/City for the West Census Region ... 7
Table 3-1 Energy Efficiency Component Requirements for Alternative Building Designs ... 10
Table 3-2 HVAC Energy Efficiency Requirements for Alternative Building Designs ... 11
Table 4-1 New Commercial Building Construction (West, 2003 through 2007) ... 16
Table 5-1 Greenhouse Gas Global Warming Potentials ... 19
Table 6-1 Average Annual Energy Use by Building Type and Energy Standard Edition, Alaska ... 21
Table 6-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Alaska ... 22
Table 6-3 Average Percentage Change in Energy Costs, 10-Year, Alaska ... 23
Table 6-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Alaska ... 24
Table 6-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Alaska ... 25
Table 6-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Alaska ... 26
Table 6-7 Average Percentage Change in Energy Costs by City, 10-Year, Alaska ... 26
Table 6-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Alaska ... 27
Table 6-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Alaska ... 27
Table 6-10 Average Per Unit Change in Annual Energy Use, Alaska ... 28
Table 6-11 Statewide Change in Annual Energy Use for One Year of Construction, Alaska ... 29
Table 6-12 Average Per Unit Change in Energy Costs, 10-Year, Alaska ... 30
Table 6-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Alaska ... 31
Table 6-14 Average Per Unit Change in Carbon Emissions, 10-Year, Alaska ... 32
Table 6-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Alaska – Metric Tons ... 33
Table 6-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Alaska ... 33
Table 6-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Alaska ... 34
Table 7-1 Average Annual Energy Use by Building Type and Standard Edition, Arizona ... 37
Table 7-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Arizona ... 38
Table 7-3 Average Percentage Change in Energy Costs, 10-Year, Arizona ... 39
Table 7-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Arizona ... 40
Table 7-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Arizona ... 41
Table 7-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Arizona ... 42

Table 7-7 Average Percentage Change in Energy Costs by City, 10-Year, Arizona ... 43
Table 7-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Arizona ... 43
Table 7-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Arizona ... 44
Table 7-10 Average Per Unit Change in Annual Energy Use, Arizona ... 45
Table 7-11 Statewide Change in Annual Energy Use for One Year of Construction, Arizona ... 45
Table 7-12 Average Per Unit Change in Energy Costs, 10-Year, Arizona ... 46
Table 7-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Arizona ... 47
Table 7-14 Average Per Unit Change in Carbon Emissions, 10-Year, Arizona ... 48
Table 7-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Arizona – Metric Tons ... 49
Table 7-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Arizona ... 49
Table 7-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Arizona ... 50
Table 8-1 Average Annual Energy Use by Building Type and Standard Edition, California ... 53
Table 8-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, California ... 54
Table 8-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, California ... 56
Table 8-4 Average Per Unit Change in Annual Energy Use, California ... 57
Table 8-5 Statewide Change in Annual Energy Use for One Year of Construction, California ... 58
Table 8-6 Average Per Unit Change in Energy Costs, 10-Year, California ... 59
Table 8-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, California ... 59
Table 8-8 Average Per Unit Change in Carbon Emissions, 10-Year, California ... 60
Table 8-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, California – Metric Tons ... 61
Table 8-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, California ... 61
Table 8-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, California ... 62
Table 9-1 Average Annual Energy Use by Building Type and Standard Edition, Colorado ... 63
Table 9-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Colorado ... 64
Table 9-3 Average Percentage Change in Energy Costs, 10-Year, Colorado ... 65
Table 9-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Colorado ... 66
Table 9-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Colorado ... 67
Table 9-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Colorado ... 68

Table 9-7 Average Percentage Change in Energy Costs by City, 10-Year, Colorado 68
Table 9-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Colorado 69
Table 9-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Colorado 69
Table 9-10 Average Per Unit Change in Annual Energy Use, Colorado 70
Table 9-11 Statewide Change in Annual Energy Use for One Year of Construction, Colorado 71
Table 9-12 Average Per Unit Change in Energy Costs, 10-Year, Colorado 72
Table 9-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Colorado 73
Table 9-14 Average Per Unit Change in Carbon Emissions, 10-Year, Colorado 73
Table 9-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Colorado – Metric Tons 74
Table 9-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Colorado 75
Table 9-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Colorado 76
Table 10-1 Average Annual Energy Use by Building Type and Standard Edition, Hawaii 79
Table 10-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Hawaii 80
Table 10-3 Average Percentage Change in Energy Costs, 10-Year, Hawaii 81
Table 10-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Hawaii 82
Table 10-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Hawaii 82
Table 10-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Hawaii 83
Table 10-7 Average Percentage Change in Energy Costs by City, 10-Year, Hawaii 83
Table 10-8 Average Percentage Change in Carbon Emissions by City, Hawaii 84
Table 10-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Hawaii 84
Table 10-10 Average Per Unit Change in Annual Energy Use, Hawaii 85
Table 10-11 Statewide Change in Annual Energy Use for One Year of Construction, Hawaii 85
Table 10-12 Average Per Unit Change in Energy Costs, 10-Year, Hawaii 86
Table 10-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Hawaii 87
Table 10-14 Average Per Unit Change in Carbon Emissions, 10-Year, Hawaii 88
Table 10-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Hawaii – Metric Tons 89
Table 10-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Hawaii 89
Table 10-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Hawaii 90

Table 11-1 Average Annual Energy Use by Building Type and Standard Edition, Idaho ... 91
Table 11-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Idaho ... 92
Table 11-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Idaho ... 93
Table 11-4 Average Per Unit Change in Annual Energy Use, Idaho ... 94
Table 11-5 Statewide Change in Annual Energy Use for One Year of Construction, Idaho ... 95
Table 11-6 Average Per Unit Change in Energy Costs, 10-Year, Idaho ... 96
Table 11-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Idaho ... 97
Table 11-8 Average Per Unit Change in Carbon Emissions, 10-Year, Idaho ... 97
Table 11-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Idaho – Metric Tons ... 98
Table 11-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Idaho ... 99
Table 11-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Idaho ... 99
Table 12-1 Average Annual Energy Use by Building Type and Standard Editions, Montana ... 101
Table 12-2 Average Percentage Change from Adoption of Standard Editions, 10-Year, Montana ... 102
Table 12-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Montana ... 103
Table 12-4 Average Per Unit Change in Annual Energy Use, Montana ... 104
Table 12-5 Statewide Change in Annual Energy Use for One Year of Construction, Montana ... 105
Table 12-6 Average Per Unit Change in Energy Costs, 10-Year, Montana ... 106
Table 12-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Montana ... 106
Table 12-8 Average Per Unit Change in Carbon Emissions, 10-Year, Montana ... 107
Table 12-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Montana – Metric Tons ... 108
Table 12-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Montana ... 108
Table 12-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Montana ... 109
Table 13-1 Average Annual Energy Use by Building Type and Standard Editions, Nevada ... 111
Table 13-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Nevada ... 112
Table 13-3 Average Percentage Change in Energy Costs, 10-Year, Nevada ... 113
Table 13-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Nevada ... 114
Table 13-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Nevada ... 115
Table 13-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Nevada ... 116

Table 13-7 Average Percentage Change in Energy Costs by City, 10-Year, Nevada ... 116
Table 13-8 Average Percentage Change in Carbon Emissions by City, Nevada ... 117
Table 13-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Nevada ... 117
Table 13-10 Average Per Unit Change in Annual Energy Use, Nevada ... 118
Table 13-11 Statewide Change in Annual Energy Use for One Year of Construction, Nevada ... 119
Table 13-12 Average Per Unit Change in Energy Costs, 10-Year, Nevada ... 120
Table 13-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Nevada ... 121
Table 13-14 Average Per Unit Change in Carbon Emissions, 10-Year, Nevada ... 121
Table 13-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Nevada – Metric Tons ... 122
Table 13-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Nevada ... 123
Table 13-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Nevada ... 124
Table 14-1 Average Annual Energy Use by Building Type and Standard Edition, New Mexico ... 125
Table 14-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, New Mexico ... 126
Table 14-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, New Mexico ... 127
Table 14-4 Average Per Unit Change in Annual Energy Use, New Mexico ... 128
Table 14-5 Statewide Change in Annual Energy Use for One Year of Construction, New Mexico ... 129
Table 14-6 Average Per Unit Change in Energy Costs, 10-Year, New Mexico ... 130
Table 14-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, New Mexico ... 130
Table 14-8 Average Per Unit Change in Carbon Emissions, 10-Year, New Mexico ... 131
Table 14-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, New Mexico – Metric Tons ... 132
Table 14-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, New Mexico ... 132
Table 14-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, New Mexico ... 133
Table 15-1 Average Annual Energy Use by Building Type and Standard Edition, Oregon ... 135
Table 15-2 Average Percentage Change in Energy Use from Adoption of a Newer Standard Edition, 10-Year, Oregon ... 136
Table 15-3 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, 10-Year, Oregon ... 137
Table 15-4 Average Per Unit Change in Annual Energy Use, Oregon ... 139
Table 15-5 Statewide Change in Annual Energy Use for One Year of Construction, Oregon ... 139

Table 15-6 Average Per Unit Change in Energy Costs, 10-Year, Oregon 140
Table 15-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Oregon 141
Table 15-8 Average Per Unit Change in Carbon Emissions, 10-Year, Oregon 141
Table 15-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Oregon – Metric Tons 142
Table 15-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Oregon 143
Table 15-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Oregon 143
Table 16-1 Average Annual Energy Use by Building Type and Standard Edition, Utah 145
Table 16-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Utah 146
Table 16-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Utah 147
Table 16-4 Average Per Unit Change in Annual Energy Use, Utah 148
Table 16-5 Statewide Change in Annual Energy Use for One Year of Construction, Utah 149
Table 16-6 Average Per Unit Change in Energy Costs, 10-Year, Utah 150
Table 16-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Utah 150
Table 16-8 Average Per Unit Change in Carbon Emissions, 10-Year, Utah 151
Table 16-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Utah – Metric Tons 152
Table 16-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Utah 152
Table 16-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Utah 153
Table 17-1 Average Annual Energy Use by Building Type and Standard Edition, Washington 155
Table 17-2 Average Percentage Change from Adoption of a Newer Standard Edition, 10-Year, Washington 156
Table 17-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Washington 158
Table 17-4 Average Per Unit Change in Annual Energy Use, Washington 159
Table 17-5 Statewide Change in Annual Energy Use for One Year of Construction, Washington 160
Table 17-6 Average Per Unit Change in Energy Costs, 10-Year, Washington 161
Table 17-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Washington 161
Table 17-8 Average Per Unit Change in Carbon Emissions, 10-Year, Washington 162
Table 17-9 Statewide Change in Total Carbon Emissions (t) for One Year of Construction, 10-Year, Washington – Metric Tons 163
Table 17-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Washington 163
Table 17-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Washington 164

Table 18-1 Average Annual Energy Use by Building Type and Standard Edition, Wyoming ... 165
Table 18-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Wyoming ... 166
Table 18-3 Average Percentage Change in Energy Costs, 10-Year, Wyoming ... 167
Table 18-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Wyoming ... 168
Table 18-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Wyoming ... 169
Table 18-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Wyoming ... 169
Table 18-7 Average Percentage Change in Energy Costs by City, 10-Year, Wyoming ... 170
Table 18-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Wyoming ... 170
Table 18-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Wyoming ... 171
Table 18-10 Average Per Unit Change in Annual Energy Use, Wyoming ... 172
Table 18-11 Statewide Change in Annual Energy Use for One Year of Construction, Wyoming ... 172
Table 18-12 Average Per Unit Change in Energy Costs, 10-Year, Wyoming ... 173
Table 18-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Wyoming ... 174
Table 18-14 Average Per Unit Change in Carbon Emissions, 10-Year, Wyoming ... 175
Table 18-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Wyoming – Metric Tons ... 176
Table 18-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Wyoming ... 176
Table 18-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Wyoming ... 177
Table 19-1 Total Reductions by State for Adoption of the LEC Design, 10-Year ... 180
Table 19-2 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC Design by State, 10-Year ... 181
Table 19-3 Energy Cost Reduction per kWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year ... 182
Table 19-4 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year ... 183
Table 19-5 Life-Cycle Cost Reductions per Unit of New Floor Area for Adoption of the LEC Design by State, 10-Year ... 184
Table 19-6 Average Percentage Change by State from Region-wide Adoption of the LEC design, 3-Story Office Building, 10-Year ... 185
Table 19-7 West Region Average Percentage Change in Energy Use by Building Type ... 188
Table 19-8 West Region Average Percentage Change in Energy Costs by Building Type and Study Period Length ... 188
Table 19-9 West Region Average Percentage Change in Carbon Emissions by Building Type ... 189

Table 19-10 West Region Average Percentage Change in Life-Cycle Costs by Building Type and Study Period Length ... 189
Table 19-11 West Region Percentage Change for LEC by Building Type, 10-Year ... 191
Table 19-12 Average Percentage Change for LEC by Climate Zone ... 191
Table 19-13 Average Percentage Change in Energy Use for LEC by Climate Zone and State Energy Code ... 192
Table 19-14 Average Percentage Change in Energy Costs for LEC by Climate Zone and State Energy Code ... 192
Table 19-15 Average Percentage Change in Carbon Emissions for LEC by Climate Zone and State Energy Code ... 193
Table 19-16 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and State Energy Code ... 193
Table A-1 CBECS Categories and Subcategories ... 205
Table A-2 New Commercial Building Construction Volume for 2003 through 2007 by State and Building Type ... 206
Table A-3 New Commercial Building Construction Share by State and Building Type ... 207
Table A-4 Electricity Generation CO_2, CH_4, and N_2O Emissions Rates by State ... 207
Table B-1 4-Story Apartment Building Summary Table for LEC and 10-Year Study Period ... 209
Table B-2 6-Story Apartment Building Summary Table for LEC and 10-Year Study Period ... 209
Table B-3 4-Story Dormitory Summary Table for LEC and 10-Year Study Period ... 210
Table B-4 6-Story Dormitory Summary Table for LEC and 10-Year Study Period ... 210
Table B-5 15-Story Hotel Building Summary Table for LEC and 10-Year Study Period ... 211
Table B-6 2-Story High School Summary Table for LEC and 10-Year Study Period ... 211
Table B-7 8-Story Office Building Summary Table for LEC and 10-Year Study Period ... 212
Table B-8 16-Story Office Building Summary Table for LEC and 10-Year Study Period ... 212
Table B-9 1-Story Retail Store Summary Table for LEC and 10-Year Study Period ... 213
Table B-10 1-Story Restaurant Summary Table for LEC and 10-Year Study Period ... 213

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 thirteen states in the West 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.

Three states in the West Census Region have not yet adopted a state energy code for commercial buildings: Alaska, Arizona, and Wyoming. For all cities in Alaska and Wyoming and the cities in Arizona that have not adopted a local energy code, adoption of *ASHRAE 90.1-2001* leads to reductions in energy use, energy costs, and energy-related carbon emissions, but not in a life-cycle cost-effective manner. In Arizona and Wyoming, *ASHRAE 90.1-2004* leads to greater reductions in energy use, energy costs, and carbon emissions than *ASHRAE 90.1-2001*, and is life-cycle cost-effective to adopt. Alaska realizes an increase in energy use from adopting *ASHRAE 90.1-2004* while decreasing energy costs, carbon emissions, and life-cycle costs. The shift in fuel consumption from electricity to natural gas allows energy use to increase while energy costs decrease. All three states realize reductions in energy use, energy costs, carbon emissions, and life-cycle costs from adopting *ASHRAE 90.1-2007*.

Colorado is the only state in the West Census Region that has adopted *ASHRAE 90.1-2001* as its state energy code for commercial buildings. Colorado would realize reductions in energy use, energy costs, and energy-related carbon emissions as well as life-cycle costs from adopting *ASHRAE 90.1-2004*. Adopting *ASHRAE 90.1-2007* would lead to greater reductions in energy use, energy costs, carbon emissions, and life-cycle costs than adopting *ASHRAE 90.1-2004*.

Hawaii and Nevada are the states in the West Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings. Both states would realize cost-effective reductions in energy use, energy costs, and energy-related carbon emissions from adopting *ASHRAE 90.1-2007*. Nevada realizes greater total life-cycle cost savings than total energy cost savings because the relaxation of the window U-factor and SHGC requirements decreases total construction costs while still decreasing total energy use for the state.

The adoption of the LEC design is analyzed for all thirteen 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 West 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 (18.5 %), energy costs (23.7 %), and carbon emissions (23.2 %), on average, while reducing life-cycle costs (1.1 %), 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 states that have not adopted *ASHRAE 90.1-2007* realize the greatest percentage savings in energy use, energy costs, and carbon emissions. The states that have adopted *ASHRAE 90.1-2004* realize the greatest percentage reductions in life-cycle costs. The states that have already adopted *ASHRAE 90.1-2007* also realize percentage reductions in life-cycle costs. Two of the three states that have no state energy code realize an average percentage increase in life-cycle costs relative to *ASHRAE 90.1-1999*.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 5 years to 15 years, the number of building types that are cost-effective increases from eight to all eleven. The study period length is an important determinant of cost-effectiveness and size of the percentage changes in life-cycle costs.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, and carbon emissions. After controlling for each state's energy code, cities located in warmer climates tend to realize greater average percentage reductions in these measures.

Different building types realize different regional average percentage reductions in energy use, energy costs, and carbon emissions for a 10-year study period. High schools, 16-story office buildings, and hotels realize the smallest reductions while restaurants and 3-story office buildings realize the greatest reductions. The greatest percentage reductions in life-cycle costs are also realized by restaurants and 3- and 8-story office buildings while the only percentage increase is realized by 16-story office buildings.

The magnitude of a building type's average percentage change is not necessarily correlated with its changes in total energy use, energy costs, and energy-related carbon emissions relative to other building types. For example, high schools tend to realize some of the smallest percentage reductions, but some of the greatest total reductions in energy use, energy costs, and energy-related carbon emissions. Total reductions are driven largely by total new floor area constructed for the building type in a state. The adoption of the LEC design would lead to greater aggregate reductions in energy use in California than in Wyoming because the amount of newly constructed floor area for 2003 to 2007 was 63 higher times in California.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy rates, and carbon emissions rates. The greatest 10-year reductions in energy use per unit of floor area resulting from adoption of the LEC design are realized by the four states that have no state energy code or have adopted *ASHRAE 90.1-2001*, ranging from 333 kWh/m^2 (106 $kBtu/ft^2$) to 390 kWh/m^2 (124 $kBtu/ft^2$). The states that have adopted *ASHRAE 90.1-2004* or *-2007* realize reductions ranging from 141 kWh/m^2 (45 $kBtu/ft^2$) to 258 kWh/m^2 (82 $kBtu/ft^2$). States with the highest electricity rates tend to realize the largest reductions in energy costs per unit of energy consumption reduced. Similarly, states with higher CO_2e emission rates per unit of electricity generated tend to realize greater reductions in emissions per unit of energy consumption reduced. The greater the offset of electricity consumption reductions with natural gas consumption increases, the greater the reduction in both energy costs and carbon emissions per unit of energy consumption reduced.

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

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

1 Introduction

1.1 Background and Purpose

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

The purpose of this study is to estimate the impacts that the adoption of more stringent energy codes for commercial buildings would have on building energy use, operational energy costs, energy-related carbon emissions, and building life-cycle costs for states located in the West 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 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 Building Industry Reporting and Design for Sustainability (BIRDS) database to analyze the benefits and costs of increasing building energy efficiency for 73 cities located in the 13 states of the West 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 West 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, 73 cities across the thirteen states in the West 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.[3] 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. California has adopted the California Building Standards Code, otherwise known as Title 24, as its state energy code. Of the building designs considered in this study, the requirements in *ASHRAE 90.1-2007* most closely compare to Title 24. States that have not yet adopted a state energy code are assumed to meet *ASHRAE 90.1-1999* building energy efficiency requirements. A "Low Energy Case" design based on *ASHRAE 189.1-2009*, which goes beyond *ASHRAE 90.1-2007*, is included as an additional building design alternative.

Table 2-2 shows the variation in commercial building energy codes across the thirteen states in the West Census Region.[4] This study uses the status of state energy codes as of December 2011, at which point the BIRDS database was constructed. Three states currently do not have a statewide energy code while one state, two states, and seven states have adopted *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, and *ASHRAE 90.1-2007*, respectively. Three cities in Arizona (Flagstaff, Phoenix, and Tucson) and one city in Colorado (Grand Junction) have adopted a newer edition of *ASHRAE 90.1* than has the state in which it is located.

[3] California is assumed to have adopted *ASHRAE 90.1-2007* because California has adopted Title 24 as its state energy code, which is similar but the same as *ASHRAE 90.1-2007*.

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

Table 2-2 Energy Code by State/City for the West Census Region[5]

State	City	Zone	Code
AK	Anchorage	7	None
	Barrow	8	None
	Fairbanks	8	None
	Juneau	7	None
	Kodiak	7	None
	Nome	8	None
AZ	Flagstaff	5B	2004
	Phoenix	2B	2004
	Prescott	4B	None
	Tucson	2B	2004
	Winslow	5B	None
	Yuma	2B	None
CA	Arcata	4B	2007
	Bakersfield	3B	2007
	Daggett	3B	2007
	Fresno	3B	2007
	Long Beach	3B	2007
	Los Angeles	3B	2007
	Riverside	3B	2007
	Sacramento	3B	2007
	San Diego	3B	2007
	San Francisco	3C	2007
	Santa Maria	3C	2007
CO	Alamosa	6A	2001
	Boulder	5A	2001
	Colorado Springs	5A	2001
	Eagle	6A	2001
	Grand Junction	5A	2004
	Pueblo	5A	2001
HI	Hilo	1	2004
	Honolulu	1	2004
ID	Boise	5A	2007
	Lewiston	5A	2007
	Pocatello	6A	2007
MT	Billings	6B	2007
	Cut Bank	6B	2007
	Glasgow	6B	2007
	Great Falls	6B	2007
	Helena	6B	2007
	Kalispell	6B	2007
	Lewistown	6B	2007
	Miles City	6B	2007
	Missoula	6B	2007
NM	Albuquerque	4B	2007
	Roswell	3B	2007
	Tucumcari	4B	2007
NV	Elko	5B	2004
	Ely	5B	2004
	Las Vegas	3B	2004
	Reno	5B	2004
	Tonopah	5B	2004
	Winnemucca	5B	2004
OR	Astoria	4C	2007
	Burns	5B	2007
	Eugene	4C	2007
	Medford	4C	2007
	North Bend	4C	2007
	Pendleton	5B	2007
	Portland	4C	2007
	Redmond	5B	2007
	Salem	4C	2007
UT	Cedar City	5B	2007
	Salt Lake City	5B	2007
WA	Olympia	4C	2007
	Quillayute	4C	2007
	Seattle	4C	2007
	Spokane	5B	2007
	Yakima	5B	2007
WY	Casper	6B	None
	Cheyenne	6B	None
	Lander	6B	None
	Rock Springs	6B	None
	Sheridan	6B	None

The thirteen states, 73 cities, and 8 *ASHRAE* climate zones listed in Table 2-2 are shown in Figure 2-1. Larger states and states with more significant population centers have more cities included in the BIRDS database. For example, California has eleven cities while Utah has two cities. The climate zone(s) for each state vary across the West Census Region from *ASHRAE* Climate Zone 1 in Hawaii to Zone 7 and Zone 8 in Alaska. The entire region is located in the "dry" (B) and "marine" (C) subzones.

[5] State energy codes as of December 2011.

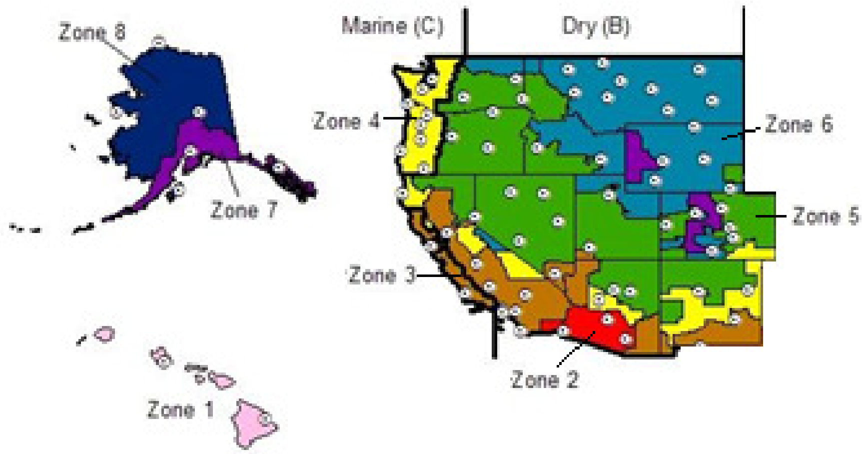


Figure 2-1 Cities and Climate Zones

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).[6] 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.

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

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

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

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

The LEC design increases the thermal efficiency of insulation and windows beyond *ASHRAE 90.1-2007*, further reduces the lighting power density, and adds daylighting and window overhangs. The lighting density of the lighting system is decreased by first increasing the efficiency of the lighting system and then decreasing the number of fixtures in the lighting system.[7] Daylighting is included for all building types and climate zones. Overhangs are placed on the east, west, and south sides of the building for each floor in Climate Zone 1 through Climate Zone 5 because these warmer climates are the zones that benefit from blocking solar radiation.[8]

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

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

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

HVAC Type	Equipment Type	Unit	ASHRAE 90.1-1999	ASHRAE 90.1-2001	ASHRAE 90.1-2004	ASHRAE 90.1-2007	Low Energy Case
Cooling	Rooftop Packaged Unit	EER	8.2 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.[10] 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*.

[10] For more detail about the ventilation requirements are see Kneifel (2011b).

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).[11] 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.

[11] 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 48.7 % of new commercial building stock floor area for 2003 through 2007 for the West 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 58.1 % of the new commercial building stock.

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

Category	Subcategory	Conditioned Floor Area 1000 m^2 (1000 ft^2)	Percentage in Category	Percentage of Total
Office	**Large**	**5261 (56 631)**	**22.2 %**	**2.9 %**
Office	**Medium**	**9574 (103 058)**	**40.4 %**	**5.3 %**
Office	**Small**	**8863 (95 405)**	**37.4 %**	**4.9 %**
Retail		**20 747 (223 319)**	**72.9 %**	**11.5 %**
Strip Mall		7713 (83 017)	27.1 %	4.3 %
School	Primary	5815 (62 593)	32.5 %	3.2 %
School	**Secondary**	**12 077 (130 001)**	**67.5 %**	**6.7 %**
Hospital		4558 (49 062)	44.1 %	2.5 %
Other Health Care		5778 (62 190)	55.9 %	3.2 %
Restaurant	**Sit Down**	**830 (8931)**	**52.9 %**	**0.5 %**
Restaurant	Fast Food	739 (7951)	47.1 %	0.4 %
Hotel	**Large**	**8030 (86 436)**	**74.2 %**	**4.4 %**
Hotel/Motel	Small	2792 (30 055)	25.8 %	1.5 %
Warehouse		25 644 (276 029)		14.2 %
Public Assembly		8835 (95 100)		4.9 %
Apartment	**High-rise**	**12 477 (134 305)**	**55.1 %**	**6.9 %**
Apartment	**Mid-rise**	**10 168 (109 443)**	**44.9 %**	**5.6 %**
No Prototype		30 821 (331 759)		17.1 %
Total (2003 to		180 722 (1 945 278)		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.[12] 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.

[12] 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.[13] 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 (GBtu) 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).[14] 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.[15]

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

[13] For states located in more than one NERC sub-region, a weighted average of emissions rates for the multiple sub-regions is implemented.

[14] Emissions rates are held constant over all study periods. A significant change in the fuel mix of electricity in an NERC subregion would impact the estimated impacts on carbon emissions.

[15] 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 Alaska

Alaska is located in the Pacific Census Division and spans two climate zones (Zone 7 and Zone 8). 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 6-1 provides an overview of Alaska's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 113 kWh/m^2 to 140 kWh/m^2 (36 kBtu/ft^2 to 44 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 448 kWh/m^2 to 480 kWh/m^2 (142 kBtu/ft^2 to 152 kBtu/ft^2) annually.

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

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

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

6.1 Percentage Savings

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

6.1.1 Energy Use

Table 6-2 shows the percentage changes in energy use for Alaska. There is minimal change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types having reductions in energy use of 0.7 % or less. There is a small decrease in energy use for 9 of 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from 0.6 % to -3.4 % with an average of -0.8 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from 4.0 % to -12.4 %, with an overall average of -4.8 %.

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

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

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

For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC in Zone 7 and Zone 8 is decreased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007*, making the requirement stricter. Buildings in colder climates benefit from additional solar heat gains. The 100 % glazing amplifies the lost heat gain from the lower SHGC, which increases natural gas consumption enough to overwhelm the energy efficiency gains obtained from other measures that decrease energy consumption, such as increased roof insulation R-values.

The LEC design realizes the greatest reductions in energy use, with the change in energy use relative to *ASHRAE 90.1-1999* ranging from -6.9 % to -33.4 % with an average of -16.7 %. Similar to the *ASHRAE 90.1-2007* design, the lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratios due to the stricter window SHGC requirement.

6.1.2 Energy Costs

Table 6-3 shows minimal change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.1 % to -1.0 %), which mirrors the energy use results described above. There is a significant variation in the percentage change in average energy costs for *ASHRAE 90.1-2004*, ranging from -5.6 % to -18.0 % depending on the building type, with an average of -12.7 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -3.2 % to -21.1 %, with an overall average of -14.3 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -14.9 % to -40.1 % with an average of -27.6 % overall.

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

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

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

6.1.3 Energy-related Carbon Emissions

Minimal changes in energy use lead to small changes (less than 1 %) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 6-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -3.6 % to -12.5 % with an average of -8.9 %. The *ASHRAE 90.1-2007* design leads to slightly greater reductions than *ASHRAE 90.1-2004*, with the average change in carbon emissions ranging from -1.0 % to -16.3 % with an overall average of -11.1 %. The LEC design leads to the greatest average carbon emissions changes, ranging from -12.9 % to -37.9 % depending on the building type with an average of -24.0 % across all building types.

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

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

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

6.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 6-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for all building types over a 10-year study period. *ASHRAE 90.1-1999* is the lowest cost building design for one building type while *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building design for two and four building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -2.6 % to 2.7 % depending on building type. The LEC design realizes a reduction in life-cycle costs for 10 of 11 building types, with the percentage change in life-cycle costs ranging from -2.4 % to 1.0 %.

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

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

6.1.5 City Comparisons

Simulations are run for 6 cities located in Alaska: Anchorage, Juneau, and Kodiak in Climate Zone 7 and Barrow, Fairbanks, and Nome in Climate Zone 8. The results vary across cities within Alaska for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

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

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

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

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

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

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

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

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

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

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

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

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

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

6.2 Total Savings

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

6.2.1 Energy Use

Table 6-10 reports the average per unit change in annual energy use by building type and building design in the state.[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 6-11 reports the estimated average annual floor area of new construction and the total annual change in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[17]

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

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

The total annual reduction in energy use ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2007*, and LEC designs all decrease overall energy use across the state. Adopting *ASHRAE 90.1-2001* results in an annual decrease of 65.0 MWh (221.9 MBtu) while adopting *ASHRAE 90.1-2007* saves 793.1 MWh (2.7 GBtu) annually. The adoption of the LEC design as the state's energy code would save energy for all building types and 5.6 GWh (19.3 GBtu) of total energy use annually

[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.

for one year's worth of new construction for these building types. The adoption of the *ASHRAE 90.1-2004* design increases total annual energy use by 106.8 MWh (365 MBtu) even though the overall average percentage change in energy use is negative for this building design. This emphasizes the importance of estimating aggregate impacts instead of relying solely on simple average percentage changes.

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

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

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

Assuming that the buildings considered in this study, which represent 56.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from LEC adoption in new commercial buildings to be 9.9 GWh (33.9 GBtu) per year. These savings imply 99.4 GWh (339 GBtu) in energy savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 1.4 GWh (4.8 GBtu) annually or 14.0 GWh (47.7 GBtu) over the 10-year study period.

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

The statewide change in energy use varies across building types within a building design. Building types that represent a greater amount of new floor area realize the largest changes in aggregate energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. For example, the building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- rank 2nd and 10th in percentage reduction, respectively, among the 11 building types, as reported in Table 6-2.

