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

Joshua Kneifel

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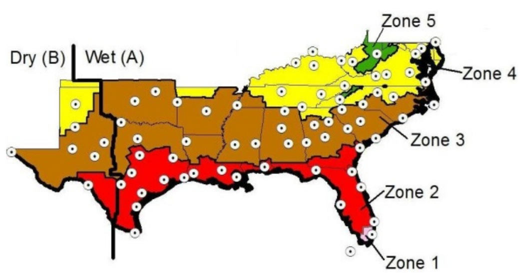
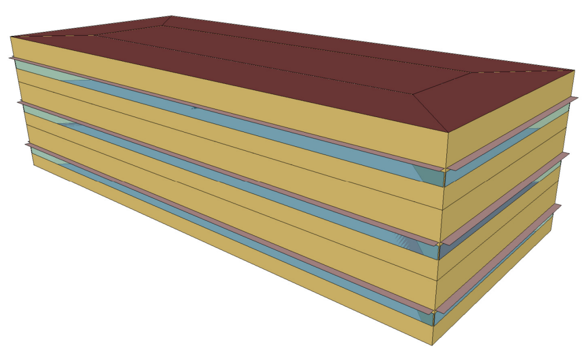


BIRDS
Building Industry Reporting and Design *for* Sustainability



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Applied Economics Office
Engineering Laboratory

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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

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Abstract

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

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

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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, Ms. Natascha Milesi-Ferretti 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.

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Table of Contents

Abstract .... **ii**
Preface .... **iv**
Acknowledgements .... **vi**
Author Information .... **vi**
List of Figures .... **xiv**
List of Tables .... **xvi**
List of Acronyms .... **xxvi**
Executive Summary .... **xxviii**
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 Alabama **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 23
6.1.4 Life-Cycle Costs 24
6.1.5 City Comparisons 25
6.2 Total Savings 27
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 32
6.3 State Summary 34
7 Arkansas **35**
7.1 Percentage Savings 35

7.1.1 Energy Use 36
7.1.2 Energy Costs 37
7.1.3 Energy-related Carbon Emissions 38
7.1.4 Life-Cycle Costs 38
7.1.5 City Comparisons 39
7.2 Total Savings 41
7.2.1 Energy Use 41
7.2.2 Energy Costs 43
7.2.3 Energy-related Carbon Emissions 44
7.2.4 Life-Cycle Costs 45
7.3 State Summary 47
8 Delaware 49
8.1 Percentage Savings 49
8.2 Total Savings 51
8.2.1 Energy Use 51
8.2.2 Energy Costs 53
8.2.3 Energy-related Carbon Emissions 54
8.2.4 Life-Cycle Costs 55
8.3 State Summary 57
9 Florida 59
9.1 Percentage Savings 59
9.1.1 Statewide Building Comparison 60
9.1.2 City Comparisons 61
9.2 Total Savings 62
9.2.1 Energy Use 62
9.2.2 Energy Costs 64
9.2.3 Energy-related Carbon Emissions 66
9.2.4 Life-Cycle Costs 67
9.3 State Summary 68
10 Georgia 69
10.1 Percentage Savings 69
10.1.1 Statewide Building Comparison 69
10.1.2 City Comparisons 71
10.2 Total Savings 72
10.2.1 Energy Use 72
10.2.2 Energy Costs 73
10.2.3 Energy-related Carbon Emissions 75
10.2.4 Life-Cycle Costs 76
10.3 State Summary 77
11 Kentucky 79
11.1 Percentage Savings 79

11.1.1 Statewide Building Comparison 79
11.1.2 City Comparisons 81
11.2 Total Savings 82
11.2.1 Energy Use 82
11.2.2 Energy Costs 84
11.2.3 Energy-related Carbon Emissions 85
11.2.4 Life-Cycle Costs 86
11.3 State Summary 88
12 Louisiana 89
12.1 Percentage Savings 89
12.1.1 Statewide Building Comparison 90
12.1.2 City Comparisons 91
12.2 Total Savings 92
12.2.1 Energy Use 92
12.2.2 Energy Costs 94
12.2.3 Energy-related Carbon Emissions 95
12.2.4 Life-Cycle Costs 96
12.3 State Summary 98
13 Maryland 99
13.1 Percentage Savings 99
13.2 Total Savings 101
13.2.1 Energy Use 101
13.2.2 Energy Costs 103
13.2.3 Energy-related Carbon Emissions 105
13.2.4 Life-Cycle Costs 106
13.3 State Summary 107
14 Mississippi 109
14.1 Percentage Savings 110
14.1.1 Energy Use 110
14.1.2 Energy Costs 111
14.1.3 Energy-related Carbon Emissions 111
14.1.4 Life-Cycle Costs 112
14.1.5 City Comparisons 113
14.2 Total Savings 115
14.2.1 Energy Use 115
14.2.2 Energy Costs 117
14.2.3 Energy-related Carbon Emissions 118
14.2.4 Life-Cycle Costs 120
14.3 State Summary 121
15 North Carolina 123
15.1 Percentage Savings 123