6.2.2 Energy Costs

Table 6-12 reports the average per unit change in energy costs by building type and building design. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

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

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$0.16	-$0.01	-$23.51	-$2.18	-$26.75	-$2.48	-$41.65	-$3.87
APART06	-$0.18	-$0.02	-$23.74	-$2.21	-$26.81	-$2.49	-$41.31	-$3.84
DORMI04	-$0.46	-$0.04	-$21.19	-$1.97	-$25.09	-$2.33	-$41.88	-$3.89
DORMI06	-$0.23	-$0.02	-$24.34	-$2.26	-$28.29	-$2.63	-$43.04	-$4.00
HOTEL15	-$0.57	-$0.05	-$22.32	-$2.07	-$17.41	-$1.62	-$32.41	-$3.01
HIGHS02	-$0.14	-$0.01	-$10.57	-$0.98	-$13.23	-$1.23	-$34.63	-$3.22
OFFIC03	-$0.72	-$0.07	-$9.31	-$0.87	-$12.26	-$1.14	-$32.47	-$3.02
OFFIC08	-$1.15	-$0.11	-$11.08	-$1.03	-$12.07	-$1.12	-$29.13	-$2.71
OFFIC16	-$0.80	-$0.07	-$9.78	-$0.91	-$4.16	-$0.39	-$21.37	-$1.99
RETAIL1	-$0.22	-$0.02	-$14.11	-$1.31	-$17.99	-$1.67	-$36.17	-$3.36
RSTRNT1	-$1.03	-$0.10	-$18.87	-$1.75	-$28.78	-$2.67	-$68.99	-$6.41

Table 6-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. The *ASHRAE 90.1-2001* design realizes small reductions in energy costs ($74 323). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $2.2 million, $2.4 million, and $5.5 million respectively. All the building types that realize an increase in total energy use from the adoption of the *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* designs realize a decrease in total energy costs because the increase in natural gas costs is less than the decrease in electricity costs.

Assuming that the buildings considered in this study, which represent 56.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of $130 850, $3.9 million, $4.3 million, and $9.8 million over the 10-year study period, respectively.

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

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

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

6.2.3 Energy-related Carbon Emissions

Table 6-14 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type and building design. The carbon emissions estimation approach is defined in Section 5.3.

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

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

Table 6-15 applies the Table 6-14 results to one year's worth of new building construction in the state to estimate statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs decrease carbon emissions overall. The adoption of *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in savings of 10 375 metric tons and 12 486 metric tons over a 10-year study period, respectively. All building types that realized an increase in total energy use from adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* realize a decrease in carbon emissions because the emissions resulting from the increase in natural gas consumption are less than the decrease in emissions from the reduction in electricity consumption. The adoption of LEC as the state's energy code decreases carbon emissions by 33 177 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types.

Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate statewide reductions in carbon emissions of 18 265 metric tons, 21 983 metric tons, and 58 411 metric tons over the 10-year study period, respectively.

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

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

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

6.2.4 Life-Cycle Costs

Table 6-16 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type and building design. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

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

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

Table 6-17 applies the Table 6-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. Total reductions in life-cycle costs over the 10-year study period vary across building designs. Adoption of the *ASHRAE 90.1-2001* design results in an increase in life-cycle costs for seven of nine building types. The *ASHRAE 90.1-2004* and *-2007* designs result in a decrease in life-cycle costs for six of nine building types, with total life-cycle costs decreasing by $463 949 and $815 858, respectively. The LEC design decreases life-cycle costs for eight of nine building types, and decreases total life-cycle costs by $1.3 million. The building types that realize a decrease in life-cycle costs far outweigh in terms of construction volume the building type that realizes an increase in life-cycle costs for the LEC design. For a 10-year study period, it is cost-effective to adopt newer editions of *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, or the LEC design.

Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate statewide changes in life-cycle costs of $3.8 million, -$816 812, -$1.4 million, and -$2.4 million over the 10-year study period, respectively.

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

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

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

6.3 State Summary

Alaska is one of the states that has no state energy code for commercial buildings, and is located in the coldest climates in the United States. On average, adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions at negative life-cycle costs. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy savings of 14.0 GWh (47.7 GBtu), energy cost savings of $4.3 million, and 21 983 metric tons of carbon emissions reductions while saving $1.4 million in life-cycle costs for one year's worth of commercial building construction.

However, adopting the *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* design increases energy use for some location-building type combinations in Alaska. *ASHRAE 90.1-2004* condenses the 26 climate zones defined in *ASHRAE 90.1-1999/2001* into 8 climate zones. As a result, some of the building envelope requirements (window U-factors and insulation R-values) are slightly less stringent for cities in Zone 8. Additionally, *ASHRAE 90.1-2007* restricts the window SHGC below that required in *ASHRAE 90.1-2004* for Alaska's climate zones, leading to losses in beneficial heat gain through fenestration.

The adoption of the LEC design leads to savings in total energy use and energy-related carbon emissions in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design would be even more beneficial for the state than adopting *ASHRAE 90.1-2007*, with savings of 99.4 GWh (339.4 GBtu), $9.8 million of energy costs, 58 411 metric tons of carbon emissions, and $2.4 million of life-cycle costs for one year's worth of commercial building construction.

7 Arizona

Arizona is located in the Mountain Census Division and spans four climate zones (Zone 2B, Zone 3B, Zone 4B, and Zone 5B). 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. However, it is common for cities in Arizona to adopt local energy codes for commercial buildings. Arizona is the only state in this study in which more than one city has adopted a local energy code that is two editions of *ASHRAE 90.1* beyond its assumed baseline standard edition (*ASHRAE 90.1-1999*). Table 7-1 provides an overview of Arizona's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy for the *ASHRAE 90.1-1999* design at 122 kWh/m^2 (39 kBtu/ft^2) annually. The 4-story dormitory uses the least amount of energy for the LEC design at 79 kWh/m^2 (25 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy for the *ASHRAE 90.1-1999* design at 195 kWh/m^2 (62 kBtu/ft^2) annually. The high school uses the greatest amount of energy for the LEC design at 137 kWh/m^2 (43 kBtu/ft^2) annually.

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

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	159	50	157	50	128	41	121	38	104	33
APART06	158	50	156	50	127	40	121	39	102	32
DORMI04	126	40	122	39	99	31	93	29	79	25
DORMI06	175	56	171	54	140	44	132	42	111	35
HOTEL15	145	46	143	45	120	38	119	38	101	32
HIGHS02	178	56	175	56	166	53	154	49	137	43
OFFIC03	134	43	130	41	119	38	106	34	82	26
OFFIC08	122	39	118	38	106	34	103	33	82	26
OFFIC16	143	45	141	45	130	41	133	42	109	35
RETAIL1	144	46	140	45	124	39	107	34	91	29
RSTRNT1	195	62	188	60	167	53	151	48	105	33

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.

7.1 Percentage Savings

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

7.1.1 Energy Use

Table 7-2 shows significant changes in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types realizing increases in energy use of 2.4 % to 11.1 %. Three cities in Arizona have already adopted *ASHRAE 90.1-2004* as their local energy code. As a result, adopting *ASHRAE 90.1-2001* increases energy use for each of these three cities. There is a decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from -3.5 % to -10.9 % with an average of -7.6 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -1.9 % to -19.9 %, with an overall average of -12.9 %. The smallest reduction in energy use is realized by the 16-story office building while the greatest reduction is realized by the retail store.

Table 7-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Arizona

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	11.1	-9.4	-14.3	-26.6
APART06	11.1	-9.5	-13.6	-27.1
DORMI04	9.9	-10.9	-16.4	-29.1
DORMI06	10.3	-9.8	-15.2	-28.3
HOTEL15	9.3	-8.8	-9.2	-23.1
HIGHS02	2.4	-3.5	-10.8	-21.5
OFFIC03	2.8	-6.0	-15.8	-34.7
OFFIC08	4.6	-6.7	-8.8	-28.1
OFFIC16	3.7	-4.7	-1.9	-19.6
RETAIL1	5.1	-7.1	-19.9	-31.6
RSTRNT1	4.7	-7.3	-16.1	-41.4
Average	**6.8**	**-7.6**	**-12.9**	**-28.3**

For the 16-story office building, *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC requirement in Zone 2 through Zone 5 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007* for buildings with greater than 40 % window glazing, making the requirement less strict. Buildings in warmer climates benefit from decreasing solar heat gains. The 100 % glazing amplifies the heat gain from the higher SHGC, which increases electricity 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 -19.6 % to -41.4 % with an average of -28.3 %.The lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratios. 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.

7.1.2 Energy Costs

Table 7-3 shows a significant percentage change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (3.7 % to 15.6 %), which mirrors the energy use results described above. There is a significant variation in the percentage change in average energy costs for *ASHRAE 90.1-2004*, ranging from -4.9 % to -13.3 % depending on the building type with an average of -9.3 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -0.4 % to -18.6 %, with an overall average of -12.8 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -20.5 % to -43.6 % with an average of -31.2 % overall.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	15.4	-12.0	-15.9	-31.1
APART06	15.6	-12.1	-15.3	-32.5
DORMI04	14.4	-13.3	-16.9	-32.1
DORMI06	15.0	-12.4	-16.7	-33.6
HOTEL15	14.6	-11.3	-8.9	-26.4
HIGHS02	3.8	-4.9	-11.4	-27.4
OFFIC03	3.7	-6.4	-14.1	-34.9
OFFIC08	4.7	-6.9	-7.8	-28.0
OFFIC16	5.1	-5.4	-0.4	-20.5
RETAIL1	6.6	-8.3	-18.6	-32.4
RSTRNT1	6.8	-8.7	-14.6	-43.6
Average	**9.6**	**-9.3**	**-12.8**	**-31.2**

For the *ASHRAE 90.1-2001* and *-2004* designs, the average percentage change in energy costs is greater than the change in energy use for all building types because the percentage change in electricity consumption is greater than the change in natural gas consumption. Electricity is more expensive than natural gas on a per unit of energy basis, which increases the percentage change in energy costs. For 6 of 11 building types, the average percentage reduction in energy costs is less than the reduction in energy use from adopting the *ASHRAE 90.1-2007* design because the percentage reduction in electricity consumption is less than the reduction in natural gas consumption. For the LEC design, the average reductions in energy costs are greater than the reductions in energy use for 10 of 11 building types because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. For 7 of the 11 building types, adopting the LEC design increases natural gas consumption while decreasing electricity consumption. The buildings use electricity for all energy consumption except for the heating component of the HVAC system, which uses natural gas. The energy efficiency measures adopted lead to a decrease in energy use for both lighting and cooling the building, but an increase in heating loads. Since electricity is more expensive than natural gas on a per unit of energy basis, the shift in energy use from cooling to heating magnifies the decrease in energy costs for the building.

7.1.3 Energy-related Carbon Emissions

The significant increases in energy use lead to percentage increases (3.9 % to 16.9 %) in cradle-to-grave energy-related carbon emissions from adopting the *ASHRAE 90.1-2001* design across all building types. Table 7-4 shows a significant decrease in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, with changes ranging from -5.3 % to -13.9 % with an average of -9.7 %. 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 0.0 % to -18.3 % with an overall average of -12.8 %. The LEC design leads to the greatest average changes in carbon emissions, ranging from -20.8 % to -44.2 % depending on the building type with an average of -31.9 % across all building types.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	16.8	-12.7	-16.3	-32.4
APART06	16.9	-12.7	-15.7	-34.0
DORMI04	15.6	-13.9	-17.0	-32.9
DORMI06	16.4	-13.0	-17.1	-35.1
HOTEL15	16.2	-12.0	-8.8	-27.3
HIGHS02	4.2	-5.3	-11.6	-29.2
OFFIC03	3.9	-6.5	-13.7	-35.0
OFFIC08	4.8	-7.0	-7.6	-28.0
OFFIC16	5.5	-5.5	0.0	-20.8
RETAIL1	7.0	-8.5	-18.3	-32.6
RSTRNT1	7.3	-9.1	-14.2	-44.2
Average	**10.4**	**-9.7**	**-12.8**	**-31.9**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, the percentage changes in carbon emissions are greater than the percentage changes in energy use for all building types from adopting *ASHRAE 90.1-2001* and *-2004* and 10 of 11 building types for the LEC design because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. Meanwhile, 6 of 11 building types realize smaller reductions in carbon emissions than reductions in energy use from adopting *ASHRAE 90.1-2007*. The reduction in electricity relative to natural gas consumption drives these results because electricity has a higher carbon emissions rate per unit of energy than natural gas in Arizona.

7.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 7-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for all 11 building types over a 10-year study period. The current state energy code is never the lowest cost option. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building designs for two building types each. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* ranges from -2.2 % to 3.0 % depending on the building type. The LEC design is the lowest cost building design for seven building types, with the percentage change in life-cycle costs ranging from -5.2 % to -0.0 %. Given that all building types realize a reduction in life-cycle costs, the LEC design is cost-effective for the state to adopt as its state energy code for commercial buildings.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	1.4	-1.3	**-1.8**	-1.6
APART06	1.4	-1.3	**-1.7**	-1.7
DORMI04	5.1	0.8	-0.1	**-1.6**
DORMI06	1.5	-1.6	-2.2	**-2.4**
HOTEL15	1.6	**-1.5**	-1.3	-1.0
HIGHS02	0.8	-0.3	-1.5	**-2.8**
OFFIC03	4.7	2.4	0.6	**-3.1**
OFFIC08	5.2	2.3	1.4	**-2.3**
OFFIC16	0.7	**-0.6**	-0.0	-0.0
RETAIL1	3.5	0.4	-1.7	**-1.8**
RSTRNT1	6.2	3.0	0.8	**-5.2**
Average	**2.9**	**0.2**	**-0.7**	**-2.1**

7.1.5 City Comparisons

Simulations are run for six cities located in Arizona: Phoenix, Tucson, and Yuma in Climate Zone 2B, Prescott in Zone 4B, and Flagstaff and Winslow in Climate Zone 5B.

There are no significant population centers in the counties of Arizona located in Zone 3B. The results may vary across cities within Arizona for four reasons. First, the cities in the state selected for this study cover 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. Finally, three cities have adopted a stricter building energy code than the state (Flagstaff, Phoenix, and Tucson).

As can be seen in Table 7-6, average reductions in energy use for all building types from adopting newer energy standard editions vary across and within climate zones. The variation within climate zones is a result of variation in local energy codes. The cities with no local energy code realize greater percentage reductions in energy use. Consider the adoption of *ASHRAE 90.1-2007* for the three cities in Zone 2B. The two cities that have adopted ASHRAE 90.1-2004 as their local energy code realize an average reduction of 8.7 % while the city that has no local energy code realizes a reduction of 24.2 %. After controlling for local energy codes, cities in warmer climate zones realize greater percentage reductions in energy use.

Table 7-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Arizona

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Phoenix	2B	17.3	0.0	-8.6	-26.5
Tucson	2B	19.9	0.0	-8.7	-26.3
Yuma	2B	-3.3	-17.9	-24.2	-39.2
Prescott	4B	-1.6	-13.8	-16.1	-31.0
Flagstaff	5B	10.4	0.0	-3.7	-16.2
Winslow	5B	-1.7	-14.1	-16.2	-30.4
Average		**6.8**	**-7.6**	**-12.9**	**-28.3**

The variation in energy costs across cities is a result of three factors, the reduction in energy use, the fuel source of the reduction, and the local energy code. Table 7-7 shows that the cities that have adopted *ASHRAE 90.1-2004* as their local energy code realize the smallest reductions in energy costs. The climate zone with the greatest reduction in energy use realizes the greatest reduction in energy costs for each of the building designs. Two of the six cities (Prescott and Winslow) realize larger percentage reductions in energy costs than percentage reductions in energy use for all building designs because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Since electricity is more expensive than natural gas on a per unit basis, greater relative reduction in electricity leads to additional reductions in energy costs. The other four cities realize lower reductions in energy costs than reductions in energy use for the *ASHRAE 90.1-2007* design because the percentage reduction in electricity consumption is less than the reduction in natural gas consumption.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Phoenix	2B	19.8	0.0	-6.7	-26.5
Tucson	2B	24.2	0.0	-5.9	-26.3
Yuma	2B	-3.4	-18.9	-24.1	-39.9
Prescott	4B	-1.8	-18.4	-19.2	-37.2
Flagstaff	5B	20.7	0.0	-1.8	-20.6
Winslow	5B	-1.9	-18.2	-19.1	-36.4
Average		**9.6**	**-9.3**	**-12.8**	**-31.2**

Table 7-8 reports changes in energy-related carbon emissions by city for Arizona. For all cities, the more stringent standard editions result in greater reductions in carbon emissions. Prescott and Winslow realize greater reductions in carbon emissions than reductions in energy use for all building designs. Meanwhile, the other four cities realize smaller reductions in carbon emissions than energy use for the *ASHRAE 90.1-2007* and LEC designs.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Phoenix	2B	19.5	0.0	-7.1	-27.5
Tucson	2B	24.0	0.0	-6.0	-27.2
Yuma	2B	-3.1	-18.2	-24.1	-40.3
Prescott	4B	-1.6	-18.7	-19.6	-38.7
Flagstaff	5B	22.9	0.0	-1.6	-22.5
Winslow	5B	-1.7	-18.5	-19.5	-37.9
Average		**10.0**	**-9.2**	**-13.0**	**-32.3**

The data reported in Table 7-9 show that, over a 10-year period, average life-cycle costs increase for all cities for the *ASHRAE 90.1-2001* design compared to the local energy code. For the three cities with no local energy code, adopting the *ASHRAE 90.1-2004* design leads to a percentage increase in life-cycle costs. The additional energy efficiency measures increase construction costs and overwhelm lower future energy costs. Adoption of the *ASHRAE 90.1-2007* design results in average reductions in life-cycle costs for four of the six cities. Adoption of the LEC design realizes the greatest average percentage reductions in life-cycle costs for all cities in all climate zones. For the LEC design, buildings in warmer climate zones realize greater percentage reductions in life-cycle costs.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Phoenix	2B	2.6	0.0	-1.5	**-3.0**
Tucson	2B	2.8	0.0	-1.3	**-2.5**
Yuma	2B	3.2	0.4	-1.1	**-2.9**
Prescott	4B	3.1	0.4	0.1	**-1.5**
Flagstaff	5B	2.7	0.0	-0.3	**-1.3**
Winslow	5B	3.1	0.4	0.0	**-1.6**
Average		**2.9**	**0.2**	**-0.7**	**-2.1**

7.2 Total Savings

How much can Arizona 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 7-10 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 7-11 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]

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

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

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	13.8	4.4	-15.1	-4.8	-22.0	-7.0	-39.4	-12.5
APART06	13.8	4.4	-15.2	-4.8	-20.9	-6.6	-40.0	-12.7
DORMI04	9.3	3.0	-13.8	-4.4	-19.8	-6.3	-34.0	-10.8
DORMI06	13.8	4.4	-17.4	-5.5	-25.7	-8.2	-46.2	-14.7
HOTEL15	11.0	3.5	-12.6	-4.0	-12.7	-4.0	-31.0	-9.8
HIGHS02	3.4	1.1	-8.0	-2.5	-21.0	-6.7	-44.9	-14.2
OFFIC03	3.1	1.0	-6.1	-1.9	-17.9	-5.7	-35.0	-11.1
OFFIC08	4.4	1.4	-8.3	-2.6	-10.6	-3.4	-32.5	-10.3
OFFIC16	4.8	1.5	-6.7	-2.1	-2.8	-0.9	-26.9	-8.5
RETAIL1	6.2	2.0	-10.2	-3.2	-27.4	-8.7	-43.1	-13.7
RSTRNT1	7.5	2.4	-14.3	-4.5	-30.0	-9.5	-75.5	-23.9

The annual reduction in energy use, shown in Table 7-11, ranges widely across building designs, with *ASHRAE 90.1-2001* increasing overall energy use and the other building designs decreasing energy use across the state relative to the current state and local codes. Adopting the *ASHRAE 90.1-2001* design increases total annual energy use for the state because the increases in energy use for the cities that have already adopted *ASHRAE 90.1-2004* as their local energy code overwhelm the energy use reductions from the three cities with no local energy code. Adopting the *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* designs result in annual decreases of 25.6 GWh (87.6 GBtu) and 54.0 GWh (184.5 GBtu), respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 106.1 GWh (362.1 GBtu) of total energy use annually for one year's worth of new construction for these building types.

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

Building Type	Subcat. Weight.	m^2 (1000s)	ft^2 (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	94	1009	1292	4410	-1413	-4825	-2063	-7043	-3696	-12 620
APART06	55.1 %	115	1236	1588	5421	-1741	-5944	-2399	-8191	-4588	-15 665
HOTEL15	100.0 %	209	2254	2306	7873	-2632	-8987	-2660	-9083	-6488	-22 154
HIGHS02	100.0 %	459	4938	1550	5292	-2807	-9585	-8196	-27 984	-16 060	-54 836
OFFIC03	37.4 %	302	3248	923	3151	-2408	-8221	-6351	-21 684	-13 540	-46 231
OFFIC08	40.4 %	325	3502	1444	4931	-2693	-9194	-3438	-11 738	-10 571	-36 095
OFFIC16	22.2 %	179	1927	860	2935	-1202	-4105	-493	-1685	-4819	-16 453
RETAIL1	100.0 %	978	10 529	6026	20 575	-9978	-34 070	-26 805	-91 525	-42 206	-144 110
RSTRNT1	100.0 %	54	584	407	1389	-774	-2644	-1627	-5554	-4093	-13 977
Total		**2715**	**29 227**	**16 394**	**55 978**	**-25 649**	**-87 575**	**-54 032**	**-184 487**	**-106 062**	**-362 141**

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 57.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from adopting the LEC design in new commercial buildings to be 185.7 GWh (634.2 GBtu) per year. These savings imply 1.9 TWh (6.3 TBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 94.6 GWh (323.1 GBtu) annually or 946.3 GWh (3230.9 GBtu) over the 10-year study period.

The relative statewide changes in energy use across the 9 building types with reported floor area data vary across and within the *ASHRAE 90.1-2001*, *-2004*, *-2007*, and LEC designs. For the *ASHRAE 90.1-2007* and LEC designs, building types that represent the greatest amount of new floor area realize the largest changes in aggregate energy use, with retail stores and high schools realizing the greatest total reductions in energy use and accounting for 36.0 % and 16.9 %, respectively, of the combined new construction in the state for the building types in this study. All other building types represent 12.0 % or less of new construction. The amount of new construction overwhelms the relative percentage changes in energy use, with the retail store and high school ranked 3rd and 10th in percentage reduction, respectively, among the 11 building types for the LEC design as reported in Table 7-2.

7.2.2 Energy Costs

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

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

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	$12.23	$1.14	-$12.83	-$1.19	-$16.43	-$1.53	-$30.50	-$2.83
APART06	$12.31	$1.14	-$12.87	-$1.20	-$15.87	-$1.47	-$31.80	-$2.95
DORMI04	$8.75	$0.81	-$11.53	-$1.07	-$14.22	-$1.32	-$25.36	-$2.36
DORMI06	$12.64	$1.17	-$14.71	-$1.37	-$19.24	-$1.79	-$36.24	-$3.37
HOTEL15	$10.52	$0.98	-$10.78	-$1.00	-$8.72	-$0.81	-$23.24	-$2.16
HIGHS02	$2.70	$0.25	-$6.04	-$0.56	-$13.56	-$1.26	-$31.76	-$2.95
OFFIC03	$3.66	$0.34	-$5.37	-$0.50	-$12.11	-$1.12	-$28.62	-$2.66
OFFIC08	$3.24	$0.30	-$6.11	-$0.57	-$6.85	-$0.64	-$23.22	-$2.16
OFFIC16	$4.37	$0.41	-$5.29	-$0.49	-$0.66	-$0.06	-$19.41	-$1.80
RETAIL1	$5.25	$0.49	-$8.03	-$0.75	-$17.71	-$1.65	-$30.07	-$2.79
RSTRNT1	$6.87	$0.64	-$11.54	-$1.07	-$18.48	-$1.72	-$53.03	-$4.93

Table 7-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. The *ASHRAE 90.1-2001* design realizes increases in energy costs of $14.6 million. *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $20.6 million, $35.5 million, and $77.4 million respectively.

Assuming that the buildings considered in this study, which represent 57.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide changes in energy costs of $25.6 million, -$36.1 million, -$62.2 million, and -$135.6 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	**2004**	**2007**	**LEC**
APART04	44.9 %	94	1009	$1 146 574	-$1 202 456	-$1 540 419	-$2 859 098
APART06	55.1 %	115	1236	$1 413 648	-$1 477 542	-$1 821 540	-$3 651 187
HOTEL15	100.0 %	209	2254	$2 202 478	-$2 258 356	-$1 826 482	-$4 866 383
HIGHS02	100.0 %	459	4938	$1 678 824	-$2 463 183	-$5 555 403	-$13 131 758
OFFIC03	37.4 %	302	3248	$814 701	-$1 822 865	-$4 091 443	-$9 581 207
OFFIC08	40.4 %	325	3502	$1 053 827	-$1 989 078	-$2 227 792	-$7 553 979
OFFIC16	22.2 %	179	1927	$781 816	-$947 012	-$118 028	-$3 474 105
RETAIL1	100.0 %	978	10 529	$5 140 291	-$7 852 851	-$17 328 555	-$29 417 748
RSTRNT1	100.0 %	54	584	$372 720	-$625 865	-$1 002 068	-$2 874 925
Total		**2715**	**29 227**	**$14 604 878**	**-$20 639 206**	**-$35 511 728**	**-$77 410 390**

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

7.2.3 Energy-related Carbon Emissions

Table 7-14 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type and building design. The carbon emissions estimation approach is defined in Section 5.3.

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

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	137.4	28.1	-143.0	-29.3	-178.6	-36.6	-333.9	-68.4
APART06	138.4	28.3	-143.4	-29.4	-173.0	-35.4	-350.1	-71.7
DORMI04	99.1	20.3	-128.1	-26.2	-153.2	-31.4	-275.5	-56.4
DORMI06	142.6	29.2	-163.7	-33.5	-209.1	-42.8	-397.8	-81.5
HOTEL15	119.5	24.5	-120.4	-24.7	-93.0	-19.0	-252.7	-51.8
HIGHS02	42.4	8.7	-60.2	-12.3	-128.7	-26.4	-316.7	-64.9
OFFIC03	30.3	6.2	-65.8	-13.5	-142.4	-29.2	-341.0	-69.8
OFFIC08	35.0	7.2	-66.3	-13.6	-72.0	-14.7	-249.8	-51.2
OFFIC16	49.3	10.1	-58.1	-11.9	-3.9	-0.8	-209.2	-42.9
RETAIL1	58.6	12.0	-88.2	-18.1	-186.1	-38.1	-321.8	-65.9
RSTRNT1	77.6	15.9	-127.4	-26.1	-191.8	-39.3	-568.4	-116.4

Table 7-15 applies the Table 7-14 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 90.1-2004*, *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 227 670 metric tons and 374 667 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 836 915 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 341 335 metric tons, 561 719 metric tons, and 1.3 million metric tons over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2001	2004	2007	LEC
APART04	44.9 %	94	1009	12 878	-13 404	-16 736	-31 292
APART06	55.1 %	115	1236	15 885	-16 463	-19 860	-40 189
HOTEL15	100.0 %	209	2254	25 038	-25 212	-19 475	-52 921
HIGHS02	100.0 %	459	4938	19 444	-27 609	-59 055	-145 302
OFFIC03	37.4 %	302	3248	9141	-19 862	-42 950	-102 875
OFFIC08	40.4 %	325	3502	11 393	-21 561	-23 421	-81 288
OFFIC16	22.2 %	179	1927	8817	-10 403	-704	-37 459
RETAIL1	100.0 %	978	10 529	57 326	-86 246	-182 067	-314 772
RSTRNT1	100.0 %	54	584	4208	-6910	-10 397	-30 816
Total		**2715**	**29 227**	**164 131**	**-227 670**	**-374 667**	**-836 915**

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

7.2.4 Life-Cycle Costs

Table 7-16 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type and building design. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

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

Building Type	Standard Edition 2001 $/m²	2001 $/ft²	2004 $/m²	2004 $/ft²	2007 $/m²	2007 $/ft²	LEC $/m²	LEC $/ft²
APART04	$12.96	$1.20	-$12.42	-$1.15	-$17.22	-$1.60	-$15.53	-$1.44
APART06	$12.77	$1.19	-$12.77	-$1.19	-$16.56	-$1.54	-$16.36	-$1.52
DORMI04	$46.77	$4.34	$7.56	$0.70	-$1.60	-$0.15	-$14.68	-$1.36
DORMI06	$14.86	$1.38	-$16.51	-$1.53	-$21.54	-$2.00	-$24.36	-$2.26
HOTEL15	$14.46	$1.34	-$13.75	-$1.28	-$11.79	-$1.10	-$9.91	-$0.92
HIGHS02	$6.28	$0.58	-$2.49	-$0.23	-$11.97	-$1.11	-$21.85	-$2.03
OFFIC03	$37.21	$3.46	$19.44	$1.81	$3.61	$0.34	-$25.83	-$2.40
OFFIC08	$41.79	$3.88	$18.18	$1.69	$10.92	$1.01	-$19.33	-$1.80
OFFIC16	$5.40	$0.50	-$4.75	-$0.44	-$0.29	-$0.03	-$0.31	-$0.03
RETAIL1	$22.85	$2.12	$2.72	$0.25	-$11.49	-$1.07	-$12.12	-$1.13
RSTRNT1	$79.36	$7.37	$38.47	$3.57	$9.58	$0.89	-$68.94	-$6.41

Table 7-17 applies the Table 7-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient 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 all 9 building types and increases total life-cycle costs by $61.0 million. Adopting the *ASHRAE 90.1-2004* design results in a decrease in life-cycle costs for 5 of 9 building types, and increases total life-cycle costs by $9.0 million. Adopting the *ASHRAE 90.1-2007* design results in a decrease in life-cycle costs for 6 of 9 building types, and decreases total life-cycle costs by $17.6 million. The LEC design decreases life-cycle costs for all 9 building types, and decreases total life-cycle costs by $45.2 million. For a 10-year study period, it is cost-effective to adopt the *ASHRAE 90.1-2007* and LEC designs as Arizona's state energy code for commercial buildings. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the adoption of the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC design can be extrapolated to estimate statewide changes in life-cycle costs of $106.9 million, $15.8 million, -$30.8 million, and -$79.1 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	94	1009	$1 215 168	-$1 164 373	-$1 613 730	-$1 455 445
APART06	55.1 %	115	1236	$1 465 974	-$1 466 162	-$1 900 827	-$1 878 440
HOTEL15	100.0 %	209	2254	$3 027 829	-$2 879 901	-$2 469 988	-$2 075 366
HIGHS02	100.0 %	459	4938	$2 881 704	-$1 142 843	-$5 490 030	-$10 024 851
OFFIC03	37.4 %	302	3248	$11 225 261	$5 864 154	$1 090 044	-$7 792 153
OFFIC08	40.4 %	325	3502	$13 597 461	$5 915 708	$3 552 387	-$6 290 184
OFFIC16	22.2 %	179	1927	$966 273	-$849 565	-$52 104	-$56 141
RETAIL1	100.0 %	978	10 529	$22 350 562	$2 656 358	-$11 242 130	-$11 859 954
RSTRNT1	100.0 %	54	584	$4 302 906	$2 085 725	$519 321	-$3 738 021
Total		**2715**	**29 227**	**$61 033 138**	**$9 019 100**	**-$17 607 057**	**-$45 170 554**

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

7.3 State Summary

Arizona is one of three states in the West Census Region that have not yet adopted a state energy code for commercial buildings. The impacts on individual cities of adopting a state energy code vary significantly across cities in the state because some cities have adopted local energy codes. On average, adopting *ASHRAE 90.1-2004* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions, but not in a life-cycle cost-effective manner over 10 years. Adopting *ASHRAE 90.1-2007* leads to greater reductions than adopting *ASHRAE 90.1-2004* while decreasing life-cycle costs. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 946.3 GWh (3230.9 GBtu), energy cost savings of $62.2 million, and carbon emissions reductions of 561 719 metric tons while decreasing life-cycle costs by $30.8 million for one year's worth of commercial building construction. The adoption of the LEC design leads to even greater savings of 1.9 TWh (6.3 TBtu) of energy use, $135.6 million of energy costs, 1.3 million metric tons of carbon emissions, and $79.1 million of life-cycle costs for one year's worth of commercial building construction.