15.1.1 Statewide Building Comparison 124
15.1.2 City Comparisons 125
15.2 Total Savings 126
15.2.1 Energy Use 126
15.2.2 Energy Costs 128
15.2.3 Energy-related Carbon Emissions 130
15.2.4 Life-Cycle Costs 131
15.3 State Summary 132
16 Oklahoma 133
16.1 Percentage Savings 133
16.1.1 Energy Use 134
16.1.2 Energy Costs 135
16.1.3 Energy-related Carbon Emissions 135
16.1.4 Life-Cycle Costs 136
16.1.5 City Comparisons 137
16.2 Total Savings 139
16.2.1 Energy Use 139
16.2.2 Energy Costs 141
16.2.3 Energy-related Carbon Emissions 142
16.2.4 Life-Cycle Costs 143
16.3 State Summary 145
17 South Carolina 147
17.1 Percentage Savings 147
17.1.1 Energy Use 148
17.1.2 Energy Costs 148
17.1.3 Energy-related Carbon Emissions 149
17.1.4 Life-Cycle Costs 150
17.1.5 City Comparisons 151
17.2 Total Savings 153
17.2.1 Energy Use 153
17.2.2 Energy Costs 155
17.2.3 Energy-related Carbon Emissions 156
17.2.4 Life-Cycle Costs 158
17.3 State Summary 159
18 Tennessee 161
18.1 Percentage Savings 161
18.1.1 Energy Use 162
18.1.2 Energy Costs 162
18.1.3 Energy-related Carbon Emissions 163
18.1.4 Life-Cycle Costs 164
18.1.5 City Comparisons 165

18.2 Total Savings 167
18.2.1 Energy Use 167
18.2.2 Energy Costs 169
18.2.3 Energy-related Carbon Emissions 171
18.2.4 Life-Cycle Costs 172
18.3 State Summary 174
19 Texas 175
19.1 Percentage Savings 175
19.1.1 Statewide Building Comparison 175
19.1.2 City Comparisons 177
19.2 Total Savings 178
19.2.1 Energy Use 179
19.2.2 Energy Costs 180
19.2.3 Energy-related Carbon Emissions 182
19.2.4 Life-Cycle Costs 183
19.3 State Summary 184
20 Virginia 185
20.1 Percentage Savings 185
20.1.1 Statewide Building Comparison 185
20.1.2 City Comparisons 187
20.2 Total Savings 188
20.2.1 Energy Use 188
20.2.2 Energy Costs 190
20.2.3 Energy-related Carbon Emissions 191
20.2.4 Life-Cycle Costs 192
20.3 State Summary 194
21 West Virginia 195
21.1 Percentage Savings 195
21.1.1 Energy Use 196
21.1.2 Energy Costs 197
21.1.3 Energy-related Carbon Emissions 198
21.1.4 Life-Cycle Costs 199
21.1.5 City Comparisons 199
21.2 Total Savings 201
21.2.1 Energy Use 201
21.2.2 Energy Costs 203
21.2.3 Energy-related Carbon Emissions 205
21.2.4 Life-Cycle Costs 206
21.3 State Summary 207
22 State Comparisons for the Adoption of the Low Energy Case Design 209
22.1 Total Savings Comparison 209

22.2 Percentage Change Comparison 214
22.2.1 3-Story Office Building 214
22.2.2 Region-wide Results by Study Period Length 218
22.2.3 Region-wide Results by Building Type 221
22.2.4 Region-wide Results by Climate Zone 221
23 Discussion 225
23.1 Key Findings 225
23.2 Limitations and Future Research 227
References 230
A Building and Energy Characteristics 234
B Additional BIRDS Database Results 238