8 California

California has adopted the California Building Standards Code, otherwise known as Title 24. California's state energy code for commercial buildings is assumed to be *ASHRAE 90.1-2007* for this study because it is the edition of *ASHRAE 90.1* that most closely correlates to the requirements in Title 24. California is located in the Pacific Census Division, and spans five climate zones and seven subzones (Zone 2B, Zone 3B, Zone 3C, Zone 4B, Zone 4C, Zone 5B, and Zone 6B). Simulations are run for cities in Zone 3B, Zone 3C, and Zone 4C, which are the subzones that cover most of the state and contain the most significant population centers in California. Table 8-1 provides an overview of California's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 4-story dormitory uses the least amount of energy at 59 kWh/m^2 to 71 kWh/m^2 (19 kBtu/ft^2 to 23 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy for the *ASHRAE 90.1-1999* design at 125 kWh/m^2 (40 kBtu/ft^2) annually. The high school uses the greatest amount of energy for the LEC design at 108 kWh/m^2 (34 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	96	31	81	26
APART06	97	31	79	25
DORMI04	71	23	59	19
DORMI06	105	33	86	27
HOTEL15	98	31	81	26
HIGHS02	124	39	108	34
OFFIC03	92	29	69	22
OFFIC08	92	29	73	23
OFFIC16	115	36	92	29
RETAIL1	92	29	77	24
RSTRNT1	125	40	83	26

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

8.1 Percentage Savings

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

8.1.1 Statewide Building Comparison

Table 8-2 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, ranging from -13.7 % to -34.1 % depending on the building type with an overall average of -19.8 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

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

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-16.1	-22.5	-19.8	0.2
APART06	-18.2	-26.1	-22.8	-0.1
DORMI04	-18.2	-22.3	-20.6	-1.3
DORMI06	-17.9	-26.3	-22.7	-0.4
HOTEL15	-18.2	-24.5	-21.8	0.0
HIGHS02	-13.7	-23.4	-19.2	-1.8
OFFIC03	-24.5	-25.5	-25.1	-3.0
OFFIC08	-21.4	-21.9	-21.8	-2.8
OFFIC16	-19.8	-21.8	-21.0	-0.1
RETAIL1	-16.1	-17.8	-17.1	-0.0
RSTRNT1	-34.1	-37.5	-36.2	-5.2
Average	**-19.8**	**-24.5**	**-22.6**	**-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 -17.8 % to -37.5 % depending on the building type with an average of -24.5 % 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, adopting the LEC design leads to an increase in natural gas consumption and a decrease in electricity consumption for all 11 building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 34.4 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 1.7 times the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 2 through 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 -17.1 % to -36.2 % with an average of -22.6 %. 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 -5.2 % to 0.2 % for a 10-year study period. Nine of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -1.3 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

8.1.2 City Comparisons

Simulations are run for eleven cities located in California: Bakersfield, Daggett, Fresno, Long Beach, Los Angeles, Riverside, Sacramento, and San Diego in Zone 3B, San Francisco and Santa Maria in Zone 3C, and Arcata in Zone 4B. There are no significant population centers in the counties of California located in Zone 2B, Zone 3B, Zone 5B, and Zone 6B. The results vary across cities within the state for several reasons. First, the cities in the state selected for this study cover three climate subzones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 8-3 shows the percentage changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design vary across cities, ranging from -14.3 % to -24.4 % with an overall average of -19.8 %. There is significant variation across climate subzones, with cities in Zone 3B realizing greater average percentage reductions in energy use (21.1 %) compared to Zone 3C (17.5 %) and Zone 4B (14.3 %). There is also significant variation between cities within Zone 3B, ranging from 17.7 % to 25.1 %. The further north and inland a city is located, the smaller the percentage reduction in energy use.

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

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Bakersfield	3B	-19.1	-22.8	-21.6	-1.4
Daggett	3B	-20.1	-23.0	-22.1	-1.4
Fresno	3B	-18.1	-23.0	-21.2	-1.6
Long Beach	3B	-23.8	-25.9	-25.4	-1.4
Los Angeles	3B	-24.4	-26.5	-26.0	-1.6
Riverside	3B	-20.7	-24.8	-23.4	-1.8
Sacramento	3B	-17.7	-23.4	-21.2	-1.4
San Diego	3B	-25.1	-26.3	-26.1	-1.4
San Francisco	3C	-17.2	-24.6	-21.4	-0.3
Santa Maria	3C	-17.8	-25.4	-22.2	-0.9
Arcata	4B	-14.3	-23.9	-19.4	-1.2
Average		**-19.8**	**-24.5**	**-22.7**	**-1.3**

The average percentage change in energy costs for all building types also varies across cities, ranging from -22.8 % to -26.5 % 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 across cities, ranging from -19.4 % to -26.1 %. Changes in life-cycle costs for all building types vary across cities, with the percentage change in life-cycle costs ranging from -1.8 % to -0.3 %. Cities located in Zone 3B realize the greatest percentage reductions in life-cycle costs while cities in Zone 3C realize the smallest percentage reductions.

8.2 Total Savings

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

8.2.1 Energy Use

Table 8-4 reports the average per unit change in annual energy use by building type and building design in the state.[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 8-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[21]

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

Building Type	Standard Edition	
	LEC	
	kWh/m²	kBtu/ft²
APART04	-15.4	-4.9
APART06	-17.6	-5.6
DORMI04	-12.9	-4.1
DORMI06	-18.5	-5.9
HOTEL15	-17.5	-5.6
HIGHS02	-22.4	-7.1
OFFIC03	-16.0	-5.1
OFFIC08	-19.8	-6.3
OFFIC16	-22.6	-7.2
RETAIL1	-14.9	-4.7
RSTRNT1	-42.5	-13.5

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 141.7 GWh (483.7 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 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 254.3 GWh (868.4 GBtu) per year. These savings imply 2.5 TWh (8.7 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. The greatest total reductions are realized by retail stores and high schools because they represent 26.3 % and 17.6 %, respectively, of the combined new construction in the state for the building types in this study while all other building

[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.

types represent 13.3 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 10th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 8-2.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	877	9445	-13 551 088	-46 269 240
APART06	55.1 %	1075	11 569	-18 892 097	-64 505 744
HOTEL15	100.0 %	626	6736	-10 971 677	-37 462 024
HIGHS02	100.0 %	1417	15 252	-22 659 386	-77 368 888
OFFIC03	37.4 %	690	7428	-15 485 457	-52 874 008
OFFIC08	40.4 %	744	8010	-14 719 305	-50 258 035
OFFIC16	22.2 %	409	4407	-9 264 539	-31 633 118
RETAIL1	100.0 %	2125	22 869	-31 580 788	-107 830 389
RSTRNT1	100.0 %	107	1149	-4 534 187	-15 481 663
Total		**8070**	**86 866**	**-141 658 523**	**-483 683 109**

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

8.2.2 Energy Costs

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

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

Building Type	Standard Edition LEC	
	$/m²	$/ft²
APART04	-$19.20	-$1.78
APART06	-$22.50	-$2.09
DORMI04	-$14.88	-$1.38
DORMI06	-$24.01	-$2.23
HOTEL15	-$20.78	-$1.93
HIGHS02	-$24.14	-$2.24
OFFIC03	-$24.20	-$2.25
OFFIC08	-$21.18	-$1.97
OFFIC16	-$24.75	-$2.30
RETAIL1	-$16.25	-$1.51
RSTRNT1	-$45.36	-$4.21

Table 8-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $170.2 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 $305.6 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC
APART04	44.9 %	877	9445	-$16 848 968
APART06	55.1 %	1075	11 569	-$24 182 352
HOTEL15	100.0 %	626	6736	-$13 002 075
HIGHS02	100.0 %	1417	15 252	-$34 288 714
OFFIC03	37.4 %	690	7428	-$16 656 170
OFFIC08	40.4 %	744	8010	-$15 759 279
OFFIC16	22.2 %	409	4407	-$10 132 012
RETAIL1	100.0 %	2125	22 869	-$34 518 887
RSTRNT1	100.0 %	107	1149	-$4 843 949
Total		**8070**	**86 866**	**-$170 232 407**

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

8.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-85.2	-17.5
APART06	-98.9	-20.3
DORMI04	-67.7	-13.9
DORMI06	-105.1	-21.5
HOTEL15	-93.7	-19.2
HIGHS02	-101.1	-20.7
OFFIC03	-112.6	-23.1
OFFIC08	-99.0	-20.3
OFFIC16	-114.8	-23.5
RETAIL1	-75.4	-15.4
RSTRNT1	-212.2	-43.5

Table 8-9 applies the Table 8-8 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 764 202 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 1.4 million metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	877	9445	-74 788
APART06	55.1 %	1075	11 569	-106 330
HOTEL15	100.0 %	626	6736	-58 644
HIGHS02	100.0 %	1417	15 252	-143 296
OFFIC03	37.4 %	690	7428	-77 714
OFFIC08	40.4 %	744	8010	-73 652
OFFIC16	22.2 %	409	4407	-46 992
RETAIL1	100.0 %	2125	22 869	-160 131
RSTRNT1	100.0 %	107	1149	-22 656
Total		**8070**	**86 866**	**-764 202**

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

8.2.4 Life-Cycle Costs

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

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

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$2.70	$0.25
APART06	-$0.56	-$0.05
DORMI04	-$14.00	-$1.30
DORMI06	-$4.84	-$0.45
HOTEL15	$0.37	$0.03
HIGHS02	-$16.50	-$1.53
OFFIC03	-$27.64	-$2.57
OFFIC08	-$27.10	-$2.52
OFFIC16	-$1.01	-$0.09
RETAIL1	-$0.15	-$0.01
RSTRNT1	-$77.09	-$7.16

Table 8-11 applies the Table 8-10 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 7 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $69.6 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 ($23.4 million, $20.2 million, and $19.1 million, respectively) while 4-story apartment buildings and hotels realize an increase in life-cycle costs ($2.4 million and $231 526, 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 $124.9 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	877	9445	$2 372 624
APART06	55.1 %	1075	11 569	-$598 745
HOTEL15	100.0 %	626	6736	$231 526
HIGHS02	100.0 %	1417	15 252	-$23 376 695
OFFIC03	37.4 %	690	7428	-$19 075 494
OFFIC08	40.4 %	744	8010	-$20 170 590
OFFIC16	22.2 %	409	4407	-$415 565
RETAIL1	100.0 %	2125	22 869	-$320 656
RSTRNT1	100.0 %	107	1149	-$8 231 538
Total		**8070**	**86 866**	**-$69 585 133**

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

8.3 State Summary

ASHRAE 90.1-2007 is used to represent California's state energy code for commercial buildings (Title 24). 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 2.5 TWh (8.7 TBtu), energy cost savings of $305.6 million, and carbon emissions reductions of 1.4 million metric tons while decreasing life-cycle costs by $124.9 million for one year's worth of commercial building construction.

9 Colorado

Colorado is the only state in the West Census Region that has adopted *ASHRAE 90.1-2001* as its state energy code for commercial buildings, is located in the Mountain Census Division, and spans four climate zones (Zone 4B, Zone 5B, Zone 6B, and Zone 7). Table 9-1 provides an overview of Colorado's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 80 kWh/m^2 to 113 kWh/m^2 (25 $kBtu/ft^2$ to 36 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 203 kWh/m^2 to 228 kWh/m^2 (65 $kBtu/ft^2$ to 72 $kBtu/ ft^2$) annually.

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

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	163	52	145	46	139	44	124	39
APART06	160	51	141	45	136	43	121	38
DORMI04	128	41	114	36	108	34	93	30
DORMI06	175	56	156	50	153	49	136	43
HOTEL15	158	50	142	45	149	47	130	41
HIGHS02	228	72	224	71	216	69	203	65
OFFIC03	120	38	112	35	105	33	84	27
OFFIC08	113	36	103	33	99	31	80	25
OFFIC16	149	47	139	44	148	47	124	39
RETAIL1	145	46	134	42	119	38	102	32
RSTRNT1	201	64	185	59	161	51	118	37

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

9.1 Percentage Savings

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

9.1.1 Energy Use

Table 9-2 shows that the average percentage changes in energy use from adopting the *ASHRAE 90.1-2004* design relative to *ASHRAE 90.1-2001* range from -1.4 % to -9.1 % depending on the building type, with an overall average of -6.9 %. The average percentage change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from 0.3 % to -18.6 %, with an overall average of -10.4 %.

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

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

For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum allowable window SHGC in Zone 5 and Zone 6 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007* for buildings with fenestration accounting for greater than 40 % of total wall surface area. The 100 % glazing amplifies the impact of this requirement relaxation enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

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

9.1.2 Energy Costs

Table 9-3 shows a significant variation in the average change in energy costs over 10 years of operation from adopting the *ASHRAE 90.1-2004* design relative to *ASHRAE 90.1-2001*, ranging from -6.3 % to -19.8 % depending on the building type, with an overall average of -14.1 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -2.4 % to -22.0 %, with an overall average of -15.2 %. As with energy use savings, adopting *ASHRAE 90.1-2004* results in greater reductions in energy costs than adopting *ASHRAE 90.1-2007* for the two high rise buildings (16-story office building and 15-story hotel) because of the 100 % glazing in the buildings and the relaxed window SHGC requirements.

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

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

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

9.1.3 Energy-related Carbon Emissions

Table 9-4 shows significant changes in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -7.0 % to -21.1 % with an average of -15.0 % overall. The average change in carbon emissions from constructing buildings using *ASHRAE 90.1-2007* requirements is -15.8 % overall with the average change in carbon emissions varying across building types from -2.7 % to -23.1 %. The LEC design leads to the greatest average percentage changes in carbon emissions, ranging from -21.7 % to -47.0 % depending on the building type with an overall average of -33.8 % across all building types.

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

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

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

9.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 9-5. The *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs realize the lowest life-cycle costs for one, five, and five building types, respectively. Both *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* realize lower life-cycle costs than *ASHRAE 90.1-2001* for all 11 building types. The LEC design results in significant reductions in life-cycle costs for 10 of 11 building types. The change in life-cycle costs for the LEC design ranges from -7.4 % to 0.1 %. Based on the overall average change of -2.8 % in life-cycle costs, the LEC design is likely to be cost-effective if the state adopted it as its state energy code for commercial buildings.

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

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

9.1.5 City Comparisons

Simulations are run for 6 cities located in Colorado: Boulder, Colorado Springs, Grand Junction, and Pueblo in Climate Zone 5B and Alamosa and Eagle in Climate Zone 6B. Colorado has no significant population centers located Zone 4B or Zone 7. The results vary across cities within the state for several reasons. First, the cities selected for this study span two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality. Finally, Grand Junction has adopted a stricter building energy code than has the state (*ASHRAE 90.1-2004*).

As can be seen in Table 9-6, the average percentage reduction in energy use for all building types from adopting newer energy standard editions is generally greater for the cities located in Zone 5. For the LEC design, Zone 5 excluding Grand Junction realizes an average change in energy use of -25.8 % compared to -22.5 % for Zone 6. Grand Junction realizes much lower reductions in energy use for the *ASHRAE 90.1-2007* and LEC designs because it has already adopted *ASHRAE 90.1-2004* as its jurisdictional energy code.

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

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

The variations in energy cost changes across cities are a result of two factors, the size of the reductions in energy use and the fuel source of the reduction. Table 9-7 shows that the average reduction in energy costs for all building types is similar across both Zone 5 and Zone 6 for both *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* if Grand Junction is excluded from the analysis. The LEC design realizes nearly twice the percentage reduction in energy costs than *ASHRAE 90.1-2007*, with Zone 5 cities excluding Grand Junction realizing an average change in energy costs of -35.7 % compared to -33.2 % for Zone 6. The reductions in energy costs are significantly greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Since Grand Junction has already adopted *ASHRAE 90.1-2004*, it realizes much smaller changes in energy costs for the *ASHRAE 90.1-2007* and LEC designs.

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

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

Table 9-8 reports changes in energy-related carbon emissions by city for the state. For all cities, the more energy efficient building designs result in greater reductions in carbon emissions. As with energy use, the cities in Zone 6 realize slightly lower average emission reductions than the cities in Zone 5 (excluding Grand Junction) for all building designs. For both climate zones, adopting the *ASHRAE 90.1-2007* and *ASHRAE 90.1-2004* designs would decrease energy-related carbon emissions on average. The LEC design realizes the greatest percentage reductions in carbon emissions, with the average percentage reduction ranging from -23.8 % to -37.1 % depending on the location.

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

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

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

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

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

9.2 Total Savings

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

9.2.1 Energy Use

Table 9-10 reports the average per unit change in annual energy use by building type and building design in the state.[22] The reduction per m^2 (ft^2) is multiplied by the estimated annual m^2 (ft^2) of new construction of each building type, and Table 9-11 reports the estimated average annual floor area of new construction and the total annual 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 9-10 Average Per Unit Change in Annual Energy Use, Colorado

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

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

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

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

Building Type	Subcat. Weight.	m^2 (1000s)	ft^2 (1000s)	Standard Edition					
				2004		2007		LEC	
				kWh	kBtu	kWh	kBtu	kWh	kBtu
APART04	44.9 %	183	1967	-2 581 945	-8 815 869	-3 724 753	-12 717 908	-6 401 934	-21 858 955
APART06	55.1 %	224	2410	-3 204 843	-10 942 711	-4 358 644	-14 882 284	-7 860 201	-26 838 104
HOTEL15	100.0 %	199	2147	-2 601 371	-8 882 201	-1 096 565	-3 744 144	-4 942 031	-16 874 218
HIGHS02	100.0 %	331	3561	-996 825	-3 403 588	-3 663 683	-12 509 390	-7 870 278	-26 872 513
OFFIC03	37.4 %	162	1739	-1 082 947	-3 697 645	-2 169 553	-7 407 787	-5 608 663	-19 150 389
OFFIC08	40.4 %	174	1875	-1 465 291	-5 003 132	-2 089 987	-7 136 114	-5 491 202	-18 749 324
OFFIC16	22.2 %	96	1032	-747 292	-2 551 575	40 723	139 045	-2 210 409	-7 547 288
RETAIL1	100.0 %	579	6235	-5 465 300	-18 660 885	-14 251 754	-48 661 618	-23 662 413	-80 793 652
RSTRNT1	100.0 %	40	428	-506 957	-1 730 969	-1 477 307	-5 044 160	-3 172 792	-10 833 277
Total		**1988**	**21 394**	**-18 652 769**	**-63 688 575**	**-32 791 523**	**-111 964 360**	**-67 219 923**	**-229 517 720**
Note: Dormitories are excluded because no such floor area category is reported in the construction data.									

Assuming that the buildings considered in this study, which represent 60.4 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy use savings to be 111.3 GWh (380.0 GBtu) annually. Annual savings of 111.3 GWh (380.0 GBtu) implies 1113 GWh (3800.0 GBtu) in energy savings over the 10-year study period. In comparison, *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* would save 30.9 GWh and 54.3 GWh annually, or 308.8 GWh and 542.9 GWh over the 10-year study period, respectively.

The statewide change in energy use varies across the 9 building types with reported floor area data within a building design. Building types that represent a greater amount of new floor area realize the largest total changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. For example, the building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores, high schools, and high-rise apartment buildings -- rank 3rd, 11th , and 6th in percentage reduction, respectively, among the 11 building types, as reported in Table 9-2. The two high-rise buildings with 100 % window glazing realize the smallest statewide reductions in energy use for *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* due to the consolidation of climate zones from *ASHRAE 90.1-2001* to *ASHRAE 90.1-2004*, which relaxes the window U-factor requirements. *ASHRAE 90.1-2007* results in a small increase in energy use for 16-story office buildings due to relaxation of the window SHGC requirements relative to *ASHRAE 90.1-2004*.

9.2.2 Energy Costs

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

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

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

Table 9-13 reports the statewide changes in total energy costs by building type and building design, which account for one year’s worth of new construction evaluated over 10 years of building operation. Overall, reductions in energy costs are greater for the more energy efficient building designs: $18.5 million, $21.1 million, and $43.9 million for adopting *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC, respectively. All building types realize energy cost savings for all three of these building designs.

Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate the total statewide energy cost savings of $30.6 million, $35.0 million, and $72.7 million over the 10-year study period, respectively.

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

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

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

9.2.3 Energy-related Carbon Emissions

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

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

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

Table 9-15 applies the Table 9-14 results to one year's worth of new building construction in the state to estimate statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs all decrease carbon emissions. The adoption of *ASHRAE 90.1-2004* results in savings of 293 683 metric tons while adopting *ASHRAE 90.1-2007* saves 327 025 metric tons over a 10-year study period. The adoption of the LEC design as the state's energy code decreases carbon emissions by 680 244 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types.

Assuming that the buildings considered in this study are generally representative of the entire new building stock in the state, the results for *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC can be extrapolated to estimate statewide reductions in carbon emissions of 486 230 metric tons, 541 432 metric tons, and 1.1 million metric tons over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition		
				2004	2007	LEC
APART04	44.9 %	183	1967	-43 777	-48 088	-77 740
APART06	55.1 %	224	2410	-54 085	-58 262	-99 177
HOTEL15	100.0 %	199	2147	-45 345	-32 784	-68 685
HIGHS02	100.0 %	331	2403	-20 947	-27 639	-73 418
OFFIC03	37.4 %	162	1739	-14 958	-17 723	-52 588
OFFIC08	40.4 %	174	1875	-17 552	-18 757	-52 512
OFFIC16	22.2 %	96	1032	-11 302	-3318	-25 429
RETAIL1	100.0 %	579	6235	-77 772	-109 222	-202 911
RSTRNT1	100.0 %	40	428	-7945	-11 232	-27 785
Total		**1988**	**20 235**	**-293 683**	**-327 025**	**-680 244**

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

9.2.4 Life-Cycle Costs

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

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

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

Table 9-17 applies the Table 9-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient codes. Total reductions in life-cycle costs over the 10-year study period vary across building designs. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in a decrease in life-cycle costs for all 9 building types while the LEC design decreases life-cycle costs for 8 of 9 building types. The 16-story office building realizes the smallest total reductions in life-cycle costs for all three alternative building designs and, for the LEC design, realizes increases in life-cycle costs. *ASHRAE 90.1-2007* results in greater total reductions in life-cycle costs than *ASHRAE 90.1-2004* for the building types considered in this study ($32.5 million versus $27.8 million). The LEC design leads to the greatest total reductions in life-cycle costs of $36.0 million.

Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide changes in life-cycle costs of $46.1 million, $53.9 million, and $59.7 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2004	2007	LEC
APART04	44.9 %	183	1967	-$2 780 914	-$3 331 475	-$2 195 187
APART06	55.1 %	224	2410	-$3 381 651	-$3 878 490	-$2 586 926
HOTEL15	100.0 %	199	2147	-$4 001 180	-$3 112 617	-$2 139 459
HIGHS02	100.0 %	331	2403	-$1 373 361	-$1 992 603	-$3 382 270
OFFIC03	37.4 %	162	1739	-$3 015 796	-$3 342 811	-$7 123 855
OFFIC08	40.4 %	174	1875	-$3 363 646	-$3 733 863	-$7 405 617
OFFIC16	22.2 %	96	1032	-$727 029	-$232 930	$105 555
RETAIL1	100.0 %	579	6235	-$7 915 065	-$10 570 652	-$7 401 280
RSTRNT1	100.0 %	40	428	-$1 282 163	-$2 351 325	-$3 905 355
Total		**1988**	**20 235**	**-$27 840 805**	**-$32 546 766**	**-$36 034 394**

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

9.3 State Summary

Colorado is one of the few states that has adopted *ASHRAE 90.1-2001* as its state energy code for commercial buildings, and represents the Rocky Mountain region of the United States. On average, adopting a newer edition of *ASHRAE 90.1* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions. However, adopting *ASHRAE 90.1-2007* increases energy use for some location-building type combinations, particularly for 16-story office buildings. *ASHRAE 90.1-2004* condenses the 26 climate zones defined in *ASHRAE 90.1-1999/2001* into 8 climate zones. As a result, some of the building envelope requirements (window U-factors and insulation R-values) are slightly less stringent for some locations. Additionally, *ASHRAE 90.1-2007* further relaxes the window SHGC requirements for some locations.

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

Despite these factors, the adoption of more efficient building design requirements leads to savings in energy use and life-cycle costs. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 543 GWh, energy cost savings of $35.0 million, life-cycle cost savings of $53.9 million, and 541 432 metric tons of carbon emissions reductions for one year's worth of commercial building construction. Adopting the LEC design would be even more beneficial for the state with savings of 1113 GWh (3800.0 GBtu),

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

10 Hawaii

Hawaii is one of two states in the West Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings, and is located in the Pacific Census Division and Climate Zone 1. Table 10-1 provides an overview of Hawaii's simulated energy use keyed to building type and energy standard edition. Average energy use varies across building types and building designs. The 4-story dormitory uses the least amount of energy at 74 kWh/m^2 to 95 kWh/m^2 (24 kBtu/ ft^2 to 30 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy for the *ASHRAE 90.1-1999* design at 157 kWh/m^2 (50 kBtu/ft^2) annually. The 6-story dormitory uses the greatest amount of energy for the LEC design at 106 kWh/m^2 (34 kBtu/ft^2) annually.

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

Building Type	Standard Edition					
	2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	124	39	121	38	99	31
APART06	124	39	121	38	99	31
DORMI04	95	30	93	29	74	24
DORMI06	138	44	135	43	106	34
HOTEL15	96	30	98	31	78	25
HIGHS02	115	37	114	36	84	27
OFFIC03	119	38	118	37	86	27
OFFIC08	111	35	109	35	87	28
OFFIC16	114	36	118	37	95	30
RETAIL1	121	38	120	38	94	30
RSTRNT1	157	50	153	49	102	32

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

10.1 Percentage Savings

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

10.1.1 Energy Use

Table 10-2 shows a large variation in the percentage change in energy use for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 3.1 % to -2.9 % with an average of -1.1 %. For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2007* is actually less energy efficient than *ASHRAE 90.1-2004* because the maximum window SHGC requirement in Zone 1 for buildings with fenestration accounting for greater than 40 % of wall surface area is less stringent for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*. Buildings in warmer climate zones benefit from decreasing external heat gains through fenestration. The resulting higher heat gain through fenestration increases cooling load requirements. The 100 % glazing amplifies the energy loss enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-value.

Table 10-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Hawaii

Building Type	Standard Edition	
	2007	LEC
APART04	-2.7	-20.4
APART06	-2.5	-20.7
DORMI04	-2.9	-22.1
DORMI06	-2.3	-23.0
HOTEL15	2.1	-18.0
HIGHS02	-1.0	-26.7
OFFIC03	-1.6	-28.0
OFFIC08	-1.4	-21.3
OFFIC16	3.1	-16.4
RETAIL1	-0.5	-22.3
RSTRNT1	-2.6	-34.8
Average	**-1.1**	**-23.1**

The LEC design realizes percentage decreases in energy use relative to *ASHRAE 90.1-2004,* ranging from -16.4 % to -34.8 % with an average of -23.1 %. Similar to the *ASHRAE 90.1-2007* design, the smallest reductions in energy use for the LEC design occurs in the 16-story office building and hotel.

10.1.2 Energy Costs

Table 10-3 shows significant variation in the percentage changes in average energy costs for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 3.1 % to -2.9 % depending on the building type, with an average of -1.1 %. As with energy use savings, adopting *ASHRAE 90.1-2007* results in an increase in energy costs relative to *ASHRAE 90.1-2004* for the two high-rise buildings. The LEC design realizes greater reductions in energy costs than the *ASHRAE 90.1-2007* design, with the average percentage change by building type ranging from -16.4 % to -34.8 % with an overall average of -23.1 % for 10 years of building operation. The percentage reductions in energy costs are nearly identical to the reductions in energy use for all building types because electricity consumption accounts for nearly 100 % of total energy use.

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

Building Type	Standard Edition	
	2007	LEC
APART04	-2.7	-20.4
APART06	-2.5	-20.7
DORMI04	-2.9	-22.1
DORMI06	-2.3	-23.0
HOTEL15	2.1	-18.1
HIGHS02	-1.0	-26.7
OFFIC03	-1.6	-28.0
OFFIC08	-1.4	-21.3
OFFIC16	3.1	-16.4
RETAIL1	-0.5	-22.3
RSTRNT1	-2.6	-34.8
Average	**-1.1**	**-23.1**

10.1.3 Energy-related Carbon Emissions Reduction

Table 10-4 shows significant variation in the average percentage change in energy-related carbon emissions for the *ASHRAE 90.1-2007* design across building types, ranging from 3.1 % to -2.9 % with an average of -1.1 %. The LEC design leads to significant changes in average carbon emissions, ranging from -16.4 % to -34.8 % depending on the building type with an average of -23.1 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. The percentage reductions in carbon emissions are nearly identical to the reductions in energy use for all building types because electricity consumption accounts for nearly 100 % of total energy use and, therefore, driving any changes in carbon emissions.

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

Building Type	Standard Edition 2007	LEC
APART04	-2.7	-20.4
APART06	-2.5	-20.7
DORMI04	-2.9	-22.1
DORMI06	-2.3	-23.0
HOTEL15	2.2	-18.1
HIGHS02	-1.0	-26.7
OFFIC03	-1.6	-28.0
OFFIC08	-1.4	-21.3
OFFIC16	3.1	-16.4
RETAIL1	-0.5	-22.3
RSTRNT1	-2.6	-34.8
Average	**-1.1**	**-23.1**

10.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 10-5. The LEC design is the most life-cycle cost-effective building design for all building types. Since the percentage changes in life-cycle costs resulting from the adoption of the LEC design range from -6.3 % to -0.6 %, the LEC design is cost effective for the state to adopt as its state energy code for commercial buildings. For 9 of 11 building types, *ASHRAE 90.1-2007* leads to percentage reductions in life-cycle costs relative to *ASHRAE 90.1-2004*. The 16-story office building and hotel are the only buildings that realize increases in life-cycle costs. Given that nine building types realize a percentage decrease in life-cycle costs, it is likely that adopting *ASHRAE 90.1-2007* will decrease total life-cycle costs.

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

Building Type	Standard Edition 2007	LEC
APART04	-0.5	**-1.7**
APART06	-0.4	**-1.6**
DORMI04	-0.8	**-3.6**
DORMI06	-0.4	**-2.5**
HOTEL15	0.3	**-0.6**
HIGHS02	-0.1	**-4.2**
OFFIC03	-0.3	**-5.7**
OFFIC08	-0.3	**-3.6**
OFFIC16	0.6	**-0.6**
RETAIL1	-0.0	**-3.1**
RSTRNT1	-0.6	**-6.3**
Average	**-0.2**	**-3.1**

10.1.5 City Comparisons

Simulations are run for two cities located in Hawaii, both of which are located in Zone 1: Hilo and Honolulu. 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.

As can be seen in Table 10-6, the average reduction in energy use for all building types from adopting newer energy standard editions does not vary significantly across cities. For the *ASHRAE 90.1-2007* design, the percentage change in average energy use ranges minimally from -1.1 % to -1.2 %. For the LEC design, the percentage change in average energy use ranges from -22.9 % to -23.2 %. There is not a significant impact from the variation in weather across cities in Hawaii.

Table 10-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Hawaii

Cities	Zone	Standard Edition	
		2007	LEC
Hilo	1	-1.2	-22.9
Honolulu	1	-1.1	-23.2
Average		**-1.1**	**-23.1**

The variations in energy costs across cities are a result of two factors, the reduction in energy use and the fuel source of the reduction. Table 10-7 shows that the average reduction in energy costs for all building types varies marginally between cities. For the *ASHRAE 90.1-2007* design, the percentage change in average energy costs ranges from -1.1 % to -1.2 %. For the LEC design, the percentage change in average energy costs ranges from -22.9 % to -23.2 %.

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

Cities	Zone	Standard Edition	
		2007	LEC
Hilo	1	-1.2	-22.9
Honolulu	1	-1.1	-23.2
Average		**-1.1**	**-23.1**

Table 10-8 reports energy-related carbon emissions by city for the state. For both cities, the more energy efficient designs result in greater reductions in carbon emissions. The average percentage change in carbon emissions varies minimally between cities.

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

Cities	Zone	Standard Edition	
		2007	LEC
Hilo	1	-1.2	-23.7
Honolulu	1	-1.1	-24.0
Average		**-1.2**	**-23.9**

The data reported in Table 10-9 show that adoption of the *ASHRAE 90.1-2007* design decreases life-cycle costs for both cities, with no variation in the change in life-cycle costs (-0.1 %). The LEC design realizes the greatest reduction in life-cycle costs between cities in the state with minimal variation (-4.1 % to -4.2 %).

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

Cities	Zone	Standard Edition	
		2007	LEC
Hilo	1	-0.1	**-4.1**
Honolulu	1	-0.1	**-4.2**
Average		**-0.1**	**-4.1**

10.2 Total Savings

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

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

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-3.4	-1.1	-25.3	-8.0
APART06	-3.1	-1.0	-25.8	-8.2
DORMI04	-2.7	-0.9	-21.0	-6.7
DORMI06	-3.2	-1.0	-31.7	-10.1
HOTEL15	2.1	0.7	-17.3	-5.5
HIGHS02	-1.9	-0.6	-33.5	-10.6
OFFIC03	-1.2	-0.4	-30.8	-9.8
OFFIC08	-1.6	-0.5	-23.6	-7.5
OFFIC16	3.5	1.1	-18.7	-5.9
RETAIL1	-0.6	-0.2	-27.0	-8.6
RSTRNT1	-4.1	-1.3	-54.8	-17.4

The annual reduction in energy use shown in Table 10-11 ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs both decrease total statewide energy use. The adoption of the *ASHRAE 90.1-2007* design results in reductions of 863.0 MWh (2.9 GBtu) annually. *ASHRAE 90.1-2007* increases total energy use for the two high-rise buildings and decreases total energy use for the other seven building types with the 6- and 4-story apartment buildings realizing the greatest reductions. The adoption of the LEC design as the state's energy code for commercial buildings would save 9.9 GWh (33.7 GBtu) of total statewide energy use annually for one year's worth of new construction for these building types.

Table 10-11 Statewide Change in Annual Energy Use for One Year of Construction, Hawaii

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition			
				2007		LEC	
				kWh	kBtu	kWh	kBtu
APART04	44.9 %	115	1238	-385 506	-1 316 282	-2 906 299	-9 923 355
APART06	55.1 %	141	1516	-432 225	-1 475 801	-3 628 358	-12 388 776
HOTEL15	100.0 %	18	198	37 835	129 185	-317 386	-1 083 693
HIGHS02	100.0 %	18	197	-21 597	-73 740	-563 322	-1 923 424
OFFIC03	37.4 %	13	138	-24 301	-82 973	-428 551	-1 463 257
OFFIC08	40.4 %	14	148	-21 940	-74 913	-325 800	-1 112 422
OFFIC16	22.2 %	8	82	26 537	90 608	-142 047	-485 008
RETAIL1	100.0 %	55	588	-34 571	-118 041	-1 474 736	-5 035 383
RSTRNT1	100.0 %	2	19	-7278	-24 852	-96 687	-330 132
Total		**383**	**4124**	**-863 045**	**-2 946 808**	**-9 883 187**	**-33 745 449**

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 71.4 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the statewide savings to be 1.2 GWh (4.1 GBtu) and 13.8 GWh (47.3 GBtu) per year for adoption of the *ASHRAE 90.1-2007* and LEC designs, respectively. These savings imply 12.1 GWh (41.3 GBtu) and 138.4 GWh (472.6 GBtu) in energy use savings over the 10-year study period.

The relative reduction in energy use across building types in Table 10-11 is consistent across building designs. The greatest total reductions are realized by 6- and 4-story apartment buildings because they represent 36.8 % and 30.0 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent less than 14.3 %. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design – 4- and 6-story apartment buildings -- rank 8th and 9th in percentage reduction, respectively, among the 11 building types, as reported in Table 10-2.

10.2.2 Energy Costs

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

Building Type	Standard Edition			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$5.80	-$0.54	-$43.69	-$4.06
APART06	-$5.30	-$0.49	-$44.53	-$4.14
DORMI04	-$4.75	-$0.44	-$36.37	-$3.38
DORMI06	-$5.53	-$0.51	-$54.86	-$5.10
HOTEL15	$3.56	$0.33	-$29.87	-$2.78
HIGHS02	-$3.29	-$0.31	-$57.97	-$5.39
OFFIC03	-$2.04	-$0.19	-$53.23	-$4.94
OFFIC08	-$2.75	-$0.26	-$40.87	-$3.80
OFFIC16	$6.05	$0.56	-$32.39	-$3.01
RETAIL1	-$1.09	-$0.10	-$46.70	-$4.34
RSTRNT1	-$7.13	-$0.66	-$94.71	-$8.80

Table 10-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. Overall, reductions in energy costs are greater for the more energy efficient building designs: $1.5 million and $17.1 million for adopting the *ASHRAE 90.1-2007* and LEC design, respectively. The increase in energy use for the high-rise buildings leads to an increase in energy costs for those buildings for *ASHRAE 90.1-2007*. All building types realize energy cost savings for the LEC design. The energy cost savings are highly correlated with the energy use savings. Assuming that the buildings considered in this study, which represent 71.4 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC design can be extrapolated to estimate the total statewide energy cost savings of $2.1 million and $23.9 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	115	1238	-$666 591	-$5 025 381
APART06	55.1 %	141	1516	-$747 375	-$6 273 919
HOTEL15	100.0 %	18	198	$65 458	-$548 923
HIGHS02	100.0 %	18	197	-$37 361	-$974 138
OFFIC03	37.4 %	13	138	-$42 019	-$741 022
OFFIC08	40.4 %	14	148	-$37 937	-$563 352
OFFIC16	22.2 %	8	82	$45 910	-$245 644
RETAIL1	100.0 %	55	588	-$59 778	-$2 550 016
RSTRNT1	100.0 %	2	19	-$12 585	-$167 185
Total		**383**	**4124**	**-$1 492 279**	**-$17 089 580**

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

10.2.3 Energy-related Carbon Emissions

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

Building Type	Standard Edition			
	2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-28.0	-5.7	-211.2	-43.2
APART06	-25.6	-5.3	-215.2	-44.1
DORMI04	-23.0	-4.7	-175.8	-36.0
DORMI06	-26.7	-5.5	-265.1	-54.3
HOTEL15	17.2	3.5	-144.4	-29.6
HIGHS02	-9.9	-2.0	-257.3	-52.7
OFFIC03	-15.9	-3.3	-280.2	-57.4
OFFIC08	-13.3	-2.7	-197.5	-40.5
OFFIC16	29.3	6.0	-156.5	-32.1
RETAIL1	-5.3	-1.1	-225.7	-46.2
RSTRNT1	-34.5	-7.1	-457.8	-93.8

Table 10-15 applies the Table 10-14 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs decrease carbon emissions for the state as a whole. The adoption of *ASHRAE 90.1-2007* saves 7212 metric tons over a 10-year study period. The adoption of the LEC design decreases carbon emissions by 82 598 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC designs can be extrapolated to estimate the statewide reduction in carbon emissions of 10 813 metric tons and 123 836 metric tons over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	115	1238	-3222	-24 289
APART06	55.1 %	141	1516	-3612	-30 323
HOTEL15	100.0 %	18	198	316	-2653
HIGHS02	100.0 %	18	197	-181	-4708
OFFIC03	37.4 %	13	138	-203	-3582
OFFIC08	40.4 %	14	148	-183	-2723
OFFIC16	22.2 %	8	82	222	-1187
RETAIL1	100.0 %	55	588	-289	-12 325
RSTRNT1	100.0 %	2	19	-61	-808
Total		**383**	**4124**	**-7212**	**-82 598**

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

10.2.4 Life-Cycle Costs

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

Building Type	Standard Edition			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$5.99	-$0.56	-$21.92	-$2.04
APART06	-$4.96	-$0.46	-$21.75	-$2.02
DORMI04	-$10.52	-$0.98	-$46.53	-$4.32
DORMI06	-$5.16	-$0.48	-$35.23	-$3.27
HOTEL15	$4.27	$0.40	-$6.99	-$0.65
HIGHS02	-$1.18	-$0.11	-$46.61	-$4.33
OFFIC03	-$3.35	-$0.31	-$66.42	-$6.17
OFFIC08	-$3.31	-$0.31	-$42.72	-$3.97
OFFIC16	$6.67	$0.62	-$6.61	-$0.61
RETAIL1	-$0.23	-$0.02	-$30.57	-$2.84
RSTRNT1	-$11.20	-$1.04	-$117.17	-$10.89

Table 10-17 applies the Table 10-16 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of more energy-efficient codes. *ASHRAE 90.1-2007* results in total reductions in life-cycle costs of $1.4 million over the 10-year study period relative to *ASHRAE*

90.1-2004 for the building types considered in this study. The LEC design leads to a decrease in total statewide life-cycle costs of $9.9 million, while reducing life-cycle costs for all 9 building types. The *ASHRAE 90.1-2007* design both lead to an increase in life-cycle costs for hotels and 16-story office buildings. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2007* and LEC design can be extrapolated to estimate the total reductions in life-cycle costs of $2.0 million and $13.9 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	115	1238	-$688 775	-$2 521 478
APART06	55.1 %	141	1516	-$698 930	-$3 064 132
HOTEL15	100.0 %	18	198	$78 376	-$128 502
HIGHS02	100.0 %	18	197	-$21 521	-$853 066
OFFIC03	37.4 %	13	138	-$42 769	-$848 972
OFFIC08	40.4 %	14	148	-$45 659	-$588 859
OFFIC16	22.2 %	8	82	$50 621	-$50 100
RETAIL1	100.0 %	55	588	-$12 661	-$1 669 534
RSTRNT1	100.0 %	2	19	-$19 766	-$206 818
Total		**383**	**4124**	**-$1 401 083**	**-$9 931 461**

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

10.3 State Summary

Hawaii is one of two states in the West Census Region that have adopted *ASHRAE 90.1-2004* as their current state energy code for commercial buildings. On average, adopting the *ASHRAE 90.1-2007* 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 *ASHRAE 90.1-2007* as the state's energy code would lead to energy use savings of 12.1 GWh (41.3 GBtu), energy cost savings of $2.1 million, carbon emissions reductions of 10 813 metric tons, and life-cycle cost savings of $2.0 million. The LEC design would be lead to even greater impacts for the state with savings of 138.4 GWh (472.6 GBtu), energy cost savings of $23.9 million, carbon emissions reductions of 123 836 metric tons for one year's worth of commercial building construction while decreasing life-cycle costs by $13.9 million.

11 Idaho

Idaho has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the Mountain Census Division, and spans two climate zones (Zone 5B and Zone 6B). Table 11-1 provides an overview of Idaho's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 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 206 kWh/m^2 to 220 kWh/m^2 (65 kBtu/ft^2 to 70 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	145	46	130	41
APART06	143	45	127	40
DORMI04	113	36	99	31
DORMI06	159	50	142	45
HOTEL15	155	49	136	43
HIGHS02	220	70	206	65
OFFIC03	106	34	85	27
OFFIC08	98	31	79	25
OFFIC16	149	47	126	40
RETAIL1	117	37	100	32
RSTRNT1	160	51	118	37

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

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 -6.0 % to -26.0 % depending on the building type with an overall average of -14.3 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 11-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Idaho

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.2	-14.8	-14.9	0.8
APART06	-11.1	-16.5	-16.5	0.8
DORMI04	-12.7	-16.4	-16.5	-1.2
DORMI06	-10.6	-15.6	-15.7	0.5
HOTEL15	-12.3	-15.9	-15.9	0.7
HIGHS02	-6.0	-11.8	-11.9	-0.2
OFFIC03	-19.7	-22.0	-22.1	-2.7
OFFIC08	-19.3	-20.4	-20.4	-2.4
OFFIC16	-15.3	-17.7	-17.8	0.9
RETAIL1	-14.2	-16.3	-16.3	1.2
RSTRNT1	-26.0	-30.8	-30.9	-2.7
Average	**-14.3**	**-18.0**	**-18.1**	**-0.4**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -11.8 % to -30.8% depending on the building type with an average of -18.0 % 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. For 5 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 41.8 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is nearly twice the percentage reduction in energy use. The LEC design incorporates daylighting into the building design for all climate zones and overhangs 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 -11.9 % to -30.9 % with an average of -18.1 %. 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 5 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 -2.7 % to 1.2 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -0.4 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

11.1.2 City Comparisons

Simulations are run for three cities located in Idaho: Boise and Lewiston in Zone 5B and Pocatello in Zone 6B. The results vary across cities within Idaho for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and may impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 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 change in energy use for all building types from adopting the LEC design varies minimally across cities, ranging from -13.7 % to -14.7 %. Cities in Zone 5B realize slightly greater reductions than the city in Zone 6B.

Table 11-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Idaho

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Boise	5B	-14.7	-19.1	-19.2	-0.4
Lewiston	5B	-14.6	-18.7	-18.8	-0.8
Pocatello	6B	-13.7	-16.4	-16.5	0.1
Average		**-14.3**	**-18.0**	**-18.2**	**-0.4**

The average percentage change in energy costs for all building types also varies slightly across cities, ranging from -16.4 % to -19.1 % 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 slightly across cities, ranging from -16.5 % to -19.2 %. Percentage changes in life-cycle costs for all building types vary across cities, ranging from 0.1 % to -0.8 %, with the city in Zone 6B (Pocatello) realizing an increase and the cities in Zone 5B (Boise and Lewiston) realizing a decrease in life-cycle costs.

11.2 Total Savings

How much can Idaho 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.[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 11-5 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]

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

Building Type	Standard Edition	
	LEC	
	kWh/m^2	kBtu/ft^2
APART04	-14.7	-4.7
APART06	-15.8	-5.0
DORMI04	-14.4	-4.6
DORMI06	-16.7	-5.3
HOTEL15	-19.0	-6.0
HIGHS02	-20.9	-6.6
OFFIC03	-13.3	-4.2
OFFIC08	-18.9	-6.0
OFFIC16	-22.7	-7.2
RETAIL1	-16.8	-5.3
RSTRNT1	-41.5	-13.2

[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.

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 8.9 GWh (30.4 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 63.6 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 14.0 GWh (47.8 GBtu) per year. These savings imply 139.9 GWh (477.7 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. The greatest total reductions are realized by retail stores and high schools because they represent 27.4 % and 24.9 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 11.3 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 5th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 11-2.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	21	225	-307 982	-1 051 583
APART06	55.1 %	26	276	-405 457	-1 384 405
HOTEL15	100.0 %	44	475	-836 589	-2 856 476
HIGHS02	100.0 %	127	1369	-1 691 060	-5 774 006
OFFIC03	37.4 %	54	577	-1 119 489	-3 822 416
OFFIC08	40.4 %	58	622	-1 091 942	-3 728 358
OFFIC16	22.2 %	32	342	-720 644	-2 460 587
RETAIL1	100.0 %	140	1505	-2 344 554	-8 005 314
RSTRNT1	100.0 %	9	99	-380 359	-1 298 710
Total		**510**	**5490**	**-8 898 075**	**-30 381 855**

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, Idaho

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$8.04	-$0.75
APART06	-$8.92	-$0.83
DORMI04	-$7.24	-$0.67
DORMI06	-$9.36	-$0.87
HOTEL15	-$9.37	-$0.87
HIGHS02	-$10.77	-$1.00
OFFIC03	-$9.32	-$0.87
OFFIC08	-$9.67	-$0.90
OFFIC16	-$11.59	-$1.08
RETAIL1	-$8.23	-$0.76
RSTRNT1	-$21.05	-$1.96

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 a statewide reduction in energy costs of $4.8 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 $7.6 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	21	225	-$168 362
APART06	55.1 %	26	276	-$228 678
HOTEL15	100.0 %	44	475	-$413 642
HIGHS02	100.0 %	127	1369	-$1 185 996
OFFIC03	37.4 %	54	577	-$576 926
OFFIC08	40.4 %	58	622	-$558 751
OFFIC16	22.2 %	32	342	-$368 403
RETAIL1	100.0 %	140	1505	-$1 150 752
RSTRNT1	100.0 %	9	99	-$192 788
Total		**510**	**5490**	**-$4 844 297**

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, Idaho

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-77.4	-15.9
APART06	-85.9	-17.6
DORMI04	-69.6	-14.3
DORMI06	-90.1	-18.4
HOTEL15	-90.2	-18.5
HIGHS02	-89.9	-18.4
OFFIC03	-103.6	-21.2
OFFIC08	-93.1	-19.1
OFFIC16	-111.5	-22.8
RETAIL1	-79.2	-16.2
RSTRNT1	-202.5	-41.5

Table 11-9 applies the Table 11-8 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 46 630 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 69 910 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	21	225	-1621
APART06	55.1 %	26	276	-2202
HOTEL15	100.0 %	44	475	-3979
HIGHS02	100.0 %	127	1369	-11 434
OFFIC03	37.4 %	54	577	-5551
OFFIC08	40.4 %	58	622	-5376
OFFIC16	22.2 %	32	342	-3545
RETAIL1	100.0 %	140	1505	-11 068
RSTRNT1	100.0 %	9	99	-1855
Total		**510**	**5490**	**-46 630**

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, Idaho

Building Type	Standard Edition LEC $/m²	Standard Edition LEC $/ft²
APART04	$7.74	$0.72
APART06	$7.69	$0.71
DORMI04	-$10.73	-$1.00
DORMI06	$5.20	$0.48
HOTEL15	$6.58	$0.61
HIGHS02	-$1.78	-$0.17
OFFIC03	-$21.36	-$1.98
OFFIC08	-$19.00	-$1.76
OFFIC16	$6.45	$0.60
RETAIL1	$6.99	$0.65
RSTRNT1	-$34.04	-$3.16

Table 11-11 applies the Table 11-10 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 $947 944 in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Three-story and 8-story office buildings realize the greatest reductions in life-cycle costs ($1.1 million each). Retail stores realize the greatest increase in life-cycle costs ($977 602). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $1.5 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC
APART04	44.9 %	21	225	$162 002
APART06	55.1 %	26	276	$197 018
HOTEL15	100.0 %	44	475	$290 222
HIGHS02	100.0 %	127	1369	-$226 410
OFFIC03	37.4 %	54	577	-$1 144 028
OFFIC08	40.4 %	58	622	-$1 097 521
OFFIC16	22.2 %	32	342	$205 001
RETAIL1	100.0 %	140	1505	$977 602
RSTRNT1	100.0 %	9	99	-$311 829
Total		**510**	**5490**	**-$947 944**

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

11.3 State Summary

Idaho 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 139.9 GWh (477.8 GBtu), energy cost savings of $7.6 million, and carbon emissions reductions of 69 910 metric tons while decreasing life-cycle costs of $1.5 million for one year's worth of commercial building construction.

12 Montana

Montana has adopted *ASHRAE 90.1-2007* as its state energy code, and is located in the Mountain Census Division and Climate Zone 6B. Table 12-1 provides an overview of Montana's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 88 kWh/m^2 to 106 kWh/m^2 (28 $kBtu/ft^2$ to 34 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 248 kWh/m^2 to 274 kWh/m^2 (79 $kBtu/ft^2$ to 87 $kBtu/ft^2$) annually.

Table 12-1 Average Annual Energy Use by Building Type and Standard Editions, Montana

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	169	54	153	48
APART06	166	53	151	48
DORMI04	137	43	119	38
DORMI06	186	59	170	54
HOTEL15	183	58	166	53
HIGHS02	274	87	248	79
OFFIC03	118	38	97	31
OFFIC08	106	34	88	28
OFFIC16	171	54	151	48
RETAIL1	137	43	115	36
RSTRNT1	184	58	140	44

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

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 Montana.

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 -8.6 % to -24.1 % depending on the building type with an overall average of -13.3 %. The 6-story dormitory realizes the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 12-2 Average Percentage Change from Adoption of Standard Editions, 10-Year, Montana

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-9.6	-15.2	-14.5	0.6
APART06	-9.5	-15.1	-14.4	0.6
DORMI04	-12.9	-17.1	-16.6	-1.2
DORMI06	-8.6	-13.6	-12.9	0.3
HOTEL15	-9.4	-11.5	-11.3	0.4
HIGHS02	-9.7	-13.9	-13.3	-0.6
OFFIC03	-18.0	-20.1	-19.9	-1.9
OFFIC08	-16.9	-18.1	-18.0	-1.5
OFFIC16	-11.7	-12.5	-12.5	0.4
RETAIL1	-16.0	-17.7	-17.5	0.1
RSTRNT1	-24.1	-28.9	-28.4	-1.4
Average	**-13.3**	**-16.7**	**-16.3**	**-0.4**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -11.5 % to -28.9 % depending on the building type with an average of -16.7 % 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. The greater relative percentage reduction in electricity consumption leads to greater 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 -11.3 % to -28.4 % with an average of -16.3 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity.

The percentage change in life-cycle costs varies across building types, ranging from -1.9 % to 0.6 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs, with 3-story office buildings realizing the greatest percentage reduction in life-cycle costs, while 4- and 6-story apartment buildings realize the largest increases in life-cycle costs (0.6 %). Based on the overall average percentage change of -0.4 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

12.1.2 City Comparisons

Simulations are run for nine cities located in Montana, all of which are located in Zone 6B: Billings, Cut Bank, Glasgow, Great Falls, Helena, Kalispell, Lewistown, Miles City, and Missoula. While the nine cities are located in the same climate zone, the results may still vary for two reasons. First, cities within the same climate zone may have some variation in the local climate, which can lead to variation in energy consumption. Second, construction material and labor costs may vary significantly by locality.

Table 12-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage change in energy use for all building types from adopting the LEC design varies slightly across cities, ranging from -12.4 % to -15.5 % with an overall average of -13.3 %.

Table 12-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Montana

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Billings	6B	-13.7	-17.1	-16.9	-0.6
Cut Bank	6B	-13.1	-16.7	-16.3	-0.3
Glasgow	6B	-12.4	-15.8	-15.5	-0.3
Great Falls	6B	-13.3	-16.7	-16.4	-0.6
Helena	6B	-13.1	-16.8	-16.5	-0.2
Kalispell	6B	-15.5	-17.9	-17.6	-0.1
Lewistown	6B	-13.0	-16.6	-16.3	-0.4
Miles City	6B	-13.0	-16.4	-16.1	-0.6
Missoula	6B	-12.6	-16.4	-16.1	-0.2
Average		**-13.3**	**-16.7**	**-16.4**	**-0.4**

The average percentage change in energy costs for all building types varies minimally across cities, ranging from -15.8 % to -17.9 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies slightly across cities, ranging from -15.5 % to -17.6 %. Changes in life-cycle costs for all building types vary slightly across cities, ranging from -0.1 % to -0.6 %.

12.2 Total Savings

How much can Montana 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.[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 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.[29]

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

Building Type	Standard Edition LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-16.1	-5.1
APART06	-15.8	-5.0
DORMI04	-17.5	-5.6
DORMI06	-15.9	-5.0
HOTEL15	-17.3	-5.5
HIGHS02	-21.4	-6.8
OFFIC03	-26.7	-8.5
OFFIC08	-17.9	-5.7
OFFIC16	-19.9	-6.3
RETAIL1	-21.9	-7.0
RSTRNT1	-44.3	-14.0

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 3.3 GWh (11.4 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 statewide savings to

[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.

be 5.2 GWh (17.9 GBtu) per year. These savings imply 52.5 GWh (179.1 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 larger changes in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 33.5 % and 23.0 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 15.5 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated total reductions in energy use for the LEC design – retail stores and high schools -- only rank 4th and 7th 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, Montana

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				LEC	
				kWh	kBtu
APART04	44.9 %	4	43	-64 705	-220 931
APART06	55.1 %	5	53	-77 568	-264 852
HOTEL15	100.0 %	24	253	-405 658	-1 385 089
HIGHS02	100.0 %	35	374	-928 840	-3 171 460
OFFIC03	37.4 %	11	120	-237 944	-812 443
OFFIC08	40.4 %	12	129	-215 134	-734 561
OFFIC16	22.2 %	7	71	-131 680	-449 612
RETAIL1	100.0 %	51	545	-1 109 215	-3 787 336
RSTRNT1	100.0 %	4	39	-160 404	-547 688
Total		**151**	**1627**	**-3 331 148**	**-11 373 972**

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, Montana

Building Type	Standard Edition LEC $/m^2$	Standard Edition LEC $/ft^2$
APART04	-$10.29	-$0.96
APART06	-$10.19	-$0.95
DORMI04	-$9.70	-$0.90
DORMI06	-$10.15	-$0.94
HOTEL15	-$8.71	-$0.81
HIGHS02	-$12.64	-$1.17
OFFIC03	-$14.31	-$1.33
OFFIC08	-$10.97	-$1.02
OFFIC16	-$10.65	-$0.99
RETAIL1	-$11.60	-$1.08
RSTRNT1	-$25.22	-$2.34

Table 12-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with statewide reductions in energy costs of $1.8 million for 10 years of building operation. 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 statewide energy cost savings of $2.9 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	4	43	-$41 320
APART06	55.1 %	5	53	-$50 121
HOTEL15	100.0 %	24	253	-$204 793
HIGHS02	100.0 %	35	374	-$497 334
OFFIC03	37.4 %	11	120	-$140 793
OFFIC08	40.4 %	12	129	-$131 762
OFFIC16	22.2 %	7	71	-$70 384
RETAIL1	100.0 %	51	545	-$586 907
RSTRNT1	100.0 %	4	39	-$91 395
Total		**151**	**1627**	**-$1 814 810**

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, Montana

Building Type	Standard Edition LEC	
	kg/m^2	lb/ft^2
APART04	-89.9	-18.4
APART06	-88.9	-18.2
DORMI04	-85.8	-17.6
DORMI06	-88.7	-18.2
HOTEL15	-77.8	-15.9
HIGHS02	-127.0	-26.0
OFFIC03	-111.1	-22.8
OFFIC08	-96.2	-19.7
OFFIC16	-94.5	-19.4
RETAIL1	-103.1	-21.1
RSTRNT1	-222.6	-45.6

Table 12-9 applies the Table 12-8 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with total reductions in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 16 083 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 24 113 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	4	43	-361
APART06	55.1 %	5	53	-438
HOTEL15	100.0 %	24	253	-1829
HIGHS02	100.0 %	35	374	-4415
OFFIC03	37.4 %	11	120	-1238
OFFIC08	40.4 %	12	129	-1155
OFFIC16	22.2 %	7	71	-625
RETAIL1	100.0 %	51	545	-5216
RSTRNT1	100.0 %	4	39	-807
Total		**151**	**1627**	**-16 083**

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, Montana

Building Type	Standard Edition LEC $/m²	Standard Edition LEC $/ft²
APART04	$5.33	$0.49
APART06	$5.99	$0.56
DORMI04	-$10.65	-$0.99
DORMI06	$3.39	$0.31
HOTEL15	$3.88	$0.36
HIGHS02	-$4.53	-$0.42
OFFIC03	-$14.61	-$1.36
OFFIC08	-$11.66	-$1.08
OFFIC16	$2.82	$0.26
RETAIL1	$0.56	$0.05
RSTRNT1	-$16.74	-$1.56

Table 12-11 applies the Table 12-10 results to one year's worth of new building construction in the state to estimate changes in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $332 355 in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Three-story office buildings, high schools, and 8-story office buildings realize the greatest statewide decreases in life-cycle costs (-\$162 813, -\$157 629, and -\$140 036, respectively) while hotels realize the largest increase in life-cycle costs of \$91 122. 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 \$523 393 over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	4	43	\$21 395
APART06	55.1 %	5	53	\$29 480
HOTEL15	100.0 %	24	253	\$91 122
HIGHS02	100.0 %	35	374	-\$157 629
OFFIC03	37.4 %	11	120	-\$162 813
OFFIC08	40.4 %	12	129	-\$140 036
OFFIC16	22.2 %	7	71	\$18 650
RETAIL1	100.0 %	51	545	\$28 132
RSTRNT1	100.0 %	4	39	-\$60 656
Total		**151**	**1627**	**-\$332 355**

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

12.3 State Summary

Montana 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 52.5 GWh (179.1 GBtu), energy cost savings of \$2.9 million, and carbon emissions reductions of 24 113 metric tons while decreasing life-cycle costs by \$523 393 million for one year's worth of commercial building construction.

13 Nevada

Nevada is one of two states in the West Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings, is located in the Mountain Census Division, and spans two climate zones (Zone 3B and Zone 4B). Table 13-1 provides an overview of Nevada's simulated energy use keyed to building types and energy standard edition. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 79 kWh/m^2 to 102 kWh/m^2 (25 kBtu/ ft^2 to 32 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 188 kWh/m^2 to 206 kWh/m^2 (60 kBtu/ ft^2 to 65 kBtu/ft^2) annually.

Table 13-1 Average Annual Energy Use by Building Type and Standard Editions, Nevada

Building Type	Standard Edition					
	2004		2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	139	44	133	42	119	38
APART06	136	43	131	42	116	37
DORMI04	108	34	103	33	90	29
DORMI06	150	48	146	46	129	41
HOTEL15	133	42	141	45	121	38
HIGHS02	206	65	199	63	188	60
OFFIC03	111	35	104	33	83	26
OFFIC08	102	32	99	31	79	25
OFFIC16	134	42	141	45	117	37
RETAIL1	128	41	115	37	101	32
RSTRNT1	177	56	156	49	115	36

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

13.1 Percentage Savings

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

13.1.1 Energy Use

Table 13-2 shows a large variation in percentage changes in energy use for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 6.0 % to -11.3 % with an average of -3.4 %. For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2007* is actually less energy efficient than *ASHRAE 90.1-2004* because the maximum window U-factor and SHGC requirements in Zone 3B and Zone 4B for buildings with fenestration accounting for greater than 40 % of wall surface area is less stringent for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*. The 100 % glazing amplifies the energy loss enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

Table 13-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Nevada

Building Type	Standard Edition	
	2007	LEC
APART04	-4.3	-14.5
APART06	-3.7	-14.9
DORMI04	-5.0	-17.1
DORMI06	-2.7	-14.1
HOTEL15	6.0	-8.8
HIGHS02	-3.4	-9.5
OFFIC03	-5.7	-25.3
OFFIC08	-3.2	-23.0
OFFIC16	5.8	-12.5
RETAIL1	-10.0	-21.0
RSTRNT1	-11.3	-35.1
Average	**-3.4**	**-17.8**

The LEC design realizes percentage changes in energy use relative to *ASHRAE 90.1-2004,* ranging from -8.8 % to -35.1 % with an average of -17.8 %. Similar to the *ASHRAE 90.1-2007* design, the smallest reductions in energy use for the LEC design occurs in the 16-story office building and hotel. 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.

13.1.2 Energy Costs

Table 13-3 shows significant variation in the percentage changes in average energy costs for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 7.0 % to -6.7 % depending on the building type, with an average of -1.7 %. As with energy use savings, adopting *ASHRAE 90.1-2007* results in an increase in energy costs relative to *ASHRAE 90.1-2004* for the two high-rise buildings. For these two building types, the percentage increase in energy costs is greater than the increase in energy use because electricity consumption increases by a greater percentage than natural gas consumption. The greater relative increase in electricity further increases energy costs because electricity is more expensive per unit of energy. The remaining nine building types realize smaller percentage reductions in energy costs than the reductions in energy use because adopting the *ASHRAE 90.1-2007* design decreases natural gas consumption by a greater percentage than electricity consumption.

Table 13-3 Average Percentage Change in Energy Costs, 10-Year, Nevada

Building Type	Standard Edition	
	2007	LEC
APART04	-3.7	-20.7
APART06	-3.2	-22.9
DORMI04	-3.5	-21.1
DORMI06	-2.6	-22.1
HOTEL15	6.8	-14.7
HIGHS02	-2.7	-18.2
OFFIC03	-2.7	-26.7
OFFIC08	-1.3	-23.4
OFFIC16	7.0	-16.0
RETAIL1	-6.4	-21.9
RSTRNT1	-6.7	-38.6
Average	**-1.7**	**-22.4**

The LEC design realizes greater reductions in energy costs than the *ASHRAE 90.1-2007* design, with the average percentage change by building type ranging from -14.7 % to -38.6 % with an overall average of -22.4 % for 10 years of building operation. The reductions in energy costs are greater than the reductions in energy use for all 11 building types because electricity consumption is decreased by a greater percentage than natural gas consumption. For 6 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 30.2 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is nearly twice the percentage reduction in energy use. The LEC design incorporates daylighting into the building design for all climate zones and overhangs for cities in Zone 3 and 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.

13.1.3 Energy-related Carbon Emissions Reduction

Table 13-4 shows significant variation in the average percentage change in energy-related carbon emissions for the *ASHRAE 90.1-2007* design across building types, ranging from 6.7 % to -8.1 % with an average of -2.2 %. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. However, the carbon emissions reductions (increases) are smaller (larger) than the energy use reductions (increases) for all 11 building types for the *ASHRAE 90.1-2007* design. Similar to the reductions in energy costs, this result is due to the fuel source of the reductions in energy use. For the nine building types that realize smaller reductions in carbon emissions than energy use, the percentage reduction in natural gas consumption is greater than the reduction in electricity. For the two building types that realize a greater percentage increase in carbon emissions than energy use, natural gas consumption is increased by a smaller percentage than electricity consumption.

The LEC design leads to significant changes in average carbon emissions, ranging from -13.0 % to -37.7 % depending on the building type with an average of -21.0 % across all building types. The LEC design realizes a greater percentage reduction in natural gas consumption than electricity consumption for all 11 building types, which leads to additional carbon emissions reductions because natural gas has a lower average carbon emissions rate than electricity.

Table 13-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Nevada

Building Type	Standard Edition	
	2007	LEC
APART04	-3.9	-18.8
APART06	-3.4	-20.5
DORMI04	-3.9	-19.9
DORMI06	-2.6	-19.6
HOTEL15	6.5	-13.0
HIGHS02	-3.0	-15.4
OFFIC03	-3.5	-26.3
OFFIC08	-1.8	-23.3
OFFIC16	6.7	-15.1
RETAIL1	-7.4	-21.7
RSTRNT1	-8.1	-37.7
Average	**-2.2**	**-21.0**

13.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 13-5. Based on the life-cycle costs over a 10-year study period, the *ASHRAE 90.1-2007* design realizes the lowest life-cycle costs for three building types while the LEC design has the lowest life-cycle costs for six building types. The current state energy code, *ASHRAE 90.1-2004*, results in lower life-cycle costs for the hotel and 16-story office building.