List of Figures

Figure 2-1 Cities and Climate Zones 8
Figure 22-1 Average Energy Use Savings by State, 3-Story Office Building, 10-Year 216
Figure 22-2 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year 216
Figure 22-3 Average Energy-related Carbon Emissions Reduction by State, 3-Story Office Building, 10-Year 217
Figure 22-4 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year 217
Figure 22-5 Average Change in Life-Cycle Costs by Building Type and Study Period Length 220

List of Tables

Table 2-1 Building Characteristics ... 5
Table 2-2 Energy Code by State/City for the South 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 (South, 2003 through 2007) ... 16
Table 5-1 Greenhouse Gas Global Warming Potentials ... 19
Table 6-1 Average Annual Energy Use by Building Type and Standard Edition, Alabama ... 21
Table 6-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Alabama ... 22
Table 6-3 Average Percentage Change in Energy Costs, 10-Year, Alabama ... 23
Table 6-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Alabama ... 24
Table 6-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Alabama ... 25
Table 6-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Alabama ... 26
Table 6-7 Average Percentage Change in Energy Costs by City, 10-Year, Alabama ... 26
Table 6-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Alabama ... 27
Table 6-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Alabama ... 27
Table 6-10 Average Per Unit Change in Annual Energy Use, Alabama ... 28
Table 6-11 Statewide Change in Annual Energy Use for One Year of Construction, Alabama ... 29
Table 6-12 Average Per Unit Change in Energy Costs, 10-Year, Alabama ... 30
Table 6-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Alabama ... 31
Table 6-14 Average Per Unit Change in Carbon Emissions, 10-Year, Alabama ... 31
Table 6-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Alabama – Metric Tons ... 32
Table 6-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Alabama ... 33
Table 6-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Alabama ... 34
Table 7-1 Average Annual Energy Use by Building Type and Standard Edition, Arkansas ... 35
Table 7-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Arkansas ... 36
Table 7-3 Average Percentage Change in Energy Costs, 10-Year, Arkansas ... 37
Table 7-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Arkansas ... 38
Table 7-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Arkansas ... 39
Table 7-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Arkansas ... 39
Table 7-7 Average Percentage Change in Energy Costs by City, 10-Year, Arkansas ... 40

Table 7-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Arkansas 40
Table 7-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Arkansas 40
Table 7-10 Average Per Unit Change in Annual Energy Use, Arkansas 41
Table 7-11 Statewide Change in Annual Energy Use for One Year of Construction, Arkansas 42
Table 7-12 Average Per Unit Change in Energy Costs, 10-Year, Arkansas 43
Table 7-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Arkansas 44
Table 7-14 Average Per Unit Change in Carbon Emissions, 10-Year, Arkansas........ 44
Table 7-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Arkansas – Metric Tons........ 45
Table 7-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Arkansas........ 46
Table 7-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Arkansas 47
Table 8-1 Average Annual Energy Use by Building Type and Standard Edition, Delaware........ 49
Table 8-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Delaware 50
Table 8-3 Average Per Unit Change in Annual Energy Use, Delaware 52
Table 8-4 Statewide Change in Annual Energy Use for One Year of Construction, Delaware........ 53
Table 8-5 Average Per Unit Change in Energy Costs, 10-Year, Delaware 53
Table 8-6 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Delaware 54
Table 8-7 Average Per Unit Change in Carbon Emissions, 10-Year, Delaware 54
Table 8-8 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Delaware – Metric Tons 55
Table 8-9 Average Per Unit Change in Life-Cycle Costs, 10-Year, Delaware 56
Table 8-10 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Delaware 56
Table 9-1 Average Annual Energy Use by Building Type and Standard Edition, Florida 59
Table 9-2 Average Percentage Change from Adoption of a Newer Code, 10-Year, Florida 60
Table 9-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Florida 61
Table 9-4 Average Per Unit Change in Annual Energy Use, Florida........ 63
Table 9-5 Statewide Change in Annual Energy Use for One Year of Construction, Florida 64
Table 9-6 Average Per Unit Change in Energy Costs, 10-Year, Florida........ 65
Table 9-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Florida 65
Table 9-8 Average Per Unit Change in Carbon Emissions, 10-Year, Florida........ 66