Adopting the *ASHRAE 90.1-2007* and LEC designs lead to percentage reductions in life-cycle costs for all building types except the two high-rise buildings. Given that the average percentage changes in life-cycle costs are -0.4 % and -1.6 %, respectively, it is possible that both the *ASHRAE 90.1-2007* and LEC designs are cost-effective for the state to adopt as its state energy code for commercial buildings.

Table 13-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Nevada

Building Type	Standard Edition	
	2007	LEC
APART04	**-0.4**	-0.1
APART06	**-0.3**	-0.1
DORMI04	-0.7	**-1.9**
DORMI06	-0.2	**-0.4**
HOTEL15	0.6	0.7
HIGHS02	-0.4	**-1.5**
OFFIC03	-0.4	**-4.3**
OFFIC08	-0.4	**-3.6**
OFFIC16	0.8	0.7
RETAIL1	**-1.2**	-0.6
RSTRNT1	-1.7	**-6.0**
Average	**-0.4**	**-1.6**

13.1.5 City Comparisons

Simulations are run for six cities located in Nevada: Las Vegas in Zone 3B and Elko, Ely, Reno, Tonopah, and Winnemucca in Zone 4B. The results vary across cities within the state for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zone, and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

As can be seen in Table 13-6, the average reduction in energy use for all building types from adopting the *ASHRAE 90.1-2007* varies little both across and within climate zones. For the *ASHRAE 90.1-2007* design, the percentage change in average energy use ranges from -2.7 % to -4.1 % with an average of -3.4 %. For the LEC design, the percentage change varies both within and across climate zones, with average energy use ranging from -15.7 % to -21.3 % and an average of -17.8 %. Across both building design alternatives, the city in the warmer climate zone (Zone 3B) realizes slightly greater reductions in energy use than the cities in the colder climate zone (Zone 4B).

Table 13-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Nevada

Cities	Zone	Standard Edition	
		2007	LEC
Las Vegas	3B	-2.7	-21.3
Elko	4B	-4.0	-16.4
Ely	4B	-4.1	-15.7
Reno	4B	-3.1	-17.9
Tonopah	4B	-2.9	-18.3
Winnemucca	4B	-3.6	-17.2
Average		**-3.4**	**-17.8**

The variations in energy costs across cities are a result of two factors, the reductions in energy use and the fuel source of the reduction. Table 13-7 shows that the average reduction in energy costs for all building types varies across climate zones, but minimally within Zone 4B. For the *ASHRAE 90.1-2007* design, the percentage change in average energy costs ranges from -1.0 % to -3.7 % with an average of -1.7 %. The average percentage change in energy costs is greater for the city in Zone 3B (-3.7 %) than the cities in Zone 4B (-1.3 %). For the LEC design, the percentage change in average energy costs ranges from -21.2 % to -25.0 % with an average of -22.4 %. The city in Zone 3B realizes a slightly greater change in energy use (-25.0 %) than the cities in Zone 4B (-21.9 %).

Table 13-7 Average Percentage Change in Energy Costs by City, 10-Year, Nevada

Cities	Zone	Standard Edition	
		2007	LEC
Las Vegas	3B	-3.7	-25.0
Elko	4B	-1.6	-21.2
Ely	4B	-1.6	-20.8
Reno	4B	-1.1	-22.7
Tonopah	4B	-1.0	-22.8
Winnemucca	4B	-1.4	-21.8
Average		**-1.7**	**-22.4**

Table 13-8 reports energy-related carbon emissions by city for the state. For all cities, the more energy efficient designs result in greater reductions in carbon emissions. The city in Zone 3B realizes a slightly greater average percentage change in carbon emissions than the cities in Zone 4B for *ASHRAE 90.1-2007*, -3.7 % versus -2.4 %. The average emissions reduction varies across cities for the LEC design, ranging from 24.5 % to

20.1 %. Similar to the *ASHRAE 90.1-2007* design, the city in Zone 3B realizes a greater reduction than the cities in Zone 4B.

Table 13-8 Average Percentage Change in Carbon Emissions by City, Nevada

Cities	Zone	Standard Edition	
		2007	LEC
Las Vegas	3B	-3.7	-24.5
Elko	4B	-2.7	-20.1
Ely	4B	-2.7	-19.6
Reno	4B	-2.0	-21.7
Tonopah	4B	-1.9	-22.0
Winnemucca	4B	-2.4	-20.9
Average		**-2.6**	**-21.4**

The data reported in Table 13-9 show that the *ASHRAE 90.1-2007* design decreases life-cycle costs across all cities, with changes in life-cycle costs ranging minimally from -0.3 % to -0.4 %. The LEC design realizes the greatest reduction in life-cycle costs across all cities in the state. There is variation in the average percentage changes in life-cycle costs across climate zones, with Las Vegas in Zone 3B realizing a smaller percentage reduction in life-cycle costs than cities in Zone 4B.

Table 13-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Nevada

Cities	Zone	Standard Edition	
		2007	LEC
Las Vegas	3B	-0.4	**-1.2**
Elko	4B	-0.4	**-1.8**
Ely	4B	-0.3	**-1.6**
Reno	4B	-0.4	**-1.4**
Tonopah	4B	-0.3	**-1.7**
Winnemucca	4B	-0.4	**-1.7**
Average		**-0.4**	**-1.6**

13.2 Total Savings

How much can Nevada 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 13-10 reports the average per unit change in annual energy use by building type and building design in the state.[30] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 13-11 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[31]

Table 13-10 Average Per Unit Change in Annual Energy Use, Nevada

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	-5.9	-1.9	-19.8	-6.3
APART06	-5.0	-1.6	-19.9	-6.3
DORMI04	-5.4	-1.7	-18.4	-5.8
DORMI06	-3.9	-1.2	-20.7	-6.6
HOTEL15	7.8	2.5	-11.5	-3.6
HIGHS02	-6.3	-2.0	-27.9	-8.9
OFFIC03	-7.3	-2.3	-18.4	-5.8
OFFIC08	-3.3	-1.0	-23.5	-7.5
OFFIC16	7.8	2.5	-16.6	-5.3
RETAIL1	-12.9	-4.1	-26.9	-8.5
RSTRNT1	-20.5	-6.5	-62.0	-19.7

The annual reduction in energy use shown in Table 13-11 ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs both decrease total energy use across the state. The adoption of the *ASHRAE 90.1-2007* design results in reductions of 7.3 GWh (24.9 GBtu) annually. *ASHRAE 90.1-2007* increases total energy use for the two high-rise buildings and decreases total energy use for the other seven building types.

[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 13-11 Statewide Change in Annual Energy Use for One Year of Construction, Nevada

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2007		LEC	
				kWh	kBtu	kWh	kBtu
APART04	44.9 %	258	2774	-1 530 929	-5 227 248	-5 107 986	-17 440 860
APART06	55.1 %	316	3397	-1 562 606	-5 335 407	-6 287 910	-21 469 630
HOTEL15	100.0 %	593	6379	4 640 470	15 844 562	-6 815 515	-23 271 098
HIGHS02	100.0 %	192	2067	-1 399 357	-4 778 006	-3 527 286	-12 043 670
OFFIC03	37.4 %	122	1310	-768 263	-2 623 181	-3 399 442	-11 607 158
OFFIC08	40.4 %	131	1413	-433 470	-1 480 054	-3 084 549	-10 531 977
OFFIC16	22.2 %	72	777	561 639	1 917 676	-1 201 279	-4 101 682
RETAIL1	100.0 %	476	5129	-6 169 715	-21 066 059	-12 797 093	-43 694 779
RSTRNT1	100.0 %	31	338	-644 528	-2 200 695	-1 947 196	-6 648 564
Total		**2191**	**23 585**	**-7 306 758**	**-24 948 412**	**-44 168 256**	**-150 809 417**

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

The adoption of the LEC design as the state's energy code for commercial buildings would save 44.2 GWh (150.8 GBtu) of total statewide energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 62.3 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the statewide savings to be 70.9 GWh (242.1 GBtu) per year. These savings imply over 709.0 GWh (2420.7 GBtu) in energy savings over the 10-year study period.

For both building designs, the greatest total changes in energy use are realized by retail stores and hotels because they represent 21.7 % and 27.0 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 14.4 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated changes in energy use for the LEC design -- retail stores and hotels -- only rank 4th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 13-2.

13.2.2 Energy Costs

Table 13-12 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 13-12 Average Per Unit Change in Energy Costs, 10-Year, Nevada

Building Type	Standard Edition			
	2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²
APART04	-$3.12	-$0.29	-$16.76	-$1.56
APART06	-$2.71	-$0.25	-$18.53	-$1.72
DORMI04	-$2.35	-$0.22	-$14.02	-$1.30
DORMI06	-$2.47	-$0.23	-$19.68	-$1.83
HOTEL15	$5.37	$0.50	-$11.62	-$1.08
HIGHS02	-$2.20	-$0.20	-$21.57	-$2.00
OFFIC03	-$3.02	-$0.28	-$19.91	-$1.85
OFFIC08	-$1.09	-$0.10	-$18.55	-$1.72
OFFIC16	$6.62	$0.61	-$15.25	-$1.42
RETAIL1	-$5.40	-$0.50	-$18.40	-$1.71
RSTRNT1	-$7.67	-$0.71	-$44.11	-$4.10

Table 13-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. Overall, reductions in energy costs are greater for the more energy efficient building designs: $1.8 million and $37.2 million for adopting the *ASHRAE 90.1-2007* and LEC designs, respectively. The increase in energy use for the high-rise buildings leads to an increase in energy costs for those buildings for *ASHRAE 90.1-2007*. All building types realize energy cost savings for the LEC design. The energy cost savings are highly correlated with the energy use savings. Assuming that the buildings considered in this study, which represent 62.3 % 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 *ASHRAE 90.1-2007* and LEC design can be extrapolated to estimate the total statewide energy cost savings of $2.9 million and $59.7 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2007	Standard Edition LEC
APART04	44.9 %	258	2774	-\$803 834	-\$4 317 991
APART06	55.1 %	316	3397	-\$855 198	-\$5 847 875
HOTEL15	100.0 %	593	6379	\$3 184 735	-\$6 887 978
HIGHS02	100.0 %	192	2067	-\$579 821	-\$3 823 697
OFFIC03	37.4 %	122	1310	-\$267 936	-\$2 625 327
OFFIC08	40.4 %	131	1413	-\$142 705	-\$2 435 331
OFFIC16	22.2 %	72	777	\$477 927	-\$1 101 376
RETAIL1	100.0 %	476	5129	-\$2 571 122	-\$8 765 631
RSTRNT1	100.0 %	31	338	-\$240 992	-\$1 386 024
Total		**2191**	**23 585**	**-\$1 798 946**	**-\$37 191 230**

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

13.2.3 Energy-related Carbon Emissions

Table 13-14 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 13-14 Average Per Unit Change in Carbon Emissions, 10-Year, Nevada

Building Type	Standard Edition 2007 kg/m^2	Standard Edition 2007 lb/ft^2	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-20.8	-4.3	-98.2	-20.1
APART06	-17.9	-3.7	-106.4	-21.8
DORMI04	-16.7	-3.4	-84.3	-17.3
DORMI06	-15.6	-3.2	-112.5	-23.0
HOTEL15	33.2	6.8	-65.6	-13.4
HIGHS02	-21.9	-4.5	-110.9	-22.7
OFFIC03	-17.1	-3.5	-129.2	-26.5
OFFIC08	-8.7	-1.8	-110.5	-22.6
OFFIC16	38.7	7.9	-87.8	-18.0
RETAIL1	-39.1	-8.0	-113.6	-23.3
RSTRNT1	-57.9	-11.9	-269.7	-55.2

Table 13-15 applies the Table 13-14 results to one year's worth of new building construction in the state to estimate statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs decrease carbon emissions for the state as a whole. The adoption of *ASHRAE 90.1-2007* saves

16 408 metric tons over a 10-year study period. The adoption of the LEC design decreases carbon emissions by 218 244 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC designs can be extrapolated to estimate statewide reductions in carbon emissions of 24 600 metric tons and 327 203 metric tons over the 10-year study period, respectively.

Table 13-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Nevada – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	258	2774	-5369	-25 316
APART06	55.1 %	316	3397	-5637	-33 573
HOTEL15	100.0 %	593	6379	19 660	-38 875
HIGHS02	100.0 %	192	2067	-4207	-21 291
OFFIC03	37.4 %	122	1310	-2082	-15 725
OFFIC08	40.4 %	131	1413	-1136	-14 509
OFFIC16	22.2 %	72	777	2798	-6342
RETAIL1	100.0 %	476	5129	-18 615	-54 140
RSTRNT1	100.0 %	31	338	-1820	-8474
Total		**2191**	**23 585**	**-16 408**	**-218 244**

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

13.2.4 Life-Cycle Costs

Table 13-16 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 13-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Nevada

Building Type	Standard Edition			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$4.01	-$0.37	-$0.86	-$0.08
APART06	-$3.33	-$0.31	-$1.49	-$0.14
DORMI04	-$6.86	-$0.64	-$18.49	-$1.72
DORMI06	-$2.73	-$0.25	-$4.21	-$0.39
HOTEL15	$5.81	$0.54	$7.08	$0.66
HIGHS02	-$2.95	-$0.27	-$12.71	-$1.18
OFFIC03	-$3.59	-$0.33	-$34.35	-$3.19
OFFIC08	-$3.36	-$0.31	-$30.18	-$2.80
OFFIC16	$6.19	$0.58	$5.45	$0.51
RETAIL1	-$7.59	-$0.71	-$4.04	-$0.38
RSTRNT1	-$21.87	-$2.03	-$79.92	-$7.43

Table 13-17 applies the Table 13-16 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of more energy-efficient codes. *ASHRAE 90.1-2007* results in total reductions in life-cycle costs of $3.9 million over the 10-year study period relative to *ASHRAE 90.1-2004* for the building types considered in this study. The LEC design leads to a decrease in total statewide life-cycle costs of $11.1 million, while reducing life-cycle costs for 7 of 9 building types. The *ASHRAE 90.1-2007* and LEC designs lead to an increase in life-cycle costs for hotels and 16-story office buildings. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC designs can be extrapolated to estimate total reductions in life-cycle costs of $6.3 million and $17.9 million over the 10-year study period, respectively.

Table 13-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Nevada

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	258	2774	-$1 032 318	-$222 870
APART06	55.1 %	316	3397	-$1 049 523	-$471 027
HOTEL15	100.0 %	593	6379	$3 445 646	$4 194 240
HIGHS02	100.0 %	192	2067	-$566 368	-$2 440 774
OFFIC03	37.4 %	122	1310	-$436 650	-$4 181 010
OFFIC08	40.4 %	131	1413	-$440 493	-$3 962 275
OFFIC16	22.2 %	72	777	$447 185	$393 917
RETAIL1	100.0 %	476	5129	-$3 617 242	-$1 924 864
RSTRNT1	100.0 %	31	338	-$687 082	-$2 511 213
Total		**2191**	**23 585**	**-$3 936 845**	**-$11 125 878**

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

13.3 State Summary

Nevada is one of two states in the West Census Region that have adopted *ASHRAE 90.1-2004* as their current state energy code for commercial buildings. On average, adopting *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and energy-related carbon emissions, 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 *ASHRAE 90.1-2007* as the state's energy code would lead to energy savings of 117.3 GWh (400.5 GBtu), energy cost savings of $2.9 million, carbon emissions reductions of 24 600 metric tons, and life-cycle cost savings of $6.3 million. The life-cycle cost savings are greater than the energy cost savings. The relaxation of the U-factor and SHGC requirements from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007* decreases the costs of construction by a greater amount than the other energy efficiency measures increase construction costs, while still reducing total energy costs. The LEC design would lead to even greater impacts for the state with savings of 709.0 GWh (2420.7 GBtu), energy cost savings of $59.7 million, and carbon emissions reductions of 327 203 metric tons for one year's worth of commercial building construction while decreasing life-cycle costs by $17.9 million.

14 New Mexico

New Mexico has adopted *ASHRAE 90.1-2007* as its state energy code, is located in the Mountain Census Division, and spans three climate zones (Zone 3B, Zone 4B, and Zone 5B). Table 14-1 provides an overview of New Mexico's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 4-story dormitory uses the least amount of energy at 77 kWh/m^2 to 91 kWh/m^2 (24 kBtu/ft^2 to 29 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 145 kWh/m^2 to 161 kWh/m^2 (46 kBtu/ft^2 to 51 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	118	37	102	32
APART06	117	37	100	32
DORMI04	91	29	77	24
DORMI06	131	42	111	35
HOTEL15	124	39	104	33
HIGHS02	161	51	145	46
OFFIC03	101	32	78	25
OFFIC08	99	31	78	25
OFFIC16	134	42	108	34
RETAIL1	105	33	89	28
RSTRNT1	151	48	104	33

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.

14.1 Percentage Savings

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

14.1.1 Statewide Building Comparison

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*.

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -9.6 % to -31.4 % depending on the building type with an overall average of -17.7 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

Table 14-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, New Mexico

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-13.6	-20.0	-20.0	0.5
APART06	-15.1	-23.0	-23.0	0.3
DORMI04	-15.3	-19.8	-19.8	-1.6
DORMI06	-15.2	-22.8	-22.9	-0.1
HOTEL15	-15.7	-21.1	-21.1	0.4
HIGHS02	-9.6	-19.8	-19.9	-1.0
OFFIC03	-23.3	-25.5	-25.6	-3.1
OFFIC08	-21.4	-22.5	-22.5	-2.8
OFFIC16	-18.9	-21.7	-21.7	0.3
RETAIL1	-15.6	-18.9	-18.9	0.1
RSTRNT1	-31.4	-36.6	-36.6	-4.3
Average	**-17.7**	**-22.9**	**-22.9**	**-1.0**

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 -18.9 % to -36.6 % depending on the building type with an average of -22.9 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. In fact, adopting the LEC design leads to an increase in natural gas consumption and a decrease in electricity consumption for all 11 building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 39.7 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over twice the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 3, 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 -18.9 % to -36.6 % with an overall average of -22.9 %. 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 -4.3 % to 0.5 % for a 10-year study period. Six of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -1.0 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

14.1.2 City Comparisons

Simulations are run for three cities located in New Mexico: Roswell in Zone 3B and Albuquerque and Tucumcari in Zone 4B. New Mexico has no significant population centers located in Zone 5B. The results may vary across cities within New Mexico for several reasons. First, the cities selected for the state cover two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and may impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 14-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design vary minimally across cities, ranging from -16.7 % to -18.3 % with an overall average of -17.7 %. The city located in Zone 3B realizes slightly lower reductions in energy use relative to cities in Zone 4B.

Table 14-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, New Mexico

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Roswell	3B	-16.7	-21.7	-22.0	-0.9
Albuquerque	4B	-18.2	-23.7	-23.9	-1.2
Tucumcari	4B	-18.3	-23.2	-23.5	-1.0
Average		**-17.7**	**-22.9**	**-23.1**	**-1.0**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -21.7 % to -23.7 % for 10 years of operation. For all 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 -22.0 % to -23.9 %. Reductions in life-cycle costs for all building types vary minimally across cities, with the percentage change in life-cycle costs ranging from -0.9 % to -1.2 %.

14.2 Total Savings

How much can New Mexico 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 14-4 reports the average per unit change in annual energy use by building type and building design in the state.[32] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 14-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[33]

Table 14-4 Average Per Unit Change in Annual Energy Use, New Mexico

Building Type	Standard Edition	
	LEC	
	kWh/m²	kBtu/ft²
APART04	-16.0	-5.1
APART06	-17.7	-5.6
DORMI04	-13.8	-4.4
DORMI06	-19.9	-6.3
HOTEL15	-19.4	-6.1
HIGHS02	-23.6	-7.5
OFFIC03	-15.4	-4.9
OFFIC08	-21.2	-6.7
OFFIC16	-25.3	-8.0
RETAIL1	-16.3	-5.2
RSTRNT1	-47.5	-15.1

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 10.2 GWh (34.8 GBtu) of total energy use

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

annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 66.2 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 15.4 GWh (52.5 GBtu) per year. These savings imply 153.7 GWh (525.0 GBtu) in energy use savings over the 10-year study period.

The total change in energy use varies across building types. The building types that have the greatest percentage reductions in energy use are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest reductions in energy use. The greatest total reductions are realized by high schools and retail stores because they represent 28.3 % and 27.8 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 15.5 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and high schools -- only rank 6th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 14-2.

Table 14-5 Statewide Change in Annual Energy Use for One Year of Construction, New Mexico

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	8	86	-128 185	-437 677
APART06	55.1 %	10	105	-173 748	-593 249
HOTEL15	100.0 %	84	900	-1 620 405	-5 532 758
HIGHS02	100.0 %	150	1619	-2 323 480	-7 933 361
OFFIC03	37.4 %	46	497	-1 090 572	-3 723 681
OFFIC08	40.4 %	50	536	-1 057 242	-3 609 880
OFFIC16	22.2 %	27	295	-692 784	-2 365 461
RETAIL1	100.0 %	153	1647	-2 500 657	-8 538 319
RSTRNT1	100.0 %	12	134	-590 866	-2 017 472
Total		**541**	**5819**	**-10 177 939**	**-34 751 859**

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

14.2.2 Energy Costs

Table 14-6 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 14-6 Average Per Unit Change in Energy Costs, 10-Year, New Mexico

Building Type	Standard Edition LEC	
	$\$/m^2$	$\$/ft^2$
APART04	-$12.07	-$1.12
APART06	-$14.04	-$1.30
DORMI04	-$9.79	-$0.91
DORMI06	-$15.44	-$1.43
HOTEL15	-$13.55	-$1.26
HIGHS02	-$16.22	-$1.51
OFFIC03	-$15.05	-$1.40
OFFIC08	-$14.35	-$1.33
OFFIC16	-$17.48	-$1.62
RETAIL1	-$11.57	-$1.07
RSTRNT1	-$31.62	-$2.94

Table 14-7 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 $7.7 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 66.2 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $11.7 million over the 10-year study period.

Table 14-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, New Mexico

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	8	86	-$96 487
APART06	55.1 %	10	105	-$137 422
HOTEL15	100.0 %	84	900	-$1 132 771
HIGHS02	100.0 %	150	1619	-$2 263 571
OFFIC03	37.4 %	46	497	-$748 677
OFFIC08	40.4 %	50	536	-$714 142
OFFIC16	22.2 %	27	295	-$478 623
RETAIL1	100.0 %	153	1647	-$1 769 882
RSTRNT1	100.0 %	12	134	-$393 624
Total		**541**	**5819**	**-$7 735 199**

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

14.2.3 Energy-related Carbon Emissions

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

Building Type	Standard Edition LEC	
	kg/m^2	lb/ft^2
APART04	-151.9	-31.1
APART06	-176.7	-36.2
DORMI04	-123.2	-25.2
DORMI06	-194.4	-39.8
HOTEL15	-170.5	-34.9
HIGHS02	-189.6	-38.8
OFFIC03	-204.1	-41.8
OFFIC08	-180.5	-37.0
OFFIC16	-219.9	-45.0
RETAIL1	-145.5	-29.8
RSTRNT1	-397.7	-81.4

Table 14-9 applies the Table 14-8 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 97 353 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 145 956 metric tons over the 10-year study period.

Table 14-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, New Mexico – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	8	86	-1214
APART06	55.1 %	10	105	-1730
HOTEL15	100.0 %	84	900	-14 251
HIGHS02	100.0 %	150	1619	-28 520
OFFIC03	37.4 %	46	497	-9418
OFFIC08	40.4 %	50	536	-8982
OFFIC16	22.2 %	27	295	-6021
RETAIL1	100.0 %	153	1647	-22 267
RSTRNT1	100.0 %	12	134	-4951
Total		**541**	**5819**	**-97 353**

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

14.2.4 Life-Cycle Costs

Table 14-10 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 14-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, New Mexico

Building Type	Standard Edition LEC $/$m^2$	Standard Edition LEC $/$ft^2$
APART04	$4.41	$0.41
APART06	$2.89	$0.27
DORMI04	-$14.37	-$1.33
DORMI06	-$0.49	-$0.05
HOTEL15	$3.51	$0.33
HIGHS02	-$8.07	-$0.75
OFFIC03	-$23.77	-$2.21
OFFIC08	-$22.22	-$2.06
OFFIC16	$2.21	$0.21
RETAIL1	$0.39	$0.04
RSTRNT1	-$54.62	-$5.07

Table 14-11 applies the Table 14-10 results to one year's worth of new building construction in the state to estimate changes in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $3.6 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools realize the greatest statewide decreases in life-cycle costs ($1.2 million) while hotels, 16-story office buildings, and retail stores realize the greatest increases in life-cycle costs ($293 252, $60 502, and 59 978, 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 $5.5 million over the 10-year study period.

Table 14-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, New Mexico

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	8	86	$35 278
APART06	55.1 %	10	105	$28 293
HOTEL15	100.0 %	84	900	$293 252
HIGHS02	100.0 %	150	1619	-$1 213 908
OFFIC03	37.4 %	46	497	-$1 096 795
OFFIC08	40.4 %	50	536	-$1 105 995
OFFIC16	22.2 %	27	295	$60 502
RETAIL1	100.0 %	153	1647	$59 978
RSTRNT1	100.0 %	12	134	-$680 003
Total		**541**	**5819**	**-$3 619 397**

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

14.3 State Summary

New Mexico 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 153.7 GWh (525.0 GBtu), energy cost savings of $11.7 million, and carbon emissions reductions of 145 956 metric tons while decreasing life-cycle costs by $5.5 million for one year's worth of commercial building construction.

15 Oregon

Oregon has adopted *ASHRAE 90.1-2007* as its state energy code, is located in the Pacific Census Division, and spans two climate zones (Zone 4C and Zone 5B). Table 15-1 provides an overview of Oregon's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 72 kWh/m^2 to 91 kWh/m^2 (23 kBtu/ft^2 to 29 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 179 kWh/m^2 to 188 kWh/m^2 (57 kBtu/ft^2 to 60 kBtu/ft^2).

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

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

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

15.1 Percentage Savings

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

15.1.1 Statewide Building Comparison

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

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

Table 15-2 Average Percentage Change in Energy Use from Adoption of a Newer Standard Edition, 10-Year, Oregon

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

There is a significant variation in the average percentage change in energy costs for the LEC design, ranging from -11.5 % to -33.0 % depending on the building type, with an average of -19.1 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. In fact, for all 11 building types the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 59.9 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over two times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average percentage change in energy-related carbon emissions for the LEC design across building types, ranging from -12.1 % to -33.4 % with an average of -19.4 %. As 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 LEC design results in significant variations in life-cycle costs across building types. Of the 11 building types, 5 realize a reduction in life-cycle costs for a 10-year study period. The percentage change in life-cycle costs for the LEC design ranges from -4.5 % to 1.1 %. Based on the overall average change of -0.6 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

15.1.2 City Comparisons

Simulations are run for 9 cities located in Oregon: Astoria, Eugene, Medford, North Bend, Portland, and Salem in Climate Zone 4C and Burns, Pendleton, and Redmond in Climate Zone 5B. The results vary across cities within the state for several reasons. First, the state is covered by two climate zones. The LEC design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

Table 15-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state.

Table 15-3 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, 10-Year, Oregon

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

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

15.2 Total Savings

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

15.2.1 Energy Use

Table 15-4 reports the average per unit change in annual energy use by building type in the state.[34] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 15-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[35]

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

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

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

The LEC design decreases overall energy use across the state. The adoption of the LEC design as the state's energy code saves energy for all building types and 13.9 GWh (47.4 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 53.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings to be 26.1 GWh (89.2 GBtu) in energy savings per year. These savings imply 261.4 GWh (892.4 GBtu) in energy savings over the 10-year study period.

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

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

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

The statewide change in total energy use varies across building types. Building types that represent a greater amount of new floor area realize the largest changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. For example, the building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and 6-story apartment buildings -- only rank 6th and 8th in percentage reduction, respectively, among the 11 building types, as reported in Table 15-2.

15.2.2 Energy Costs

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

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

Building Type	Standard Edition LEC $/m^2	Standard Edition LEC $/ft^2
APART04	-$8.38	-$0.78
APART06	-$9.70	-$0.90
DORMI03	-$7.51	-$0.70
DORMI06	-$10.26	-$0.95
HOTEL15	-$11.33	-$1.05
HIGHS02	-$9.48	-$0.88
OFFIC03	-$12.39	-$1.15
OFFIC08	-$11.44	-$1.06
OFFIC16	-$14.61	-$1.36
RETAIL1	-$8.25	-$0.77
RSTRNT1	-$24.09	-$2.24

Table 15-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. The LEC design leads to statewide reductions in energy costs of $9.2 million. All building types realize energy cost savings, ranging from $325 917 to $2.3 million. The total reductions in energy costs are correlated with total reductions in energy use, but there is some variation due to the variation in the energy source of the reductions.

Assuming that the buildings considered in this study, which represent 53.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of \$17.4 million over the 10-year study period.

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

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

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

15.2.3 Energy-related Carbon Emissions

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

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

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

Table 15-9 applies the Table 15-8 results to one year’s worth of new building construction in the state to estimate statewide total reduction in carbon emissions from adoption of a more energy efficient code. Adoption of the LEC design as the state's energy code decreases carbon emissions by 77 601 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide reduction in carbon emissions of 146 141 metric tons over the 10-year study period. The total reduction in carbon emissions for each building type is correlated with its total reduction in energy use.

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

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

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

15.2.4 Life-Cycle Costs

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

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

Building Type	Standard Edition LEC $/m^2	$/ft^2
APART04	$10.86	$1.01
APART06	$9.96	$0.93
DORMI04	-$9.75	-$0.91
DORMI06	$7.11	$0.66
HOTEL15	$8.64	$0.80
HIGHS02	-$0.13	-$0.01
OFFIC03	-$28.91	-$2.69
OFFIC08	-$26.16	-$2.43
OFFIC16	$8.19	$0.76
RETAIL1	$5.27	$0.49
RSTRNT1	-$62.04	-$5.76

Table 15-11 applies the Table 15-10 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of a more energy-efficient code. The LEC design leads to an increase in statewide life-cycle costs of $213 782 and increases life-cycle costs for 5 of 9 building types. Retail stores and hotels account for a $2.1 million ($1.5 million and $622 209, respectively) increase in life-cycle costs.

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

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

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

Note: Dormitories are excluded because no such floor area category is

15.3 State Summary

Oregon has adopted *ASHRAE 90.1-2007* as its state commercial building energy code. On average, adopting the LEC design reduces energy use, energy costs, and energy-related carbon emissions, but does not do so in a cost-effective manner. Based on the average annual new commercial construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code would lead to statewide energy savings of 261.4 GWh (892.4 GBtu), energy cost savings of $17.4 million, and carbon emissions reductions of 146 141 metric tons at a life-cycle cost of $402 602 for one year's worth of commercial building construction. Oregon is one of two states in this report that realize an increase in life-cycle costs from adopting the LEC design.

16 Utah

Utah has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the Mountain Census Division, and spans three climate zones (Zone 3B, Zone 5B, and Zone 6B). Table 16-1 provides an overview of Utah's simulated energy use keyed to building types and energy codes. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 78 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 188 kWh/m^2 to 199 kWh/m^2 (60 kBtu/ft^2 to 63 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	134	42	119	38
APART06	132	42	116	37
DORMI04	104	33	90	29
DORMI06	147	47	130	41
HOTEL15	142	45	122	39
HIGHS02	199	63	188	60
OFFIC03	104	33	82	26
OFFIC08	98	31	78	25
OFFIC16	143	45	118	37
RETAIL1	112	36	98	31
RSTRNT1	155	49	113	36

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.

16.1 Percentage Savings

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

16.1.1 Statewide Building Comparison

Table 16-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*.

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -5.9 % to -27.1 % depending on the building type with an overall average of -15.1 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 16-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Utah

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.7	-17.6	-15.7	0.7
APART06	-11.9	-20.5	-18.2	0.6
DORMI04	-12.8	-18.2	-16.8	-1.2
DORMI06	-12.0	-20.1	-18.0	0.3
HOTEL15	-14.2	-20.2	-18.6	0.6
HIGHS02	-5.9	-15.6	-12.8	-0.8
OFFIC03	-20.8	-24.6	-23.7	-3.0
OFFIC08	-20.7	-22.5	-22.1	-2.6
OFFIC16	-17.5	-21.7	-20.8	0.6
RETAIL1	-13.0	-17.3	-16.3	1.2
RSTRNT1	-27.1	-34.7	-32.9	-3.8
Average	**-15.1**	**-21.2**	**-19.6**	**-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 -15.6 % to -34.7 % 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. In fact, adopting the LEC design leads to an increase in natural gas consumption and a decrease in electricity consumption for all 11 building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 52.3 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 2.6 times the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 3 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 -12.8 % to -32.9 % with an average of -19.6 %. 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 -3.8 % to 1.2 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -0.7 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

16.1.2 City Comparisons

Simulations are run for two cities located in Utah, both of which are located in Zone 5B: Cedar City and Salt Lake City. Utah has no significant population centers located in Zone 3B or Zone 6B. 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 16-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage change in energy use for all building types from adopting the LEC design varies minimally between cities, ranging from -14.9 % to -15.4 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 16-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Utah

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Cedar City	5B	-14.9	-21.2	-19.7	-0.7
Salt Lake City	5B	-15.4	-21.2	-19.8	-0.6
Average		**-15.1**	**-21.2**	**-19.7**	**-0.7**

The average percentage change in energy costs for all building types does not vary between cities (-21.2 %) for 10 years of operation. The average percentage change in carbon emissions for all building types varies minimally, with a difference of 0.1 percentage point. For both cities, reductions in energy costs and carbon emissions are greater than reductions in energy use because of the shift from electricity to natural gas consumption. The percentage change in life-cycle costs for all building types only varies by 0.1 percentage point.