Table 9-9 Statewide Change in Total Carbon Emissions (t) for One Year of Construction, 10-Year, Florida – Metric Tons 67
Table 9-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Florida 67
Table 9-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Florida 68
Table 10-1 Average Annual Energy Use by Building Type and Standard Edition, Georgia 69
Table 10-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Georgia 70
Table 10-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Georgia 71
Table 10-4 Average Per Unit Change in Annual Energy Use, Georgia 72
Table 10-5 Statewide Change in Annual Energy Use for One Year of Construction, Georgia 73
Table 10-6 Average Per Unit Change in Energy Costs, 10-Year, Georgia 74
Table 10-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Georgia 74
Table 10-8 Average Per Unit Change in Carbon Emissions, 10-Year, Georgia 75
Table 10-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Georgia – Metric Tons 76
Table 10-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Georgia 76
Table 10-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Georgia 77
Table 11-1 Average Annual Energy Use by Building Type and Standard Edition, Kentucky 79
Table 11-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Kentucky 80
Table 11-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Kentucky 81
Table 11-4 Average Per Unit Change in Annual Energy Use, Kentucky 82
Table 11-5 Statewide Change in Annual Energy Use for One Year of Construction, Kentucky 83
Table 11-6 Average Per Unit Change in Energy Costs, 10-Year, Kentucky 84
Table 11-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Kentucky 85
Table 11-8 Average Per Unit Change in Carbon Emissions, 10-Year, Kentucky 85
Table 11-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Kentucky – Metric Tons 86
Table 11-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Kentucky 87
Table 11-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Kentucky 88
Table 12-1 Average Annual Energy Use by Building Type and Standard Edition, Louisiana 89
Table 12-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Louisiana 90

Table 12-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Louisiana 91
Table 12-4 Average Per Unit Change in Annual Energy Use, Louisiana 92
Table 12-5 Statewide Change in Annual Energy Use for One Year of Construction, Louisiana 93
Table 12-6 Average Per Unit Change in Energy Costs, 10-Year, Louisiana 94
Table 12-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Louisiana 95
Table 12-8 Average Per Unit Change in Carbon Emissions, 10-Year, Louisiana........ 95
Table 12-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Louisiana – Metric Tons........ 96
Table 12-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Louisiana........ 97
Table 12-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Louisiana 98
Table 13-1 Average Annual Energy Use by Building Type and Standard Edition, Maryland 99
Table 13-2 Average Percentage Change from Adoption of a Newer Code, 10-Year, Maryland 100
Table 13-3 Average Per Unit Change in Annual Energy Use, Maryland........ 102
Table 13-4 Statewide Change in Annual Energy Use for One Year of Construction, Maryland 103
Table 13-5 Average Per Unit Change in Energy Costs, 10-Year, Maryland........ 104
Table 13-6 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Maryland 104
Table 13-7 Average Per Unit Change in Carbon Emissions, 10-Year, Maryland........ 105
Table 13-8 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Maryland – Metric Tons........ 106
Table 13-9 Average Per Unit Change in Life-Cycle Costs, 10-Year, Maryland........ 106
Table 13-10 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Maryland 107
Table 14-1 Average Annual Energy Use by Building Type and Standard Edition, Mississippi........ 109
Table 14-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Mississippi 110
Table 14-3 Average Percentage Change in Energy Costs, 10-Year, Mississippi........ 111
Table 14-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Mississippi........ 112
Table 14-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Mississippi........ 113
Table 14-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Mississippi 113
Table 14-7 Average Percentage Change in Energy Costs by City, 10-Year, Mississippi........ 114
Table 14-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Mississippi........ 114
Table 14-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Mississippi........ 115

Table 14-10 Average Per Unit Change in Annual Energy Use, Mississippi 116
Table 14-11 Statewide Change in Annual Energy Use for One Year of Construction, Mississippi 116
Table 14-12 Average Per Unit Change in Energy Costs, 10-Year, Mississippi 117
Table 14-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Mississippi 118
Table 14-14 Average Per Unit Change in Carbon Emissions, 10-Year, Mississippi 119
Table 14-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Mississippi – Metric Tons 120
Table 14-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Mississippi 120
Table 14-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Mississippi 121
Table 15-1 Average Annual Energy Use by Building Type and Standard Edition, North Carolina 123
Table 15-2 Average Percentage Change from Adoption of a Newer Code, 10-Year, North Carolina 124
Table 15-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, North Carolina 126
Table 15-4 Average Per Unit Change in Annual Energy Use, North Carolina 127
Table 15-5 Statewide Change in Annual Energy Use for One Year of Construction, North Carolina 128
Table 15-6 Average Per Unit Change in Energy Costs, 10-Year, North Carolina 129
Table 15-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, North Carolina 129
Table 15-8 Average Per Unit Change in Carbon Emissions, 10-Year, North Carolina 130
Table 15-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, North Carolina – Metric Tons 131
Table 15-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, North Carolina 131
Table 15-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, North Carolina 132
Table 16-1 Average Annual Energy Use by Building Type and Standard Edition, Oklahoma 133
Table 16-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Oklahoma 134
Table 16-3 Average Percentage Change in Energy Costs, 10-Year, Oklahoma 135
Table 16-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Oklahoma 136
Table 16-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Oklahoma 137
Table 16-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Oklahoma 137
Table 16-7 Average Percentage Change in Energy Costs by City, 10-Year, Oklahoma 138
Table 16-8 Average Percentage Change in Carbon Emissions by City, 10-Year, Oklahoma 138
Table 16-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Oklahoma 138

Table 16-10 Average Per Unit Change in Annual Energy Use, Oklahoma.................. 139
Table 16-11 Statewide Change in Annual Energy Use for One Year of Construction, Oklahoma 140
Table 16-12 Average Per Unit Change in Energy Costs, 10-Year, Oklahoma............. 141
Table 16-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Oklahoma 142
Table 16-14 Average Per Unit Change in Carbon Emissions, 10-Year, Oklahoma...... 142
Table 16-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Oklahoma – Metric Tons 143
Table 16-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Oklahoma........ 144
Table 16-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Oklahoma 145
Table 17-1 Average Annual Energy Use by Building Type and Standard Edition, South Carolina 147
Table 17-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, South Carolina 148
Table 17-3 Average Percentage Change in Energy Costs, 10-Year, South Carolina 149
Table 17-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, South Carolina 150
Table 17-5 Average Percentage Change in Life-Cycle Costs, 10-Year, South Carolina 151
Table 17-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, South Carolina 151
Table 17-7 Average Percentage Change in Energy Costs by City, 10-Year, South Carolina 152
Table 17-8 Average Percentage Change in Carbon Emissions by City, South Carolina 152
Table 17-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, South Carolina 153
Table 17-10 Average Per Unit Change in Annual Energy Use, South Carolina 154
Table 17-11 Statewide Change in Annual Energy Use for One Year of Construction, South Carolina 154
Table 17-12 Average Per Unit Change in Energy Costs, 10-Year, South Carolina 155
Table 17-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, South Carolina 156
Table 17-14 Average Per Unit Change in Carbon Emissions, 10-Year, South Carolina 157
Table 17-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, South Carolina – Metric Tons 158
Table 17-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, South Carolina 158
Table 17-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, South Carolina 159
Table 18-1 Average Annual Energy Use by Building Type and Standard Edition, Tennessee 161
Table 18-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Tennessee 162

Table 18-3 Average Percentage Change in Energy Costs, 10-Year, Tennessee 163
Table 18-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, Tennessee 164
Table 18-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Tennessee...... 165
Table 18-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, Tennessee........ 166
Table 18-7 Average Percentage Change in Energy Costs by City, 10-Year, Tennessee 166
Table 18-8 Average Percentage Change in Carbon Emissions by City, Tennessee...... 167
Table 18-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, Tennessee 167
Table 18-10 Average Per Unit Change in Annual Energy Use, Tennessee.................. 168
Table 18-11 Statewide Change in Annual Energy Use for One Year of Construction, Tennessee 169
Table 18-12 Average Per Unit Change in Energy Costs, 10-Year, Tennessee............. 170
Table 18-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Tennessee 171
Table 18-14 Average Per Unit Change in Carbon Emissions, 10-Year, Tennessee...... 171
Table 18-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Tennessee – Metric Tons........ 172
Table 18-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, Tennessee........ 173
Table 18-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Tennessee 174
Table 19-1 Average Annual Energy Use by Building Type and Standard Edition, Texas 175
Table 19-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Texas 176
Table 19-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Texas 178
Table 19-4 Average Per Unit Change in Annual Energy Use, Texas........................... 179
Table 19-5 Statewide Change in Annual Energy Use for One Year of Construction, Texas 180
Table 19-6 Average Per Unit Change in Energy Costs, 10-Year, Texas....................... 181
Table 19-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Texas 181
Table 19-8 Average Per Unit Change in Carbon Emissions, 10-Year, Texas............... 182
Table 19-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Texas – Metric Tons........ 183
Table 19-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Texas............... 183
Table 19-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Texas 184
Table 20-1 Average Annual Energy Use by Building Type and Standard Edition, Virginia........ 185
Table 20-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Virginia 186