16.2 Total Savings

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

16.2.1 Energy Use

Table 16-4 reports the average per unit change in annual energy use by building type and building design in the state.[36] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 16-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[37]

Table 16-4 Average Per Unit Change in Annual Energy Use, Utah

Building Type	Standard Edition LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-14.3	-4.5
APART06	-15.7	-5.0
DORMI04	-13.3	-4.2
DORMI06	-17.7	-5.6
HOTEL15	-20.1	-6.4
HIGHS02	-21.5	-6.8
OFFIC03	-11.8	-3.8
OFFIC08	-20.3	-6.4
OFFIC16	-25.1	-8.0
RETAIL1	-14.6	-4.6
RSTRNT1	-42.1	-13.3

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 16.9 GWh (57.7 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 59.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to

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

be 28.7 GWh (97.8 GBtu) per year. These savings imply 286.6 GWh (978.5 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 a greater amount of new floor area realize the largest changes in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 28.1 % and 25.0 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 10.9 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 6th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 16-2.

Table 16-5 Statewide Change in Annual Energy Use for One Year of Construction, Utah

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	56	602	-801 445	-2 736 477
APART06	55.1 %	68	737	-1 078 497	-3 682 451
HOTEL15	100.0 %	63	677	-1 266 599	-4 324 712
HIGHS02	100.0 %	254	2731	-3 004 218	-10 257 691
OFFIC03	37.4 %	102	1100	-2 198 593	-7 506 942
OFFIC08	40.4 %	110	1187	-2 234 967	-7 631 137
OFFIC16	22.2 %	61	653	-1 520 873	-5 192 914
RETAIL1	100.0 %	285	3066	-4 160 002	-14 204 037
RSTRNT1	100.0 %	15	164	-642 556	-2 193 962
Total		**1014**	**10 917**	**-16 907 748**	**-57 730 322**

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

16.2.2 Energy Costs

Table 16-6 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 16-6 Average Per Unit Change in Energy Costs, 10-Year, Utah

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	-$9.01	-$0.84
APART06	-$10.55	-$0.98
DORMI04	-$7.70	-$0.72
DORMI06	-$11.55	-$1.07
HOTEL15	-$11.45	-$1.06
HIGHS02	-$12.62	-$1.17
OFFIC03	-$11.13	-$1.03
OFFIC08	-$11.48	-$1.07
OFFIC16	-$14.72	-$1.37
RETAIL1	-$8.81	-$0.82
RSTRNT1	-$24.33	-$2.26

Table 16-7 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 $11.1 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 59.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate total statewide energy cost savings of $18.8 million over the 10-year study period.

Table 16-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Utah

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	56	602	-$503 505
APART06	55.1 %	68	737	-$722 168
HOTEL15	100.0 %	63	677	-$719 951
HIGHS02	100.0 %	254	2731	-$2 824 295
OFFIC03	37.4 %	102	1100	-$1 289 985
OFFIC08	40.4 %	110	1187	-$1 265 313
OFFIC16	22.2 %	61	653	-$893 037
RETAIL1	100.0 %	285	3066	-$2 508 674
RSTRNT1	100.0 %	15	164	-$371 550
Total		**1014**	**10 917**	**-$11 098 478**

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

16.2.3 Energy-related Carbon Emissions

Table 16-8 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 16-8 Average Per Unit Change in Carbon Emissions, 10-Year, Utah

Building Type	Standard Edition LEC	
	kg/m²	lb/ft²
APART04	-78.7	-16.1
APART06	-91.2	-18.7
DORMI04	-68.4	-14.0
DORMI06	-100.3	-20.5
HOTEL15	-102.1	-20.9
HIGHS02	-91.4	-18.7
OFFIC03	-111.8	-22.9
OFFIC08	-102.4	-21.0
OFFIC16	-130.4	-26.7
RETAIL1	-77.6	-15.9
RSTRNT1	-216.1	-44.3

Table 16-9 applies the Table 16-8 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 96 278 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 144 345 metric tons over the 10-year study period.

Table 16-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Utah – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	56	602	-4403
APART06	55.1 %	68	737	-6243
HOTEL15	100.0 %	63	677	-6418
HIGHS02	100.0 %	254	2731	-23 184
OFFIC03	37.4 %	102	1100	-11 427
OFFIC08	40.4 %	110	1187	-11 288
OFFIC16	22.2 %	61	653	-7910
RETAIL1	100.0 %	285	3066	-22 105
RSTRNT1	100.0 %	15	164	-3301
Total		**1014**	**10 917**	**-96 278**

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

16.2.4 Life-Cycle Costs

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

Building Type	Standard Edition LEC $\$/m^2$	Standard Edition LEC $\$/ft^2$
APART04	\$5.81	\$0.54
APART06	\$5.14	\$0.48
DORMI04	-\$9.82	-\$0.91
DORMI06	\$2.49	\$0.23
HOTEL15	\$5.02	\$0.47
HIGHS02	-\$5.47	-\$0.51
OFFIC03	-\$20.86	-\$1.94
OFFIC08	-\$18.89	-\$1.75
OFFIC16	\$4.34	\$0.40
RETAIL1	\$6.47	\$0.60
RSTRNT1	-\$42.98	-\$3.99

Table 16-11 applies the Table 16-10 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 $3.2 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Three-story and 8-story office buildings realize the greatest reduction in life-cycle costs (both at $2.1 million). Retail stores realize the greatest increase in life-cycle costs ($1.8 million). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $5.4 million over the 10-year study period.

Table 16-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Utah

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	56	602	$324 756
APART06	55.1 %	68	737	$352 146
HOTEL15	100.0 %	63	677	$315 489
HIGHS02	100.0 %	254	2731	-$1 387 265
OFFIC03	37.4 %	102	1100	-$2 132 105
OFFIC08	40.4 %	110	1187	-$2 081 708
OFFIC16	22.2 %	61	653	$263 132
RETAIL1	100.0 %	285	3066	$1 843 106
RSTRNT1	100.0 %	15	164	-$656 404
Total		**1014**	**10 917**	**-$3 158 854**

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

16.3 State Summary

Utah 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 286.6 GWh (978.5 GBtu), energy cost savings of $18.8 million, and carbon emissions reductions of 144 345 metric tons while decreasing life-cycle costs of $5.4 million for one year's worth of commercial building construction.

17 Washington

Washington has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the Pacific Census Division, and spans three climate zones (Zone 4C, Zone 5B, and Zone 6B). Table 17-1 provides an overview of Washington's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 73 kWh/m^2 to 91 kWh/m^2 (23 kBtu/ft^2 to 29 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 197 kWh/m^2 to 206 kWh/m^2 (63 kBtu/ft^2 to 65 kBtu/ ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	134	42	122	39
APART06	134	42	121	38
DORMI04	105	33	93	29
DORMI06	146	46	132	42
HOTEL15	144	46	126	40
HIGHS02	206	65	197	63
OFFIC03	98	31	79	25
OFFIC08	91	29	73	23
OFFIC16	138	44	115	37
RETAIL1	107	34	94	30
RSTRNT1	147	47	108	34

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

17.1 Percentage Savings

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

17.1.1 Statewide Building Comparison

Table 17-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*. The LEC design realizes changes in energy use ranging from -4.2 % to -26.4 %, with an average of -13.6 %. The lowest reduction in energy use for the LEC design occurs in the high school while the greatest reduction in energy use occurs in restaurants.

Table 17-2 Average Percentage Change from Adoption of a Newer Standard Edition, 10-Year, Washington

Building Type	LEC			
	Energy Use	Energy Costs	Carbon	LCC
APART04	-8.8	-12.8	-14.0	1.2
APART06	-9.4	-14.4	-15.8	1.2
DORMI04	-11.6	-15.0	-16.0	-0.5
DORMI06	-9.2	-14.1	-15.5	0.9
HOTEL15	-12.3	-16.2	-17.2	1.1
HIGHS02	-4.2	-9.4	-10.9	0.2
OFFIC03	-19.6	-21.9	-22.4	-2.7
OFFIC08	-20.0	-21.1	-21.3	-2.3
OFFIC16	-16.2	-19.1	-19.8	1.4
RETAIL1	-12.3	-13.9	-14.3	1.1
RSTRNT1	-26.4	-30.6	-31.6	-3.9
Average	**-13.6**	**-17.1**	**-18.1**	**-0.2**

The LEC design realizes average percentage changes in energy costs over 10 years of building operation ranging from -9.4 % to -30.6 % depending on the building type, with an average of -17.1 % overall. 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 60.8 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over twice the percentage reduction in energy use. The LEC design incorporates daylighting into the building design for all climate zones and overhangs for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

The LEC design leads to average percentage changes in energy-related carbon emissions ranging from -10.9 % to -31.6 %, depending on the building type, with an average of -18.1 % across all building types. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 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 LEC design results in average reductions in life-cycle costs for a 10-year study period for 4 of 11 building types. The average percentage change in life-cycle costs for the LEC design ranges from -3.9 % to 1.4 %. The restaurant and 3- and 8-story office buildings realize the greatest average percentage reductions in life-cycle costs while the 16-story office building and 4- and 6-story apartment buildings realize the greatest average percentage increases in life-cycle costs. Based on the overall average percentage reduction in life-cycle costs of -0.2 %, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

17.1.2 City Comparisons

Simulations are run for five cities located in Washington: Olympia, Quillayute, and Seattle in Climate Zone 4C, and Spokane and Yakima in Climate Zone 5B. Washington has no significant population centers located in Zone 6B. The results may vary across cities within the state for several reasons. First, the cities selected for the state cover two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

As can be seen in Table 17-3, the average percentage change in energy use for all building types from adopting the LEC design varies slightly across cities in the state, ranging from 12.5 % to 14.9 %. There is no distinct trend in energy use across climate zones or based on geographic location. The average reductions in energy costs and carbon emissions for all building types vary slightly across cities throughout the state, and are correlated with the reductions in energy use.

Table 17-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Washington

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Olympia	4C	-13.7	-16.9	-18.2	-0.1
Quillayute	4C	-12.5	-15.8	-17.1	-0.3
Seattle	4C	-14.9	-17.9	-19.1	-0.0
Spokane	5B	-12.8	-16.0	-17.3	-0.4
Yakima	5B	-14.3	-17.5	-18.9	-0.2
Average		**-13.6**	**-16.8**	**-18.1**	**-0.2**

The LEC design results in an average percentage reduction in life-cycle costs relative to *ASHRAE 90.1-2007* across all cities in the state, ranging from 0.0 % to 0.4 %. These cost variations are probably a result of the variation in building envelope design requirements across climate zones combined with different local construction costs across the state. Cities located further north realize smaller percentage reductions in life-cycle costs.

17.2 Total Savings

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

17.2.1 Energy Use

Table 17-4 reports the average per unit change in annual energy use by building type for the LEC design in the state.[38] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 17-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[39]

[38] 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.

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

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

Building Type	Standard Edition	
	LEC	
	kWh/m^2	kBtu/ft^2
APART04	-11.7	-3.7
APART06	-12.6	-4.0
DORMI04	-12.1	-3.8
DORMI06	-13.5	-4.3
HIGHS02	-17.8	-5.6
HOTEL15	-19.2	-6.1
OFFIC03	-8.7	-2.8
OFFIC08	-18.2	-5.8
OFFIC16	-22.2	-7.0
RETAIL1	-13.2	-4.2
RSTRNT1	-38.6	-12.2

The annual reduction in energy use shown in Table 17-5 ranges widely across building types, but the LEC design decreases overall energy use across the state relative to *ASHRAE 90.1-2007*. The adoption of the LEC design as the state's energy code would save energy for all building types, and 31.6 GWh (107.7 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 60.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate total statewide savings to be 52.5 GWh (179.3 GBtu) per year. These savings imply 525.0 GWh (1792.7 GBtu) in energy savings over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	305	3287	-3 584 523	-12 239 103
APART06	55.1 %	374	4026	-4 714 266	-16 096 532
HOTEL15	100.0 %	174	1876	-3 099 194	-10 581 980
HIGHS02	100.0 %	368	3963	-3 213 703	-10 972 965
OFFIC03	37.4 %	182	1962	-3 504 914	-11 967 283
OFFIC08	40.4 %	197	2116	-3 580 610	-12 225 744
OFFIC16	22.2 %	108	1164	-2 401 406	-8 199 434
RETAIL1	100.0 %	501	5391	-6 633 348	-22 649 103
RSTRNT1	100.0 %	21	229	-822 281	-2 807 620
Total		**2231**	**24 014**	**-31 554 246**	**-107 739 765**

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

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. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and 8-story office buildings -- only rank 5th and 2nd in percentage reduction, respectively, among the 11 building types, as reported in Table 17-2.

17.2.2 Energy Costs

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

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

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$7.26	-$0.67
APART06	-$8.18	-$0.76
DORMI04	-$6.88	-$0.64
DORMI06	-$8.74	-$0.81
HIGHS02	-$10.05	-$0.93
HOTEL15	-$10.89	-$1.01
OFFIC03	-$7.97	-$0.74
OFFIC08	-$10.14	-$0.94
OFFIC16	-$12.80	-$1.19
RETAIL1	-$7.24	-$0.67
RSTRNT1	-$21.36	-$1.98

Table 17-7 reports the statewide changes in total energy costs by building type, which account for one year's worth of new construction evaluated over 10 years of building operation. Overall, the reduction in energy costs total $19.4 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. All building types realize energy cost savings for the LEC design. The greatest energy cost savings are realized by the retail stores, 6-story apartment buildings, and high schools. The smallest reductions in energy costs are realized by restaurants. Assuming that the buildings considered in this study, which represent 60.1 % of all new floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate total statewide energy cost savings of $32.3 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	305	3287	-$2 215 913
APART06	55.1 %	374	4026	-$3 061 508
HOTEL15	100.0 %	174	1876	-$1 750 958
HIGHS02	100.0 %	368	3963	-$2 935 810
OFFIC03	37.4 %	182	1962	-$1 985 464
OFFIC08	40.4 %	197	2116	-$1 992 427
OFFIC16	22.2 %	108	1164	-$1 384 175
RETAIL1	100 %	501	5391	-$3 626 508
RSTRNT1	100 %	21	229	-$455 238
Total		**2231**	**24 014**	**-$19 408 003**

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

17.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition	
	LEC	
	kg/m^2	lb/ft^2
APART04	-66.6	-13.6
APART06	-75.7	-15.5
DORMI04	-62.1	-12.7
DORMI06	-80.8	-16.6
HOTEL15	-90.6	-18.6
HIGHS02	-77.4	-15.8
OFFIC03	-98.3	-20.1
OFFIC08	-91.1	-18.7
OFFIC16	-115.9	-23.7
RETAIL1	-64.9	-13.3
RSTRNT1	-191.9	-39.3

Table 17-9 applies the Table 17-8 results to one year's worth of new building construction in the state to estimate statewide energy-related 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 the reductions in energy use. The adoption of the LEC design as the state's energy code for commercial buildings decreases carbon emissions by 177 881 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new building stock in the state, the results for the LEC design can be extrapolated to estimate total statewide reductions in carbon emissions of 266 687 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	305	3287	-20 328
APART06	55.1 %	374	4026	-28 327
HOTEL15	100.0 %	174	1876	-15 792
HIGHS02	100.0 %	368	3963	-28 491
OFFIC03	37.4 %	182	1962	-17 916
OFFIC08	40.4 %	197	2116	-17 915
OFFIC16	22.2 %	108	1164	-12 533
RETAIL1	100.0 %	501	5391	-32 490
RSTRNT1	100.0 %	21	229	-4089
Total		**2231**	**24 014**	**-177 881**

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

17.2.4 Life-Cycle Costs

Table 17-10 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values. The average change in life-cycle costs per unit of floor area varies significantly across building types.

Table 17-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Washington

Building Type	Standard Edition LEC $/m²	Standard Edition LEC $/ft²
APART04	$12.15	$1.13
APART06	$11.94	$1.11
DORMI03	-$4.56	-$0.42
DORMI06	$9.12	$0.85
HOTEL15	$10.67	$0.99
HIGHS02	$1.92	$0.18
OFFIC03	-$21.78	-$2.02
OFFIC08	-$18.87	-$1.75
OFFIC16	$11.08	$1.03
RETAIL1	$7.41	$0.69
RSTRNT1	-$50.53	-$4.69

Table 17-11 applies the Table 17-10 results to one year's worth of new building construction in the state to estimate statewide change in total life-cycle costs from adoption of the LEC design. Adopting the LEC design increases total life-cycle costs by

$6.9 million, and reduces costs for three of the nine building types. Three-story and 8-story office buildings realize the greatest reductions in life-cycle costs while the apartment buildings and retail stores realize the greatest increases in life-cycle costs. Assuming that the buildings considered in this study are generally representative of the entire new building stock in the state, the results for the LEC design can be extrapolated to estimate an increase in total statewide life-cycle costs of $11.5 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	305	3287	$3 709 628
APART06	55.1 %	374	4026	$4 465 686
HOTEL15	100.0 %	174	1876	$1 859 063
HIGHS02	100.0 %	368	3963	$705 477
OFFIC03	37.4 %	182	1962	-$3 969 185
OFFIC08	40.4 %	197	2116	-$3 709 139
OFFIC16	22.2 %	108	1164	$1 197 957
RETAIL1	100.0 %	501	5391	$3 710 487
RSTRNT1	100.0 %	21	229	-$1 076 982
Total		**2231**	**24 014**	**$6 892 993**

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

17.3 State Summary

Washington 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 sizeable total energy use, energy cost, and carbon emissions reductions while increasing life-cycle costs. Based on the average annual new commercial construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to energy savings of 525.0 GWh (1792.7 GBtu), energy cost savings of $32.3 million, and carbon emissions savings of 266 687 metric tons while increasing life-cycle costs by $11.5 million for one year's worth of commercial building construction. Washington is one of two states in this report that realize an increase in life-cycle costs from adopting the LEC design.

18 Wyoming

Wyoming is located in the Mountain Census Division and spans three climate zones (Zone 5B, Zone 6B, 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 18-1 provides an overview of Wyoming's simulated energy use keyed to building types and energy standard editions. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 82 kWh/m^2 to 116 kWh/m^2 (26 kBtu/ft^2 to 37 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 227 kWh/m^2 to 257 kWh/m^2 (72 kBtu/ft^2 to 81 kBtu/ft^2) annually.

Table 18-1 Average Annual Energy Use by Building Type and Standard Edition, Wyoming

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	175	56	175	55	160	51	151	48	135	43
APART06	171	54	171	54	156	49	149	47	133	42
DORMI04	140	45	139	44	129	41	120	38	103	33
DORMI06	187	59	186	59	170	54	167	53	151	48
HOTEL15	171	54	170	54	156	49	164	52	147	47
HIGHS02	257	81	256	81	252	80	243	77	227	72
OFFIC03	126	40	124	39	117	37	109	35	88	28
OFFIC08	116	37	114	36	105	33	100	32	82	26
OFFIC16	157	50	156	49	147	47	156	50	137	43
RETAIL1	153	48	152	48	142	45	127	40	106	34
RSTRNT1	216	69	213	68	200	63	168	53	125	40

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

18.1 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 Wyoming.

18.1.1 Energy Use

Table 18-2 shows a small change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999*, with all 11 building types realizing a reduction of 1.8 % or less. There is significant variation in the decrease in energy use across the 11 building types from adopting the *ASHRAE 90.1-2004* design, with the percentage ranging from -1.8 % to -9.8 % with an average of -7.6 %.

Table 18-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Wyoming

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.4	-8.8	-13.7	-22.7
APART06	-0.4	-9.1	-13.3	-22.5
DORMI04	-1.1	-8.4	-14.9	-26.9
DORMI06	-0.4	-8.9	-10.6	-19.1
HOTEL15	-0.7	-8.9	-4.0	-13.8
HIGHS02	-0.4	-1.8	-5.2	-11.5
OFFIC03	-1.4	-7.1	-13.3	-30.1
OFFIC08	-1.8	-9.8	-13.7	-29.2
OFFIC16	-0.8	-6.1	-0.4	-12.8
RETAIL1	-0.7	-7.2	-16.9	-30.5
RSTRNT1	-1.4	-7.4	-22.4	-42.3
Average	**-0.9**	**-7.6**	**-11.7**	**-23.8**

The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -0.4 % to -22.4 %, with an overall average of -11.7 %. For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum allowable window SHGC in Zone 6 is increased from *ASHRAE 90.1-2004* to *ASHRAE 90.1-2007* for buildings with fenestration accounting for greater than 40 % of total wall surface area. The 100 % glazing amplifies the impact of this requirement relaxation enough to overwhelm the energy efficiency gains obtained from other measures, such as increased insulation R-values.

The LEC design realizes the greatest reductions in energy use, with the change in energy use relative to *ASHRAE 90.1-1999* ranging from -11.5 % to -42.3 % with an average of -23.8 %. The smallest reduction for the LEC design occurs in the high school, 16-story office building, and hotel. For the high-rise buildings, these small reductions are a result of the 100 % glazing combined with the relaxed SHGC requirement. The high school realizes small reductions in energy use because of its unique occupant activity, significant occupancy during the school year and minimal occupancy during the summer.

18.1.2 Energy Costs

Table 18-3 shows a small percentage change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.5 % to -2.0 %), which mirrors the energy use results described above. There is a significant variation in the percentage change in average energy costs for *ASHRAE 90.1-2004*, ranging from -6.9 % to -21.2 % depending on the building type with an average of -15.7 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -3.8 % to -24.6 %, with an overall average of -17.4 %. The LEC design realizes the greatest change in energy costs, ranging from -16.2 % to -46.2 % with an average of -31.7 % overall.

Table 18-3 Average Percentage Change in Energy Costs, 10-Year, Wyoming

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.5	-21.0	-24.0	-36.6
APART06	-0.6	-21.2	-23.7	-36.3
DORMI04	-1.5	-21.2	-24.6	-38.4
DORMI06	-0.6	-20.8	-21.8	-33.4
HOTEL15	-0.9	-19.9	-14.3	-24.7
HIGHS02	-0.6	-6.9	-9.4	-21.2
OFFIC03	-1.6	-11.0	-13.6	-31.8
OFFIC08	-2.0	-12.6	-14.0	-30.1
OFFIC16	-1.0	-10.2	-3.8	-16.2
RETAIL1	-0.9	-13.4	-18.9	-34.0
RSTRNT1	-1.8	-14.7	-22.9	-46.2
Average	**-1.1**	**-15.7**	**-17.4**	**-31.7**

Adoption of the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs lead to average reductions in energy costs that are greater than the reductions in energy use for all 11 building types. Each of these building types realizes a greater percentage reduction in electricity consumption than natural gas consumption. Since electricity is more expensive than natural gas on a per unit of energy basis, the average reduction in energy costs is increased for the building.

18.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small percentage reductions (2.0 % or less) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 18-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -6.8 % to -21.1 % with an average of -15.6 %. 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 -3.7 % to -24.5 % with an overall average of -17.3 %. The LEC design leads to the greatest average changes in carbon emissions, ranging from -16.1 %

to -46.1 % depending on the building type with an average of -31.6 % across all building types.

Table 18-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Wyoming

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.5	-20.8	-23.9	-36.4
APART06	-0.6	-21.1	-23.6	-36.2
DORMI04	-1.4	-21.1	-24.5	-38.3
DORMI06	-0.6	-20.7	-21.7	-33.2
HOTEL15	-0.9	-19.7	-14.2	-24.6
HIGHS02	-0.6	-6.8	-9.3	-21.1
OFFIC03	-1.6	-10.9	-13.6	-31.8
OFFIC08	-2.0	-12.6	-14.0	-30.0
OFFIC16	-1.0	-10.1	-3.7	-16.1
RETAIL1	-0.9	-13.4	-18.9	-34.0
RSTRNT1	-1.8	-14.6	-22.9	-46.1
Average	**-1.1**	**-15.6**	**-17.3**	**-31.6**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. Similar to energy costs, all building types realize greater percentage reductions in carbon emissions than the percentage changes in energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The relatively greater reduction in electricity increases the overall average emissions rate per unit of reduction in energy use.

18.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 18-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for all 11 building types over a 10-year study period. The current state energy code is the lowest cost option for three building types. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building design for two and four building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -2.3 % to 4.0 % depending on building type. The LEC design is the lowest cost building design for two building types and realizes a reduction in life-cycle costs for 6 of 11 building types, with the change in life-cycle costs ranging from -1.8 % to 1.3 %. Based on the overall average percentage change in life-cycle costs of -0.5 %, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

Table 18-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Wyoming

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.1	-1.6	**-2.0**	-1.4
APART06	0.0	-1.6	**-1.9**	-1.3
DORMI04	3.5	0.9	0.4	**-0.9**
DORMI06	0.0	-2.1	**-2.2**	-1.8
HOTEL15	0.0	**-2.3**	-1.8	-1.3
HIGHS02	0.6	-0.1	-0.6	**-1.3**
OFFIC03	5.1	2.5	2.2	0.3
OFFIC08	5.2	2.5	2.2	0.7
OFFIC16	0.0	**-1.0**	-0.4	0.1
RETAIL1	2.7	0.3	**-0.9**	0.4
RSTRNT1	6.8	4.0	1.6	1.3
Average	**2.2**	**0.1**	**-0.3**	**-0.5**

18.1.5 City Comparisons

Simulations are run for five cities located in Wyoming, all of which are located in Zone 6B: Casper, Cheyenne, Lander, Rock Springs, and Sheridan. There are no significant population centers in the counties of Wyoming located in Zone 5B or Zone 7.While the cities are all located in Zone 6B, 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.

As can be seen in Table 18-6, average reductions in energy use for all building types from adopting newer energy standard editions vary minimally within the climate zone. The variation between cities from adopting the *ASHRAE 90.1-2001*, *-2004*, *-2007*, and LEC designs is 0.1, 1.7, 1.2, and 1.8 percentage points, respectively. There is minimal impact on energy use from variation in weather within the climate zone.

Table 18-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Wyoming

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Casper	6B	-0.8	-7.6	-11.6	-23.7
Cheyenne	6B	-0.8	-8.3	-12.3	-24.9
Lander	6B	-0.9	-8.0	-11.9	-24.0
Rock Springs	6B	-0.9	-6.6	-11.1	-23.2
Sheridan	6B	-0.9	-7.5	-11.4	-23.1
Average		**-0.9**	**-7.6**	**-11.7**	**-23.8**

The variations in energy costs across cities are a result of two factors, the reductions in energy use and the fuel source of the reductions. Table 18-7 shows that 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. Similar to energy use, there is minimal variation in energy costs across cities in Wyoming for all building designs.

Table 18-7 Average Percentage Change in Energy Costs by City, 10-Year, Wyoming

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Casper	6B	-1.1	-15.4	-17.0	-31.3
Cheyenne	6B	-1.0	-16.1	-17.6	-32.3
Lander	6B	-1.1	-15.6	-17.1	-31.5
Rock Springs	6B	-1.1	-16.4	-18.3	-32.5
Sheridan	6B	-1.1	-15.2	-16.8	-30.9
Average		**-1.1**	**-15.7**	**-17.4**	**-31.7**

Table 18-8 reports changes in energy-related carbon emissions by city for Wyoming. For all cities, the more stringent standard editions result in greater reductions in carbon emissions. Similar to energy costs, the percentage reductions in carbon emissions are greater than percentage reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. There is minimal variation in carbon emissions across cities in Wyoming for all building designs.

Table 18-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Wyoming

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Casper	6B	-1.0	-14.6	-16.6	-31.1
Cheyenne	6B	-0.9	-15.3	-17.2	-32.1
Lander	6B	-1.0	-14.8	-16.7	-31.3
Rock Springs	6B	-1.0	-15.5	-17.8	-32.2
Sheridan	6B	-1.0	-14.5	-16.4	-30.7
Average		**-1.0**	**-15.0**	**-17.0**	**-31.5**

The data reported in Table 18-9 show that, over a 10-year period, average life-cycle costs increase for all cities for the *ASHRAE 90.1-2001* design and four of five cities for the *ASHRAE 90.1-2004* design compared to *ASHRAE 90.1-1999*. Adoption of the *ASHRAE 90.1-2007* and LEC designs results in average reductions in life-cycle costs for all cities relative to *ASHRAE 90.1-1999*. Adoption of the LEC design realizes the greatest average percentage reductions in life-cycle costs for all cities. Rock Springs realizes greater percentage reductions in life-cycle costs relative to the other four cities, which may be a result of variation in local construction costs.

Table 18-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Wyoming

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Casper	6B	2.2	0.2	-0.2	**-0.4**
Cheyenne	6B	2.1	0.2	-0.3	**-0.3**
Lander	6B	2.2	0.2	-0.2	**-0.4**
Rock Springs	6B	2.3	-0.2	-0.6	**-0.9**
Sheridan	6B	2.1	0.2	-0.2	**-0.4**
Average		**2.2**	**0.1**	**-0.3**	**-0.5**

18.2 Total Savings

How much can Wyoming 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.

18.2.1 Energy Use

Table 18-10 reports the average per unit change in annual energy use by building type and building design in the state.[40] 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 18-11 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.[41]

[40] 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.
[41] State-level subcategory data are not available.

Table 18-10 Average Per Unit Change in Annual Energy Use, Wyoming

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	-15.4	-4.9	-24.0	-7.6	-39.8	-12.6
APART06	-0.7	-0.2	-15.6	-4.9	-22.9	-7.3	-38.5	-12.2
DORMI04	-1.5	-0.5	-11.7	-3.7	-20.9	-6.6	-37.8	-12.0
DORMI06	-0.8	-0.3	-16.6	-5.3	-19.7	-6.3	-35.7	-11.3
HOTEL15	-1.1	-0.4	-15.1	-4.8	-6.7	-2.1	-23.6	-7.5
HIGHS02	-1.0	-0.3	-8.9	-2.8	-16.8	-5.3	-37.8	-12.0
OFFIC03	-1.7	-0.5	-4.6	-1.5	-13.4	-4.3	-29.5	-9.4
OFFIC08	-2.1	-0.7	-11.3	-3.6	-15.9	-5.0	-33.8	-10.7
OFFIC16	-1.2	-0.4	-9.6	-3.0	-0.6	-0.2	-20.1	-6.4
RETAIL1	-1.1	-0.3	-11.0	-3.5	-25.8	-8.2	-46.7	-14.8
RSTRNT1	-3.0	-1.0	-16.1	-5.1	-48.3	-15.3	-91.4	-29.0

The annual reduction in energy use shown in Table 18-11 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 152 MWh (520 MBtu), 1.3 GWh (4.3 GBtu), and 2.0 GWh (6.8 GBtu), respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 4.4 GWh (14.9 GBtu) of total energy use annually for one year's worth of new construction for these building types.

Table 18-11 Statewide Change in Annual Energy Use for One Year of Construction, Wyoming

Building Type	Subcat. Weight.	m² (1000s)	ft² (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	kWh	kBtu	kWh	kBtu
APART04	44.9 %	0	4	-0	-1	-5	-18	-8	-29	-14	-48
APART06	55.1 %	0	5	-0	-1	-7	-23	-10	-34	-17	-56
HOTEL15	100.0 %	33	357	-37	-128	-503	-1717	-224	-765	-784	-2676
HIGHS02	100.0 %	51	547	-51	-173	-235	-802	-684	-2335	-1499	-5120
OFFIC03	37.4 %	5	53	-8	-29	-44	-151	-83	-284	-188	-640
OFFIC08	40.4 %	5	58	-11	-39	-60	-207	-85	-291	-181	-618
OFFIC16	22.2 %	3	32	-4	-12	-28	-97	-2	-6	-59	-202
RETAIL1	100.0 %	32	339	-35	-118	-347	-1183	-812	-2772	-1470	-5020
RSTRNT1	100.0 %	2	19	-5	-19	-29	-99	-87	-297	-165	-563
Total		**131**	**1414**	**-152**	**-520**	**-1258**	**-4296**	**-1995**	**-6812**	**-4376**	**-14 942**

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 57.1% of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from adopting the LEC design in new commercial buildings to be 7.7 GWh (26.2 GBtu) per year. These savings imply 76.6 GWh (261.7 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 3.5 GWh (11.9 GBtu) annually or 34.9 GWh (119.3 GBtu) over the 10-year study period.

The statewide change in energy use across the 9 building types with reported floor area data varies across and within building designs. The building types that represent the greatest amount of new floor area have a greater impact on aggregate reductions in energy use regardless of their relative percentage reductions. The greatest total reductions are realized by retail stores, high schools, and hotels because they represent 24.0 %, 38.7 %, and 25.3 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 4.1 % or less. 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. These same three building types -- retail stores, high schools, and hotels -- rank 2nd, 11th, and 9th in percentage reduction, respectively, among the 11 building types, as reported in Table 18-2.

18.2.2 Energy Costs

Table 18-12 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 18-12 Average Per Unit Change in Energy Costs, 10-Year, Wyoming

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	-$0.38	-$0.04	-$15.06	-$1.40	-$17.23	-$1.60	-$26.29	-$2.44
APART06	-$0.40	-$0.04	-$15.14	-$1.41	-$16.93	-$1.57	-$25.97	-$2.41
DORMI04	-$0.88	-$0.08	-$12.81	-$1.19	-$14.83	-$1.38	-$23.17	-$2.15
DORMI06	-$0.46	-$0.04	-$16.22	-$1.51	-$16.98	-$1.58	-$25.97	-$2.41
HOTEL15	-$0.65	-$0.06	-$14.37	-$1.34	-$10.33	-$0.96	-$17.86	-$1.66
HIGHS02	-$0.98	-$0.09	-$6.70	-$0.62	-$8.34	-$0.77	-$19.45	-$1.81
OFFIC03	-$0.58	-$0.05	-$6.30	-$0.59	-$8.55	-$0.79	-$19.34	-$1.80
OFFIC08	-$1.23	-$0.11	-$7.60	-$0.71	-$8.45	-$0.79	-$18.14	-$1.69
OFFIC16	-$0.72	-$0.07	-$7.60	-$0.71	-$2.82	-$0.26	-$12.05	-$1.12
RETAIL1	-$0.63	-$0.06	-$9.12	-$0.85	-$12.85	-$1.19	-$23.07	-$2.14
RSTRNT1	-$1.74	-$0.16	-$13.86	-$1.29	-$21.65	-$2.01	-$43.54	-$4.04

Table 18-13 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 the smallest reductions in energy costs ($112 544). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $1.4 million, $1.5 million, and $3.0 million, respectively. Assuming that the buildings considered in this study, which represent 57.1 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of $197 099, $2.4 million, $2.6 million, and $5.3 million over the 10-year study period, respectively.

Table 18-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Wyoming

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	0	4	-$639	-$25 282	-$28 915	-$44 127
APART06	55.1 %	0	5	-$814	-$31 127	-$34 816	-$53 387
HOTEL15	100.0 %	33	357	-$16 363	-$362 423	-$260 356	-$450 335
HIGHS02	100.0 %	51	547	-$17 907	-$196 333	-$266 233	-$602 434
OFFIC03	37.4 %	5	53	-$16 549	-$113 132	-$140 843	-$328 458
OFFIC08	40.4 %	5	58	-$22 419	-$138 464	-$153 885	-$330 286
OFFIC16	22.2 %	3	32	-$7170	-$76 112	-$28 209	-$120 720
RETAIL1	100.0 %	32	339	-$26 264	-$379 698	-$535 000	-$960 020
RSTRNT1	100.0 %	2	19	-$4418	-$35 277	-$55 102	-$110 826
Total		**131**	**1414**	**-$112 544**	**-$1 357 848**	**-$1 503 359**	**-$3 000 595**

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

18.2.3 Energy-related Carbon Emissions

Table 18-14 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 18-14 Average Per Unit Change in Carbon Emissions, 10-Year, Wyoming

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	-4.4	-0.9	-172.4	-35.3	-197.5	-40.4	-301.5	-61.8
APART06	-4.5	-0.9	-173.3	-35.5	-194.1	-39.7	-297.8	-61.0
DORMI04	-10.1	-2.1	-146.5	-30.0	-170.0	-34.8	-265.9	-54.5
DORMI06	-5.2	-1.1	-185.6	-38.0	-194.5	-39.8	-297.7	-61.0
HOTEL15	-7.5	-1.5	-164.5	-33.7	-118.0	-24.2	-204.7	-41.9
HIGHS02	-6.6	-1.4	-72.0	-14.8	-98.1	-20.1	-221.9	-45.4
OFFIC03	-11.3	-2.3	-76.8	-15.7	-95.9	-19.6	-223.5	-45.8
OFFIC08	-14.1	-2.9	-87.2	-17.9	-97.1	-19.9	-208.4	-42.7
OFFIC16	-8.2	-1.7	-87.0	-17.8	-32.1	-6.6	-138.3	-28.3
RETAIL1	-7.2	-1.5	-104.5	-21.4	-147.8	-30.3	-265.2	-54.3
RSTRNT1	-19.9	-4.1	-158.7	-32.5	-249.1	-51.0	-500.7	-102.5

Table 18-15 applies the Table 18-14 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 13 943 metric tons and 15 252 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 30 201 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 24 419 metric tons, 26 710 metric tons, and 52 892 metric tons over the 10-year study period, respectively.

Table 18-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Wyoming – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2001	2004	2007	LEC
APART04	44.9 %	0	4	-2	-60	-69	-106
APART06	55.1 %	0	5	-2	-74	-83	-128
HOTEL15	100.0 %	33	357	-247	-5463	-3917	-6796
HIGHS02	100.0 %	51	547	-336	-3664	-4988	-11 284
OFFIC03	37.4 %	5	53	-56	-381	-475	-1108
OFFIC08	40.4 %	5	58	-76	-466	-519	-1114
OFFIC16	22.2 %	3	32	-24	-256	-94	-407
RETAIL1	100.0 %	32	339	-228	-3293	-4656	-8356
RSTRNT1	100.0 %	2	19	-36	-286	-449	-902
Total		**131**	**1414**	**-1006**	**-13 943**	**-15 252**	**-30 201**

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

18.2.4 Life-Cycle Costs

Table 18-16 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 18-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Wyoming

Building Type	Standard Edition 2001 $/m²	2001 $/ft²	2004 $/m²	2004 $/ft²	2007 $/m²	2007 $/ft²	LEC $/m²	LEC $/ft²
APART04	$0.64	$0.06	-$14.21	-$1.32	-$18.23	-$1.69	-$12.70	-$1.18
APART06	$0.20	$0.02	-$14.49	-$1.35	-$17.38	-$1.61	-$11.27	-$1.05
DORMI04	$29.33	$2.73	$7.68	$0.71	$2.91	$0.27	-$7.58	-$0.70
DORMI06	-$0.05	$0.00	-$19.29	-$1.79	-$20.42	-$1.90	-$16.74	-$1.56
HOTEL15	-$0.27	-$0.03	-$20.14	-$1.87	-$15.85	-$1.47	-$11.57	-$1.07
HIGHS02	$4.53	$0.42	-$1.09	-$0.10	-$4.54	-$0.42	-$9.67	-$0.90
OFFIC03	$35.27	$3.28	$17.06	$1.59	$15.33	$1.42	$1.75	$0.16
OFFIC08	$37.22	$3.46	$17.84	$1.66	$15.97	$1.48	$4.89	$0.45
OFFIC16	$0.01	$0.00	-$6.97	-$0.65	-$2.77	-$0.26	$0.57	$0.05
RETAIL1	$15.46	$1.44	$1.60	$0.15	-$5.33	-$0.50	$2.11	$0.20
RSTRNT1	$75.40	$7.01	$44.91	$4.17	$17.62	$1.64	$14.03	$1.30

Table 18-17 applies the Table 18-16 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 8 of 9 building types and increases total life-cycle costs by $2.2 million. Adopting the *ASHRAE 90.1-2004* design results in a decrease in life-cycle costs for 5 of 9 building types, and increases total life-cycle costs by $128 730. Adopting the *ASHRAE 90.1-2007* design results in a decrease in life-cycle costs for 6 of 9 building types, and decreases total life-cycle costs by $262 329. The LEC design decreases life-cycle costs for 4 of 9 building types, and decreases total life-cycle costs by $389 675. For a 10-year study period, it is cost-effective overall to adopt the *ASHRAE 90.1-2007* and LEC designs as Wyoming's state energy code for commercial buildings. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the adoption of the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC design can be extrapolated to estimate statewide changes in life-cycle costs of $3.9 million, $225 446, -$459 421, and -$682 443 over the 10-year study period, respectively.

Table 18-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Wyoming

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	0	4	$1076	-$23 859	-$30 598	-$21 315
APART06	55.1 %	0	5	$410	-$29 785	-$35 740	-$23 168
HOTEL15	100.0 %	33	357	-$6885	-$507 760	-$399 523	-$291 730
HIGHS02	100.0 %	51	547	$141 233	-$33 972	-$141 266	-$301 257
OFFIC03	37.4 %	5	53	$595 478	$288 111	$258 801	$29 533
OFFIC08	40.4 %	5	58	$677 748	$324 766	$290 883	$89 095
OFFIC16	22.2 %	3	32	$90	-$69 818	-$27 727	$5726
RETAIL1	100.0 %	32	339	$643 268	$66 718	-$222 013	$87 715
RSTRNT1	100.0 %	2	19	$191 939	$114 327	$44 852	$35 726
Total		131	1414	**$2 244 356**	**$128 730**	**-$262 329**	**-$389 675**

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

18.3 State Summary

Wyoming is one of three states in the West Census Region that have not yet adopted a state energy code for commercial buildings. On average, adopting *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and cradle-to-grave 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 *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 34.9 GWh (119.3 GBtu), energy cost savings of $2.6 million, and 22 866 metric tons of carbon emissions reductions while decreasing life-cycle costs by $459 421 for one year's worth of commercial building construction. Adopting the LEC design would be lead to even greater impacts than adopting *ASHRAE 90.1-2007*, with savings of 76.6 GWh (261.7 GBtu), $5.3 million of energy costs, and 45 279 metric tons of carbon emissions while decreasing life-cycle costs by $682 443 for one year's worth of commercial building construction.

19 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 West 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 three states with no state energy code and the two states that have adopted *ASHRAE 90.1-2001* would realize greater benefits from adopting the LEC design relative to the other eleven states in the West Census Region that have adopted the more energy efficient *ASHRAE 90.1-2007*.

19.1 Total Savings Comparison

By comparing the aggregate results from the detailed state-by-state analysis, some interesting trends emerge. Table 19-1 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 West 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 19-1 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)
AK	1999	290 (3116)	99.4	9.8	58.4	2.4
AZ	1999	4758 (51 214)	1857.5	135.6	1254.7	79.1
CA	2007	14 492 (155 996)	2543.2	305.6	1372.0	124.9
CO	2001	3292 (35 437)	1112.9	72.7	1126.2	59.7
HI	2004	536 (5773)	138.4	23.9	123.8	13.9
ID	2007	802 (8629)	139.9	7.6	69.9	1.5
MT	2007	238 (2562)	52.5	2.9	24.1	0.5
NM	2007	817 (8790)	153.7	11.7	146.0	5.5
NV	2004	3516 (37 844)	709.0	59.7	327.2	17.9
OR	2007	1745 (18 788)	261.4	17.4	146.1	-0.4
UT	2007	1718 (18 492)	286.6	18.8	144.3	5.4
WA	2007	3710 (39 937)	525.0	32.3	266.7	-11.5
WY	1999	230 (2477)	76.6	5.3	52.9	0.7
Total		**36 144 (389 056)**	**7956.1**	**703.3**	**4878.4**	**299.6**

Total energy use savings varies across states for a number of reasons. First, states with more newly constructed commercial floor area realize greater reductions in energy use. Second, states located in warmer climate zones realize greater reductions in energy use than the states located in colder climate zones because the buildings in warmer climates benefit more from the overhangs and daylighting installed in the LEC design. Third, a state's current state energy code for commercial buildings drives variation in energy use across states.

Consider the reductions in energy use for three states with similar amounts of new floor area: Colorado, Nevada, and Washington. Of these three states, Colorado realizes the greatest amount of total reductions in energy use (1112.9 GWh) followed by Nevada (709.0 GWh) and Washington (525.0 GWh). Even though Colorado has less new floor area construction than Nevada or Washington, it realizes greater total reductions because Colorado has adopted an older edition of *ASHRAE 90.1* (*-2001*) as its state energy code than have Nevada (*-2004*) and Washington (*-2007*).

Table 19-2 shows the 10-year reduction in energy use per unit of newly constructed floor area by state. The reduction in energy use per unit of floor area also is driven by the state's adopted energy code for commercial buildings. The greatest reduction in energy use per unit of floor area resulting from adoption of the LEC design is realized by the four states that have no state energy code or have adopted *ASHRAE 90.1-2001*, ranging from 333 kWh/m^2 (106 $kBtu/ft^2$) to 390 kWh/m^2 (124 $kBtu/ft^2$). The states that have adopted *ASHRAE 90.1-2004* and *-2007* realize reductions ranging from 141 kWh/m^2 (45 kBtu/ft^2) to 258 kWh/m^2 (82 kBtu/ft^2).

Table 19-2 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC Design by State, 10-Year

State	Code	Floor Area Ranking	Average Annual New Floor Area 1000 m^2 (1000 ft^2)	Energy Use Reduction		
				GWh	kWh/m^2	kBtu/ft^2
AZ	1999	8	4758 (51 214)	1857.5	390	124
AK	1999	46	290 (3116)	99.4	343	109
CO	2001	17	3292 (35 437)	1112.9	338	107
WY	1999	48	230 (2477)	76.6	333	106
HI	2004	40	536 (5773)	138.4	258	82
MT	2007	47	238 (2562)	52.5	221	70
NV	2004	14	3516 (37 844)	709	202	64
NM	2007	37	817 (8790)	153.7	188	60
CA	2007	2	14 492 (155 996)	2543.2	175	56
ID	2007	38	802 (8629)	139.9	175	56
UT	2007	28	1718 (18 492)	286.6	167	53
OR	2007	27	1745 (18 788)	261.4	150	48
WA	2007	12	3710 (39 937)	525	141	45

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 19-3 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 the reduction in electricity consumption offset by the change in natural gas consumption.[42] 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, excluding Hawaii, and are always cheaper per unit of energy.

There is some fluctuation in the results due to the fuel source of the reductions in energy use. For example, Montana has a higher electricity rate than Utah, Wyoming, Oregon, and Colorado. However, Montana realizes a smaller average energy cost savings per unit of energy use savings ($0.06) than the other four states ($0.07 each) because Montana realizes a reduction in both electricity and natural gas consumption, which lowers the average reduction in energy costs. Meanwhile, the other four states realize a shift in fuel consumption from electricity to natural gas, leading to additional savings.

[42] 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 19-3 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)
HI	2004	0.0	21.9	8.8	0.17
CA	2007	13.0	13.4	2.3	0.12
AK	1999	-24.9	14.5	2.8	0.10
NV	2004	1.1	10.6	3.2	0.08
NM	2007	16.0	8.4	2.2	0.08
AZ	1999	2.2	9.4	3.6	0.07
CO	2001	8.6	8.2	2.2	0.07
OR	2007	18.8	7.5	3.5	0.07
WY	1999	6.9	7.3	2.3	0.07
UT	2007	21.7	7.0	2.2	0.07
MT	2007	-38.9	8.3	2.8	0.06
WA	2007	19.4	7.0	3.6	0.06
ID	2007	8.4	6.5	2.9	0.05

Table 19-4 shows the weighted average fraction of electricity consumption offset by a change in natural gas consumption, the average CO_2 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 for the thirteen states in this study. There is a direct correlation between the CO_2 emissions rate for electricity generation in a state and the reduction in carbon emissions per unit of reduction in energy use. However, the correlation is not perfect. For example, Montana realizes smaller reductions in carbon emissions per unit of energy than Nevada, Idaho, Utah, Washington, and Oregon even though it has a greater electricity emissions rate. Montana realizes a reduction in both electricity and natural gas consumption, which lowers the average reduction in carbon emissions. Meanwhile, the other five states realize a shift in fuel consumption from electricity to natural gas, leading to additional savings.

Table 19-4 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year

State	Code	Offset (%)	CO_2e Emissions Rate for Electricity (t/GWh)	CO_2e Emissions Rate for Natural Gas (t/GWh)	CO_2e Reduction (t/GWh)
CO	2001	8.6	994	241	1012
NM	2007	16.0	835	241	950
HI	2004	0.0	835	241	895
WY	1999	6.9	661	241	690
AZ	1999	2.2	801	241	675
AK	1999	-24.9	663	241	588
OR	2007	18.8	494	241	559
CA	2007	13.0	497	241	539
WA	2007	19.4	494	241	508
UT	2007	21.7	494	241	503
ID	2007	8.4	494	241	500
NV	2004	1.1	494	241	461
MT	2007	-38.9	573	241	459

The relative change in life-cycle costs per unit of new floor area is shown in Table 19-5. There is some correlation between the energy use savings (Table 19-3) and the life-cycle cost-effectiveness of adopting the LEC design. However, the correlation is not perfect because in order to obtain energy use savings, additional construction costs are usually required. Eleven of thirteen Western states realize an average decrease in life-cycle costs from adoption of the LEC design, with the change in life-cycle costs ranging from \$3.10/m^2 (\$0.29/ft^2) to -\$25.92/m^2 (-\$2.41/ft^2). There is not a strong correlation between the state energy code and the total statewide reduction in life-cycle costs per unit of floor area.

Table 19-5 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	$/m²	$/ft²
HI	2004	40	258	13.9	25.92	2.41
CO	2001	17	338	59.7	18.13	1.68
AZ	1999	8	390	79.1	16.62	1.54
CA	2007	2	175	124.9	8.62	0.80
AK	1999	46	343	2.4	8.29	0.77
NM	2007	37	188	5.5	6.74	0.63
NV	2004	14	202	17.9	5.09	0.47
UT	2007	28	167	5.4	3.14	0.29
WY	1999	48	333	0.7	3.04	0.28
MT	2007	47	221	0.5	2.10	0.20
ID	2007	38	175	1.5	1.87	0.17
OR	2007	27	150	-0.4	-0.23	-0.02
WA	2007	12	141	-11.5	-3.10	-0.29

19.2 Percentage Change Comparison

State comparisons are made based on the simple average changes for the cities analyzed in each state by building type.[43] One building type is chosen to illustrate the detailed analysis possible with the powerful BIRDS database compiled for this study. Energy use, energy costs, energy-related carbon emissions, and life-cycle costs are analyzed for the most common existing building type, small office buildings. Summary results for the other 10 building types are reported in Table B-1 through Table B-10 in Appendix B.

19.2.1 3-Story Office Building

Table 19-6 summaries the percentage changes in energy use, energy costs, carbon emissions, and life-cycle costs from region-wide adoption of the LEC design for the 3-story office building for a 10-year study period. On average, adoption of the LEC design for a 3-story office building decreases energy use, energy costs, and energy-related carbon emissions by more than 24 % each while reducing life-cycle costs by 2.9 %.

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

Table 19-6 Average Percentage Change by State from Region-wide Adoption of the LEC design, 3-Story Office Building, 10-Year

State	Percentage Change			
	Energy Use	Energy Cost	Carbon Emissions	LCC
AK	-25.5	-27.6	-26.9	-0.5
AZ	-34.7	-34.9	-35.0	-3.1
CA	-24.5	-25.5	-25.1	-3.0
CO	-29.3	-32.1	-32.4	-5.5
HI	-28.0	-28.0	-28.0	-5.7
ID	-19.7	-22.0	-22.1	-2.7
MT	-18.0	-20.1	-19.9	-1.9
NM	-23.3	-25.5	-25.6	-3.1
NV	-25.3	-26.7	-26.3	-4.3
OR	-21.2	-23.5	-23.6	-3.5
UT	-20.8	-24.6	-23.7	-3.0
WA	-19.6	-21.9	-22.4	-2.7
WY	-30.1	-31.8	-31.8	0.3
Avg.	**-24.5**	**-26.3**	**-26.2**	**-2.9**

These detailed results can be readily analyzed in mappings of the West Census Region. Figure 19-1, Figure 19-2, Figure 19-3, and Figure 19-4, display the average percentage energy use savings, energy cost savings, carbon emissions reduction, and life-cycle cost savings by state, respectively. The states that have no state energy code or have adopted *ASHRAE 90.1-2001* are shown with cross hatching and a bolded state border. Figure 19-1 shows that the states that have not yet adopted *ASHRAE 90.1-2007* realize the greatest reductions in energy use. Arizona and Wyoming, which have no state energy code, realize energy use savings greater than 30 % by adopting the LEC design. Alaska, Colorado, Nevada, and Hawaii realize reductions of 25 % to 30 %. None of the seven Western states that have adopted *ASHRAE 90.1-2007* realize energy use savings of greater than 25 %.

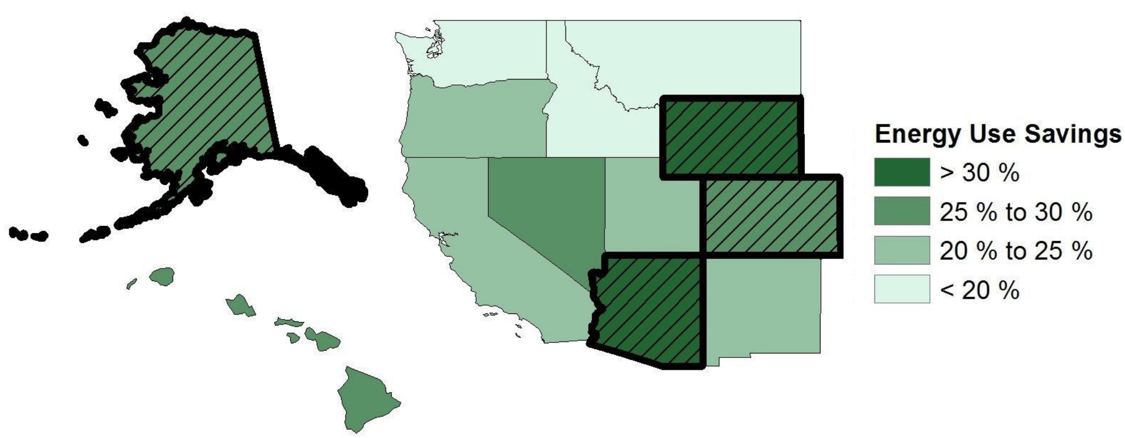


Figure 19-1 Average Energy Use Savings by State, 3-Story Office Building, 10-Year

Figure 19-2 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 %. Two of the three states that have no state energy code and the only state that has adopted *ASHRAE 90.1-2001* realize energy cost savings of greater than 30 %. The remaining state with no energy code and the two states that have adopted *ASHRAE 90.1-2004* realize energy cost savings of 25 % to 30 %. Only two of the seven states that have adopted *ASHRAE 90.1-2007* have energy cost savings greater than 25 %.

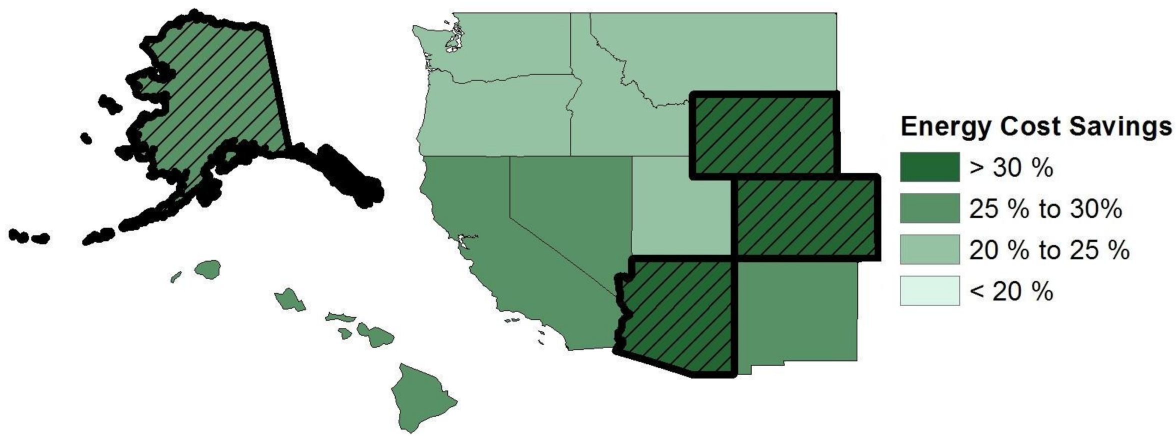


Figure 19-2 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year

Figure 19-3 shows the average reductions in energy-related carbon emissions by state from adopting the LEC design. Every state except for Montana realizes reductions in carbon emissions by at least 20 %. Similar to energy cost savings, the six states that have not yet adopted *ASHRAE 90.1-2007* realize reductions in carbon emissions of greater than 25 %. Only two of the seven states that have adopted *ASHRAE 90.1-2007* realize reductions greater than 25 %.

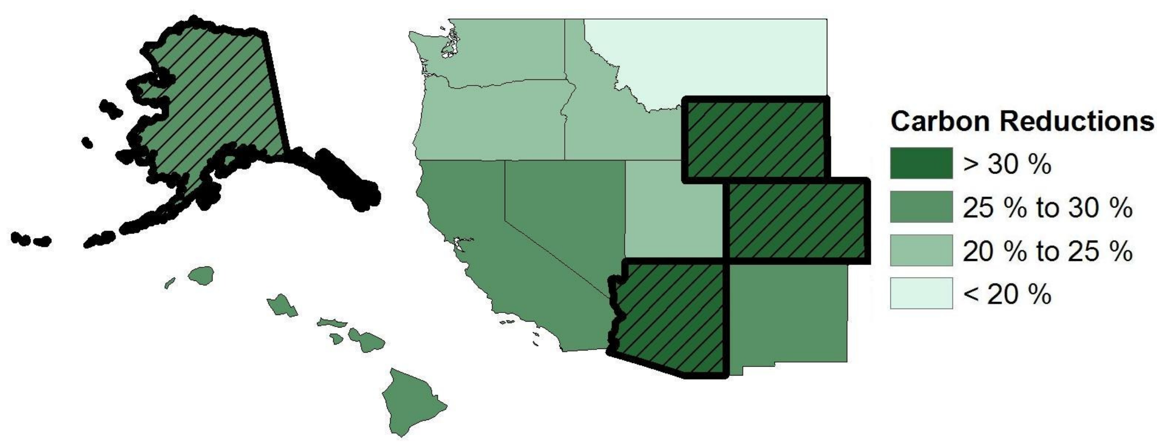


Figure 19-3 Average Energy-related Carbon Emissions Reduction by State, 3-Story Office Building, 10-Year

Figure 19-4 shows the average life-cycle cost savings over 10 years by state from adopting the LEC design. Two of the three states that have not adopted a state energy code realize increases in life-cycle costs. All three states that have adopted *ASHRAE 90.1-2001* or *-2004* realize the greatest average percentage reductions in life-cycle costs. All states that have adopted *ASHRAE 90.1-2007* realize percentage reductions life-cycle costs.

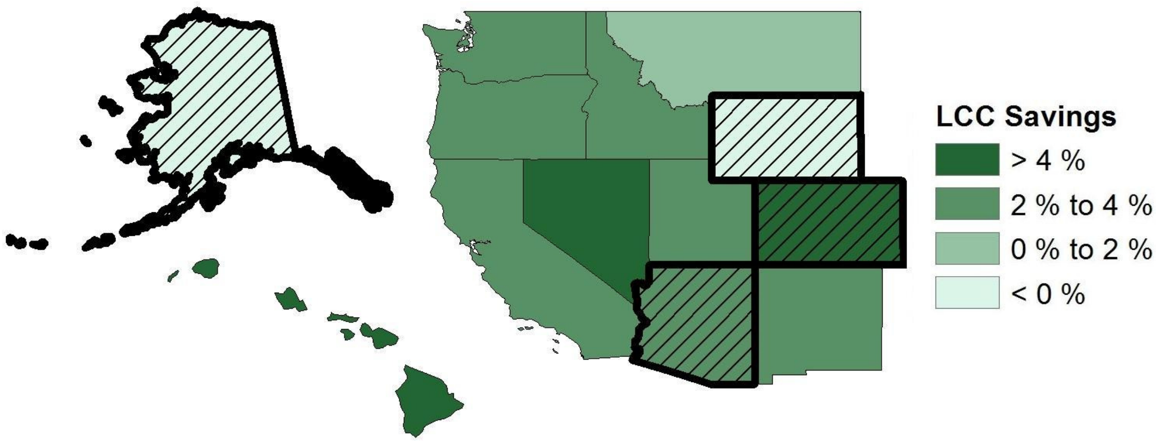


Figure 19-4 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year

For a 3-story office building, as expected, the states that have no state energy code or have adopted an older edition of *ASHRAE 90.1* have the most to gain in percentage terms in energy use, energy cost, and carbon emissions savings from adopting the LEC design. However, the benefits realized by a state with no state energy code may not be life-cycle cost-effective. States that have adopted *ASHRAE 90.1-2001*, *-2004*, or *-2007* would also realize significant benefits from the adoption of the LEC design for 3-story office buildings, and do so in a cost-effective manner.

19.2.2 Region-wide Results by Study Period Length

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

Average 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 73 cities in the study ranges from

10.5 % to 32.7 %, depending on the building type, with an overall regional average of 18.5 %. Table 19-7 shows these results.

Table 19-7 West Region Average Percentage Change in Energy Use by Building Type

Building Type	Percentage Change
APART04	-15.1
APART06	-15.7
DORMI04	-18.0
DORMI06	-15.1
HOTEL15	-13.9
HIGHS02	-10.5
OFFIC03	-24.5
OFFIC08	-22.4
OFFIC16	-15.5
RETAIL1	-20.0
RSTRNT1	-32.7
Average	**-18.5**

As shown in Table 19-8, savings in energy costs vary slightly, in percentage terms, over increasing study period lengths. The regional average reduction in energy costs across all location-building type combinations ranges from 24.0 % for a 1-year study period to 23.1 % for a 40-year study period. The minor variation within a building type is a result of some negative differential escalation rates used to adjust future energy prices, causing the percentage change in energy costs to decrease in magnitude as the study period lengthens. The regional average reduction ranges from 17.4 % to 37.3 %, depending on the building type, over all study periods.

Table 19-8 West 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	-23.1	-23.0	-22.8	-22.6	-22.4	-22.3	-22.1	-22.0	-21.9
APART06	-24.8	-24.6	-24.3	-24.1	-23.9	-23.8	-23.6	-23.5	-23.4
DORMI04	-24.3	-24.2	-24.0	-23.9	-23.8	-23.6	-23.5	-23.4	-23.4
DORMI06	-24.1	-24.0	-23.7	-23.5	-23.3	-23.2	-23.0	-22.9	-22.8
HOTEL15	-20.7	-20.6	-20.4	-20.2	-20.1	-20.0	-19.9	-19.8	-19.7
HIGHS02	-18.7	-18.6	-18.3	-18.1	-17.9	-17.8	-17.6	-17.5	-17.4
OFFIC03	-26.4	-26.3	-26.3	-26.2	-26.2	-26.2	-26.1	-26.1	-26.1
OFFIC08	-23.5	-23.5	-23.5	-23.5	-23.5	-23.4	-23.4	-23.4	-23.4
OFFIC16	-18.6	-18.5	-18.5	-18.4	-18.3	-18.3	-18.2	-18.2	-18.2
RETAIL1	-22.0	-21.9	-21.9	-21.8	-21.8	-21.8	-21.7	-21.7	-21.7
RSTRNT1	-37.3	-37.2	-37.1	-37.0	-36.9	-36.8	-36.7	-36.7	-36.6
Average	**-24.0**	**-23.9**	**-23.7**	**-23.6**	**-23.5**	**-23.4**	**-23.3**	**-23.2**	**-23.1**

Since the regional average reduction in energy use is constant over all study periods, the average energy-related carbon emissions reductions are also constant at 23.2 %. The regional average reduction in carbon emissions ranges from 17.5 % to 36.7 % depending on the building type, as shown in Table 19-9.

Table 19-9 West Region Average Percentage Change in Carbon Emissions by Building Type

Building Type	Percentage Change
APART04	-21.9
APART06	-23.4
DORMI04	-23.4
DORMI06	-22.7
HOTEL15	-19.7
HIGHS02	-17.5
OFFIC03	-26.2
OFFIC08	-23.4
OFFIC16	-18.2
RETAIL1	-21.8
RSTRNT1	-36.7
Average	**-23.2**

Table 19-10 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 19-10 West 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	-2.1	-0.2	-0.1	-0.4	-0.2	-0.4	-0.5	-0.6	-0.5
APART06	-0.2	0.0	-0.2	-0.6	-0.4	-0.6	-0.7	-0.9	-0.8
DORMI04	-9.9	-2.2	-1.6	-1.8	-1.5	-1.6	-1.7	-1.7	-1.6
DORMI06	0.3	-0.3	-0.6	-1.0	-0.9	-1.1	-1.2	-1.4	-1.3
HOTEL15	1.2	0.3	-0.1	-0.6	-0.6	-0.8	-1.0	-1.2	-1.2
HIGHS02	-2.5	-1.4	-1.2	-1.5	-1.4	-1.6	-1.7	-1.9	-1.8
OFFIC03	-13.8	-3.7	-2.9	-3.1	-2.6	-2.8	-2.9	-3.0	-2.9
OFFIC08	-4.7	-2.5	-2.4	-2.7	-2.4	-2.6	-2.7	-2.8	-2.7
OFFIC16	1.8	0.8	0.4	-0.2	-0.2	-0.5	-0.7	-0.9	-0.9
RETAIL1	-13.2	-0.6	-0.2	-0.6	-0.2	-0.4	-0.6	-0.8	-0.7
RSTRNT1	-13.5	-4.7	-3.7	-4.3	-4.0	-4.3	-4.5	-4.6	-4.6
Average	**-5.1**	**-1.3**	**-1.1**	**-1.5**	**-1.3**	**-1.5**	**-1.7**	**-1.8**	**-1.7**

Figure 19-5 shows that three building types – the 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 0.3 % to 2.2 %. By a 15-year study period, all three building types become cost-effective. The 6-story apartment building is the only building type that is cost-effective at a 1-year study period and not cost-effective at a 5-year study period. However, the 6-story apartment building becomes cost-effective again by a 10-year study period.

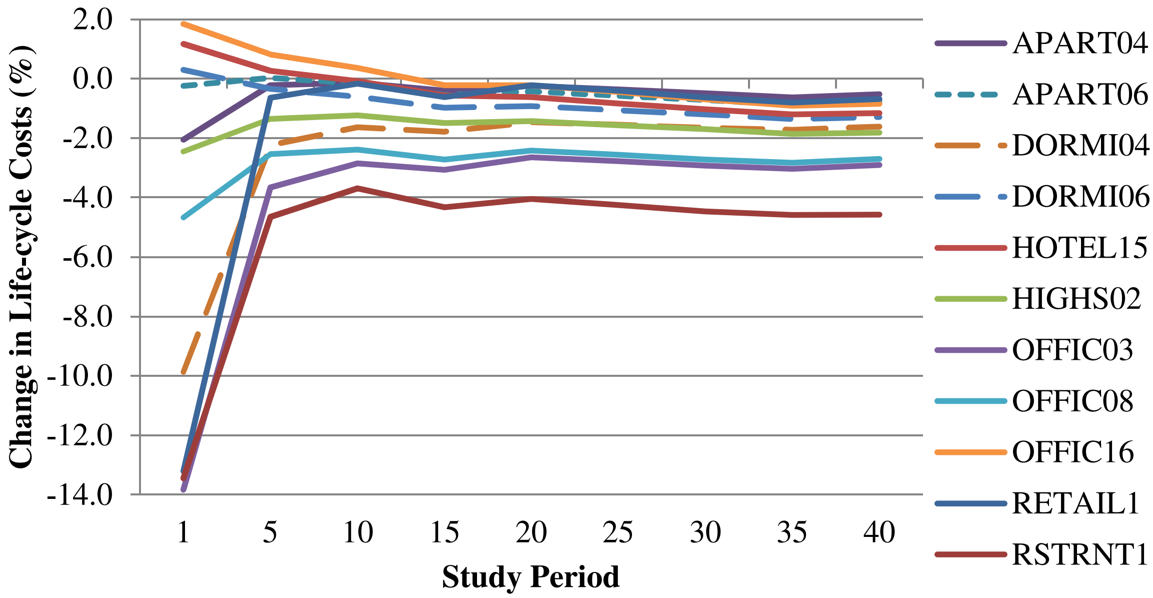


Figure 19-5 Average Change in Life-Cycle Costs by Building Type and Study Period Length

19.2.3 Region-wide Results by Building Type

For a 10-year study period length, Table 19-11 shows the simple average changes across all 73 cities in the West Census Region, in percentage terms, from adopting the LEC design. The building types that realize the smallest percentage reductions in energy use, energy costs, and energy-related carbon emissions are the high school and hotel while the greatest reductions are realized by the restaurant, 3-story office building, and 8-story office building. The percentage changes in energy costs and carbon emissions are greater than the percentage changes in energy use. Ten of 11 building types realize reductions in life-cycle costs. The restaurant, 3-story office building, and 8-story office building realize the greatest percentage reductions in life-cycle costs. The 16-story office building realizes the only increase in life-cycle costs.

Table 19-11 West Region Percentage Change for LEC by Building Type, 10-Year

Building Type	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-15.1	-22.8	-21.9	-0.1
APART06	-15.7	-24.3	-23.4	-0.2
DORMI04	-18.0	-24.0	-23.4	-1.6
DORMI06	-15.1	-23.7	-22.7	-0.6
HOTEL15	-13.9	-20.4	-19.7	-0.1
HIGHS02	-10.5	-18.3	-17.5	-1.2
OFFIC03	-24.5	-26.3	-26.2	-2.9
OFFIC08	-22.4	-23.5	-23.4	-2.4
OFFIC16	-15.5	-18.5	-18.2	0.4
RETAIL1	-20.0	-21.9	-21.8	-0.2
RSTRNT1	-32.7	-37.1	-36.7	-3.7
Average	**-18.5**	**-23.7**	**-23.2**	**-1.1**

19.2.4 Region-wide Results by Climate Zone

Table 19-12 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 19-12 Average Percentage Change for LEC by Climate Zone

Climate Zone	Energy Use	Energy Cost	Carbon Emissions	LCC
1	-23.1	-23.1	-23.9	-3.1
2	-30.7	-30.9	-31.6	-2.8
3	-20.2	-24.4	-23.4	-1.3
4	-16.6	-21.3	-26.4	-0.7
5	-17.8	-23.3	-23.4	-1.4
6	-17.5	-23.0	-23.0	-0.7
7	-23.1	-31.9	-29.0	-1.4
8	-10.2	-23.4	-18.5	-0.6
Average	**-18.5**	**-23.7**	**-23.9**	**-1.1**

Table 19-13 shows the average percentage reduction in energy use from adopting the LEC design for all cities located in a climate zone while controlling for state energy codes. The region-wide average reduction in energy use is 18.5 % with Zone 2 realizing the greatest reduction (30.7 %) followed by Zone 1 and Zone 7 (23.1 % each). Controlling for state energy codes, the warmer the climate the greater the reduction in energy use tends to be, which is a result of the energy efficiency improvement options (daylighting and overhangs) considered in the LEC design for cities located in Zone 1 through Zone 5.

Table 19-13 Average Percentage Change in Energy Use for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	2001	2004	2007	All
1			-23.1		-23.1
2	-39.2		-26.4		-30.7
3			-21.3	-20.1	-20.2
4	-31.0			-15.4	-16.6
5	-30.4	-25.9	-17.1	-14.3	-17.8
6	-23.8	-22.7		-13.3	-17.5
7	-23.1				-23.1
8	-10.2				-10.2
Grand Total	**-22.8**	**-24.6**	**-20.0**	**-15.9**	**-18.5**

Table 19-14 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 23.7 % with Zone 7 realizing the greatest average reduction in energy costs (31.9 %) and Zone 4 realizing the smallest reduction (21.3 %). Similar to energy use, after controlling for state energy codes, cities located in warmer climates tend to realize greater reductions in energy costs.

Table 19-14 Average Percentage Change in Energy Costs for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	2001	2004	2007	All
1			-23.1		-23.1
2	-39.9		-26.4		-30.9
3			-25.0	-24.3	-24.4
4	-37.2			-20.0	-21.3
5	-36.4	-35.7	-21.8	-18.8	-23.3
6	-31.7	-33.2		-16.7	-23.0
7	-31.9				-31.9
8	-23.4				-23.4
Grand Total	**-31.3**	**-34.7**	**-23.0**	**-20.1**	**-23.7**

Table 19-15 shows the average percentage reduction in energy-related carbon emissions for all cities located in a climate zone while controlling for state energy codes. Similar to energy use and energy costs, after controlling for state energy codes, cities located in warmer climates tend to realize greater reductions in the carbon emissions. However, there is some additional variation that is driven by a state's average emissions rate.

Table 19-15 Average Percentage Change in Carbon Emissions for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	2001	2004	2007	All
1			-23.9		-23.9
2	-40.3		-27.3		-31.6
3			-24.5	-23.2	-23.4
4	-38.7			-22.3	-26.4
5	-37.9	-36.8	-21.5	-18.9	-23.4
6	-31.5	-34.5		-16.4	-23.0
7	-29.0				-29.0
8	-18.5				-18.5
Grand Total	**-29.8**	**-35.9**	**-23.1**	**-19.7**	**-23.9**

Table 19-16 shows the average percentage change in life-cycle costs for all cities located in a climate zone while controlling for state energy codes. Given the same state energy code, cities in warmer climates tend to realize greater percentage reductions in life-cycle costs.

Table 19-16 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and State Energy Code

Climate Zone/Subzone	Percentage Change				
	1999	2001	2004	2007	All
1			-3.1		-3.1
2	-2.9		-2.8		-2.8
3			-1.2	-1.3	-1.3
4	-1.5			-0.6	-0.7
5	-1.6	-3.2	-1.6	-0.6	-1.4
6	-0.5	-3.0		-0.3	-0.7
7	-1.4				-1.4
8	-0.6				-0.6
Grand Total	**-1.0**	**-3.1**	**-2.0**	**-0.7**	**-1.1**

State Comparisons for the Adoption of the Low Energy Case Design

20 Discussion

This study analyzes the impacts of adopting new, more stringent state energy codes for 73 cities located across the West Census Region. Results are summarized at the regional level as well as the state level for all thirteen Southern states. This section will discuss the key findings, limitations of the research, and recommended directions for future research.

20.1 Key Findings

Three states in the West Census Region have not yet adopted a state energy code for commercial buildings: Alaska, Arizona, and Wyoming. For all cities in Alaska and Wyoming and the cities in Arizona that have not adopted a local energy code, adoption of *ASHRAE 90.1-2001* leads to reductions in energy use, energy costs, and energy-related carbon emissions, but not in a life-cycle cost-effective manner. In Arizona and Wyoming, *ASHRAE 90.1-2004* leads to greater reductions in energy use, energy costs, and carbon emissions than *ASHRAE 90.1-2001*, and is life-cycle cost-effective to adopt. Alaska realizes an increase in energy use from adopting *ASHRAE 90.1-2004* while decreasing energy costs, carbon emissions, and life-cycle costs. The shift in fuel consumption from electricity to natural gas allows energy use to increase while energy costs decrease. All three states realize reductions in energy use, energy costs, carbon emissions, and life-cycle costs from adopting *ASHRAE 90.1-2007*.

Colorado is the only state in the West Census Region that has adopted *ASHRAE 90.1-2001* as its state energy code for commercial buildings. Colorado would realize reductions in energy use, energy costs, and energy-related carbon emissions as well as life-cycle costs from adopting *ASHRAE 90.1-2004*. Adopting *ASHRAE 90.1-2007* would lead to greater reductions in energy use, energy costs, carbon emissions, and life-cycle costs than adopting *ASHRAE 90.1-2004*.

Hawaii and Nevada are the states in the West Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings. Both states would realize cost-effective reductions in energy use, energy costs, and energy-related carbon emissions from adopting *ASHRAE 90.1-2007*. Nevada realizes greater total life-cycle cost savings than total energy cost savings because the relaxation of the window U-factor and SHGC requirements decreases total construction costs while still decreasing total energy use for the state.

The adoption of the LEC design is analyzed for all thirteen 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 West 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 (18.5 %), energy costs (23.7 %), and carbon emissions (23.2 %), on average, while reducing life-cycle costs (1.1 %), 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 states that have not adopted *ASHRAE 90.1-2007* realize the greatest percentage savings in energy use, energy costs, and carbon emissions. The states that have adopted *ASHRAE 90.1-2004* realize the greatest percentage reductions in life-cycle costs. The states that have already adopted *ASHRAE 90.1-2007* also realize percentage reductions in life-cycle costs. Two of the three states that have no state energy code realize an average percentage increase in life-cycle costs relative to *ASHRAE 90.1-1999*.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 5 years to 15 years, the number of building types that are cost-effective increases from eight to all eleven. The study period length is an important determinant of cost-effectiveness and size of the percentage changes in life-cycle costs.

The climate zone of a location impacts the percentage reduction in energy use, energy costs, and carbon emissions. After controlling for each state's energy code, cities located in warmer climates tend to realize greater average percentage reductions in these measures.

Different building types realize different regional average percentage reductions in energy use, energy costs, and carbon emissions for a 10-year study period. High schools, 16-story office buildings, and hotels realize the smallest reductions while restaurants and 3-story office buildings realize the greatest reductions. The greatest percentage reductions in life-cycle costs are also realized by restaurants and 3- and 8-story office buildings while the only percentage increase is realized by 16-story office buildings.

The magnitude of a building type's average percentage change is not necessarily correlated with its changes in total energy use, energy costs, and energy-related carbon emissions relative to other building types. For example, high schools tend to realize some of the smallest percentage reductions, but some of the greatest total reductions in energy use, energy costs, and energy-related carbon emissions. Total reductions are driven largely by total new floor area constructed for the building type in a state. The adoption of the LEC design would lead to greater aggregate reductions in energy use in California than in Wyoming because the amount of newly constructed floor area for 2003 to 2007 was 63 higher times in California.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy rates, and carbon emissions rates. The greatest 10-year reductions in energy use per unit of floor area resulting from adoption of the LEC design are realized by the four states that have no state energy code or have adopted *ASHRAE 90.1-2001*, ranging from 333 kWh/m^2 (106 $kBtu/ft^2$) to 390 kWh/m^2 (124 $kBtu/ft^2$). The states that have adopted *ASHRAE 90.1-2004* or *-2007* realize reductions ranging from 141 kWh/m^2 (45 $kBtu/ft^2$) to 258 kWh/m^2 (82 $kBtu/ft^2$). States with the highest electricity rates tend to realize the largest reductions in energy costs per unit of energy consumption reduced. Similarly, states with higher CO_2e emission rates per unit of electricity generated tend to realize greater reductions in emissions per unit of energy consumption reduced. The greater the offset of electricity consumption reductions with natural gas consumption increases, the greater the reduction in both energy costs and carbon emissions per unit of energy consumption reduced.

20.2 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 13 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 37 states will allow for analysis of nationwide impacts. Also, extensive 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 state 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 West Census Region. The BIRDS database is much more expansive, allowing researchers to compare any of the editions of *ASHRAE 90.1* with any other edition of *ASHRAE 90.1* or the LEC design for any state in the country. The BIRDS database should be made available to the public through a simple-to-use software tool that allows other researchers to use the database for their own research on building energy efficiency.

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

References

ANSI/ASHRAE/USGBC/IES Standard 189.1-2011, Standard for the Design of High-Performance Green Buildings, 2011, ASHRAE, Inc. and U.S. Green Building Council.

ArcMap 10.1 software, ArcGIS desktop package, ESRI, Redlands, CA, http://www.esri.com/.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-1999 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 1999, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2001 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2001, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2004 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2004, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2007 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2007, ASHRAE, Inc.

ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2010 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2010, ASHRAE, Inc.

ASTM International, ASTM Standards of Building Economics: 7th Edition, 2012.

D.B. Belzer, K.A. Cort, D.W. Winiarski, E.E. Richman, Analysis of Potential Benefits and Costs of Adopting a Commercial Building Energy Standard in South Dakota, March 2005, Pacific Northwest National Laboratory, PNNL-15101.

Commercial Buildings Energy Consumption Survey (CBECS) database, 2003, accessed June-July 2009, http://www.eia.doe.gov/emeu/cbecs/.

Database of State Incentives for Renewables and Efficiency, Rules, Regulations, and Policies for Energy Efficiency database, building energy codes, accessed summer 2010, www.dsireusa.org/.

Department of Energy, 2009a, Building Technologies Program, EnergyPlus energy simulation software, http://apps1.eere.energy.gov/buildings/energyplus/.

Department of Energy, 2009b, Building Technologies Program, State energy codes at-a-glance, http://www.energycodes.gov/states/maps/commercialStatus.stm.

EnergyPlus Example File Generator, Building Energy Simulation Web Interface for EnergyPlus, accessed Feb. 2009, U.S. Department of Energy National Renewable Energy Laboratory, http://apps1.eere.energy.gov/buildings/energyplus/.

Environmental Protection Agency, 2007 Emissions and Generation Integrated Database.

S. Fuller, S. Petersen, Life-Cycle Costing Manual for the Federal Energy Management Program, 1996, NIST Handbook 135, 1995 Edition, U.S. Department of Commerce, Technology Administration and NIST.

M.A. Halverson, K. Gowri, E.E. Richman, Analysis of Energy Savings Impacts of New Commercial Energy Codes for the Gulf Coast, December 2006, Pacific Northwest National Laboratory, PNNL-16282.

J. Kneifel, Life-cycle Carbon and Cost Analysis of Energy Efficiency Measures in New Commercial Buildings, Energy and Buildings 42 (3) (2010) 333-340.

J. Kneifel, 2011a, Beyond the Code: Energy, Carbon, and Cost Savings using Conventional Technologies, Energy and Buildings 43 (2011) 951-959.

J. Kneifel, 2011b, Prototype Commercial Buildings for Energy and Sustainability Assessment: Whole Building Energy Simulation Design, September 2011, NIST, Technical Note 1716.

J. Kneifel, 2012, Prototype Commercial Buildings for Energy and Sustainability Assessment: Design Specification, Life-Cycle Costing and Carbon Assessment, January 2012, NIST, Technical Note 1732.

J. Kneifel, 2013, Benefits and Costs of Energy Standard Adoption in New Commercial Buildings, February 2013, NIST, Special Publication 1147.

B. Lippiatt, Greig, A., Lavappa, P., Building for Environmental and Economic Sustainability (BEES) Online software, February 2011, NIST, http://ws680.nist.gov/bees/.

National Oceanic and Atmospheric Administration, map of census regions, accessed Dec. 2010, http://marineeconomics.noaa.gov/.

National Renewable Energy Laboratory, 2011, U.S. Department of Energy Commercial Reference Building Models of the National Building Stock, TP-5500-46861.

Pacific Northwest National Laboratory, 2009, Impacts of Standard 90.1-2007 for Commercial Buildings at State Level, United States Department of Energy Building Energy Codes Program.

RS Means CostWorks databases, accessed 2009, http://www.meanscostworks.com/.

A. Rushing, B. Lippiatt, Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-April 2008, May 2008, NIST, NISTIR 85-3273-23.

M. Towers, R. Dotz, L. Romani, The Whitestone Building Maintenance and Repair Cost Reference 2008-2009, 13th Annual Edition, 2008, Whitestone Research.

U.S. Energy Information Administration, 2010a, Electric power annual state data tables, Accessed 2010, http://www.eia.doe.gov/fuelelectric.html.

U.S. Energy Information Administration, 2010b, Natural Gas Navigator, accessed 2010, http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html.

U.S. Life-Cycle Inventory Database, 2012, http://www.nrel.gov/lci/.

D. Winiarski, S. Shankle, J. Hail, B. Liu, A. Walker, The Business Case for Sustainable Design in Federal Facilities: Appendix B: Energy and Construction Cost Estimates, August 2003, Pacific Northwest National Laboratory and National Renewable Energy Laboratory.

A Building and Energy Characteristics

Table A-1 CBECS Categories and Subcategories

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

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 Volume for 2003 through 2007 by State and Building Type

State	Building Construction Floor Area in 1000 m² (1,000 ft²)										
	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total
AK	19 (201)	130 (1401)	126 (1357)	226 (2428)	111 (1190)	13 (137)	208 (2240)	231 (2484)	126 (1356)	259 (2787)	1448 (15 581)
AZ	1043 (11 223)	1505 (16 195)	1047 (11 272)	4030 (43 383)	1180 (12 701)	271 (2918)	4891 (52 646)	2294 (24 692)	3721 (40 052)	3808 (40 986)	23 790 (256 068)
CA	9761 (105 071)	3310 (35 633)	3129 (33 678)	9219 (99 228)	3092 (33 281)	534 (5747)	10 623 (114 344)	7085 (76 262)	13 364 (143 853)	12345 (132 882)	72 462 (779 978)
CO	2033 (21 885)	1387 (14 926)	997 (10 735)	2158 (23 225)	708 (7618)	199 (2142)	2896 (31 177)	1654 (17 804)	1541 (16582)	2889 (31 094)	16461 (177 186)
HI	1280 (13 773)	91 (979)	92 (989)	171 (1838)	59 (630)	9 (95)	273 (2939)	92 (985)	132 (1417)	485 (5220)	2682 (28 865)
ID	233 (2506)	372 (4001)	221 (2375)	716 (7703)	230 (2478)	46 (493)	699 (7526)	636 (6847)	360 (3876)	496 (5343)	4008 (43 147)
MT	45 (481)	122 (1313)	118 (1265)	149 (1602)	94 (1007)	18 (195)	253 (2723)	174 (1871)	76 (821)	142 (1533)	1190 (12 810)
NM	89 (957)	247 (2655)	418 (4499)	617 (6636)	350 (3770)	62 (670)	765 (8235)	752 (8097)	292 (3142)	491 (5290)	4083 (43 950)
NV	2867 (30 856)	528 (5684)	2963 (31 894)	1626 (17 504)	1195 (12 863)	157 (1691)	2382 (25 644)	960 (10 337)	1669 (17 969)	3231 (34 776)	17 579 (189 218)
OR	1253 (13 492)	918 (9885)	360 (3878)	922 (9927)	383 (4118)	68 (728)	1382 (14 881)	651 (7004)	1142 (12 291)	1648 (17 738)	8727 (93 941)
UT	622 (6695)	569 (6123)	314 (3384)	1365 (14 698)	475 (5110)	76 (822)	1424 (15 331)	1269 (13 657)	1274 (13 716)	1201 (12 926)	8590 (92 462)
WA	3397 (36 566)	1085 (11 683)	871 (9378)	2435 (26 209)	833 (8964)	107 (1147)	2504 (26 954)	1841 (19 817)	1880 (20 236)	3598 (38 731)	18 551 (199 685)
WY	4 (42)	72 (774)	166 (1787)	66 (713)	127 (1370)	9 (97)	158 (1696)	254 (2737)	67 (718)	228 (2453)	1151 (12387)
Total	22 645 (243 748)	10 336 (111 252)	10 822 (116 491)	23 699 (255 094)	8835 (95 100)	1568 (16 882)	28 460 (306 336)	17 893 (192 594)	25 644 (276 029)	30 821 (331 759)	180 722 (1 945 278)

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

State	Percentage of Building Construction Floor Area											
	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total	Rep. by Study
AK	1.3 %	9.0 %	8.7 %	15.6 %	7.6 %	0.9 %	14.4 %	15.9 %	8.7 %	17.9 %	100.0 %	56.8 %
AZ	4.4 %	6.3 %	4.4 %	16.9 %	5.0 %	1.1 %	20.6 %	9.6 %	15.6 %	16.0 %	100.0 %	57.1 %
CA	13.5 %	4.6 %	4.3 %	12.7 %	4.3 %	0.7 %	14.7 %	9.8 %	18.4 %	17.0 %	100.0 %	55.7 %
CO	12.4 %	8.4 %	6.1 %	13.1 %	4.3 %	1.2 %	17.6 %	10.0 %	9.4 %	17.5 %	100.0 %	60.4 %
HI	47.7 %	3.4 %	3.4 %	6.4 %	2.2 %	0.3 %	10.2 %	3.4 %	4.9 %	18.1 %	100.0 %	71.4 %
ID	5.8 %	9.3 %	5.5 %	17.9 %	5.7 %	1.1 %	17.4 %	15.9 %	9.0 %	12.4 %	100.0 %	63.6 %
MT	3.8 %	10.2 %	9.9 %	12.5 %	7.9 %	1.5 %	21.3 %	14.6 %	6.4 %	12.0 %	100.0 %	63.5 %
NM	2.2 %	6.0 %	10.2 %	15.1 %	8.6 %	1.5 %	18.7 %	18.4 %	7.1 %	12.0 %	100.0 %	66.2 %
NV	16.3 %	3.0 %	16.9 %	9.3 %	6.8 %	0.9 %	13.6 %	5.5 %	9.5 %	18.4 %	100.0 %	62.3 %
OR	14.4 %	10.5 %	4.1 %	10.6 %	4.4 %	0.8 %	15.8 %	7.5 %	13.1 %	18.9 %	100.0 %	53.1 %
UT	7.2 %	6.6 %	3.7 %	15.9 %	5.5 %	0.9 %	16.6 %	14.8 %	14.8 %	14.0 %	100.0 %	59.0 %
WA	18.3 %	5.9 %	4.7 %	13.1 %	4.5 %	0.6 %	13.5 %	9.9 %	10.1 %	19.4 %	100.0 %	60.1 %
WY	0.3 %	6.2 %	14.4 %	5.8 %	11.1 %	0.8 %	13.7 %	22.1 %	5.8 %	19.8 %	100.0 %	57.1 %

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

State	CO_2 (t/GWh)	CH_4 (t/GWh)	N_2O (t/GWh)
AK	603.4	57.9	1.9
AZ	746.9	53.2	1.2
CA	450.0	45.8	1.5
CO	938.8	54.0	0.8
HI	807.1	28.0	0.1
ID	465.6	27.6	0.4
MT	542.8	30.1	0.4
NM	778.5	55.3	1.3
NV	465.6	27.6	0.4
OR	465.6	27.6	0.4
UT	465.6	27.6	0.4
WA	465.6	27.6	0.4
WY	623.7	36.4	0.5

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
AK	-12.7	-31.2	-25.0	-1.7
AZ	-26.6	-31.1	-32.4	-1.6
CA	-16.1	-22.5	-19.8	0.2
CO	-21.9	-36.2	-37.9	-1.2
HI	-20.4	-20.4	-20.4	-1.7
ID	-10.2	-14.8	-14.9	0.8
MT	-9.6	-15.2	-14.5	0.6
NM	-13.6	-20.0	-20.0	0.5
NV	-14.5	-20.7	-18.8	-0.1
OR	-10.0	-15.0	-15.4	1.1
UT	-10.7	-17.6	-15.7	0.7
WA	-8.8	-12.8	-14.0	1.2
WY	-22.7	-36.6	-36.4	-1.4

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-12.2	-31.1	-24.8	-1.5
AZ	-27.1	-32.5	-34.0	-1.7
CA	-18.2	-26.1	-22.8	-0.1
CO	-22.5	-37.7	-39.5	-1.2
HI	-20.7	-20.7	-20.7	-1.6
ID	-11.1	-16.5	-16.5	0.8
MT	-9.5	-15.1	-14.4	0.6
NM	-15.1	-23.0	-23.0	0.3
NV	-14.9	-22.9	-20.5	-0.1
OR	-10.9	-17.1	-17.7	1.0
UT	-11.9	-20.5	-18.2	0.6
WA	-9.4	-14.4	-15.8	1.2
WY	-22.5	-36.3	-36.2	-1.3

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-18.1	-34.8	-29.3	-2.4
AZ	-29.1	-32.1	-32.9	-1.6
CA	-18.2	-22.3	-20.6	-1.3
CO	-24.9	-36.6	-37.9	-4.2
HI	-22.1	-22.1	-22.1	-3.6
ID	-12.7	-16.4	-16.5	-1.2
MT	-12.9	-17.1	-16.6	-1.2
NM	-15.3	-19.8	-19.8	-1.6
NV	-17.1	-21.1	-19.9	-1.9
OR	-12.7	-16.7	-17.0	-1.0
UT	-12.8	-18.2	-16.8	-1.2
WA	-11.6	-15.0	-16.0	-0.5
WY	-26.9	-38.4	-38.3	-0.9

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-11.1	-30.0	-23.7	-2.2
AZ	-28.3	-33.6	-35.1	-2.4
CA	-17.9	-26.3	-22.7	-0.4
CO	-20.7	-36.0	-37.9	-1.8
HI	-23.0	-23.0	-23.0	-2.5
ID	-10.6	-15.6	-15.7	0.5
MT	-8.6	-13.6	-12.9	0.3
NM	-15.2	-22.8	-22.9	-0.1
NV	-14.1	-22.1	-19.6	-0.4
OR	-10.6	-16.7	-17.1	0.7
UT	-12.0	-20.1	-18.0	0.3
WA	-9.2	-14.1	-15.5	0.9
WY	-19.1	-33.4	-33.2	-1.8

Table B-5 15-Story Hotel Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-6.9	-23.5	-18.0	-1.8
AZ	-23.1	-26.4	-27.3	-1.0
CA	-18.2	-24.5	-21.8	0.0
CO	-16.0	-28.8	-30.3	-1.1
HI	-18.0	-18.1	-18.1	-0.6
ID	-12.3	-15.9	-15.9	0.7
MT	-9.4	-11.5	-11.3	0.4
NM	-15.7	-21.1	-21.1	0.4
NV	-8.8	-14.7	-13.0	0.7
OR	-13.8	-18.4	-18.8	0.9
UT	-14.2	-20.2	-18.6	0.6
WA	-12.3	-16.2	-17.2	1.1
WY	-13.8	-24.7	-24.6	-1.3

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
AK	-7.7	-17.8	-14.0	-1.6
AZ	-21.5	-27.4	-29.2	-2.8
CA	-13.7	-23.4	-19.2	-1.8
CO	-10.6	-23.1	-25.0	-1.9
HI	-26.7	-26.7	-26.7	-4.2
ID	-6.0	-11.8	-11.9	-0.2
MT	-9.7	-13.9	-13.3	-0.6
NM	-9.6	-19.8	-19.9	-1.0
NV	-9.5	-18.2	-15.4	-1.5
OR	-4.9	-11.5	-12.1	0.0
UT	-5.9	-15.6	-12.8	-0.8
WA	-4.2	-9.4	-10.9	0.2
WY	-11.5	-21.2	-21.1	-1.3

Table B-7 8-Story Office Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-21.3	-25.8	-24.6	0.0
AZ	-28.1	-28.0	-28.0	-2.3
CA	-21.4	-21.9	-21.8	-2.8
CO	-28.3	-29.7	-29.9	-5.1
HI	-21.3	-21.3	-21.3	-3.6
ID	-19.3	-20.4	-20.4	-2.4
MT	-16.9	-18.1	-18.0	-1.5
NM	-21.4	-22.5	-22.5	-2.8
NV	-23.0	-23.4	-23.3	-3.6
OR	-20.9	-22.0	-22.0	-3.0
UT	-20.7	-22.5	-22.1	-2.6
WA	-20.0	-21.1	-21.3	-2.3
WY	-29.2	-30.1	-30.0	0.7

Table B-8 16-Story Office Building Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-8.1	-14.9	-12.9	-0.2
AZ	-19.6	-20.5	-20.8	0.0
CA	-19.8	-21.8	-21.0	-0.1
CO	-15.7	-21.2	-21.7	0.1
HI	-16.4	-16.4	-16.4	-0.6
ID	-15.3	-17.7	-17.8	0.9
MT	-11.7	-12.5	-12.5	0.4
NM	-18.9	-21.7	-21.7	0.3
NV	-12.5	-16.0	-15.1	0.7
OR	-17.8	-20.9	-21.1	1.0
UT	-17.5	-21.7	-20.8	0.6
WA	-16.2	-19.1	-19.8	1.4
WY	-12.8	-16.2	-16.1	0.1

Table B-9 1-Story Retail Store Summary Table for LEC and 10-Year Study Period

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-26.3	-27.3	-26.8	-0.2
AZ	-31.6	-32.4	-32.6	-1.8
CA	-16.1	-17.8	-17.1	0.0
CO	-28.4	-32.0	-32.4	-2.0
HI	-22.3	-22.3	-22.3	-3.1
ID	-14.2	-16.3	-16.3	1.2
MT	-16.0	-17.7	-17.5	0.1
NM	-15.6	-18.9	-18.9	0.1
NV	-21.0	-21.9	-21.7	-0.6
OR	-13.2	-15.3	-15.4	0.8
UT	-13.0	-17.3	-16.3	1.2
WA	-12.3	-13.9	-14.3	1.1
WY	-30.5	-34.0	-34.0	0.4

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AK	-33.4	-40.1	-37.9	1.0
AZ	-41.4	-43.6	-44.2	-5.2
CA	-34.1	-37.5	-36.2	-5.2
CO	-40.2	-46.3	-47.0	-7.4
HI	-34.8	-34.8	-34.8	-6.3
ID	-26.0	-30.8	-30.9	-2.7
MT	-24.1	-28.9	-28.4	-1.4
NM	-31.4	-36.6	-36.6	-4.3
NV	-35.1	-38.6	-37.7	-6.0
OR	-28.5	-33.0	-33.4	-4.5
UT	-27.1	-34.7	-32.9	-3.8
WA	-26.4	-30.6	-31.6	-3.9
WY	-42.3	-46.2	-46.1	1.3