Table 20-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Virginia ... 187
Table 20-4 Average Per Unit Change in Annual Energy Use, Virginia ... 188
Table 20-5 Statewide Change in Annual Energy Use for One Year of Construction, Virginia ... 189
Table 20-6 Average Per Unit Change in Energy Costs, 10-Year, Virginia ... 190
Table 20-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Virginia ... 191
Table 20-8 Average Per Unit Change in Carbon Emissions, 10-Year, Virginia ... 191
Table 20-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Virginia – Metric Tons ... 192
Table 20-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Virginia ... 193
Table 20-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Virginia ... 194
Table 21-1 Average Annual Energy Use by Building Type and Standard Edition, West Virginia ... 195
Table 21-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, West Virginia ... 196
Table 21-3 Average Percentage Change in Energy Costs, 10-Year, West Virginia ... 197
Table 21-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, West Virginia ... 198
Table 21-5 Average Percentage Change in Life-Cycle Costs, 10-Year, West Virginia 199
Table 21-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, West Virginia ... 200
Table 21-7 Average Percentage Change in Energy Costs by City, 10-Year, West Virginia ... 200
Table 21-8 Average Percentage Change in Carbon Emissions by City, 10-Year, West Virginia ... 201
Table 21-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, West Virginia ... 201
Table 21-10 Average Per Unit Change in Annual Energy Use, West Virginia ... 202
Table 21-11 Statewide Change in Annual Energy Use for One Year of Construction, West Virginia ... 203
Table 21-12 Average Per Unit Change in Energy Costs, 10-Year, West Virginia ... 204
Table 21-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, West Virginia ... 204
Table 21-14 Average Per Unit Change in Carbon Emissions, 10-Year, West Virginia 205
Table 21-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, West Virginia – Metric Tons ... 206
Table 21-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, West Virginia .. 206
Table 21-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, West Virginia ... 207
Table 22-1 Total Reductions by State for Adoption of the LEC Design, 10-Year ... 210
Table 22-2 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC Design by State, 10-Year ... 211

Table 22-3 Energy Cost Reduction per kWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year ... 212
Table 22-4 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year ... 213
Table 22-5 Life-Cycle Cost Reductions per Unit of New Floor Area for Adoption of the LEC Design by State, 10-Year ... 214
Table 22-6 Average Percentage Change by State from Region-wide Adoption of the LEC design, 3-Story Office Building, 10-Year ... 215
Table 22-7 South Region Average Percentage Change in Energy Use by Building Type ... 218
Table 22-8 South Region Average Percentage Change in Energy Costs by Building Type and Study Period Length ... 219
Table 22-9 South Region Average Percentage Change in Carbon Emissions by Building Type ... 219
Table 22-10 South Region Average Percentage Change in Life-Cycle Costs by Building Type and Study Period Length ... 220
Table 22-11 South Region Percentage Change for LEC by Building Type, 10-Year ... 221
Table 22-12 Average Percentage Change for LEC by Climate Zone ... 222
Table 22-13 Average Percentage Change in Energy Use for LEC by Climate Zone and State Energy Code ... 222
Table 22-14 Average Percentage Change in Energy Costs for LEC by Climate Zone and State Energy Code ... 223
Table 22-15 Average Percentage Change in Carbon Emissions for LEC by Climate Zone and State Energy Code ... 223
Table 22-16 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and State Energy Code ... 224
Table A-1 CBECS Categories and Subcategories ... 234
Table A-2 New Commercial Building Construction Floor Area for 2003 through 2007 by State and Building Type ... 235
Table A-3 New Commercial Building Construction Share by State and Building Type ... 236
Table A-4 Electricity Generation CO_2, CH_4, and N_2O Emissions Rates by State ... 236
Table B-1 4-Story Apartment Building Summary Table for LEC and 10-Year Study Period ... 238
Table B-2 6-Story Apartment Building Summary Table for LEC and 10-Year Study Period ... 238
Table B-3 4-Story Dormitory Summary Table for LEC and 10-Year Study Period ... 239
Table B-4 6-Story Dormitory Summary Table for LEC and 10-Year Study Period ... 239
Table B-5 15-Story Hotel Building Summary Table for LEC and 10-Year Study Period ... 240
Table B-6 2-Story High School Summary Table for LEC and 10-Year Study Period 240
Table B-7 8-Story Office Building Summary Table for LEC and 10-Year Study Period ... 241
Table B-8 16-Story Office Building Summary Table for LEC and 10-Year Study Period ... 241
Table B-9 1-Story Retail Store Summary Table for LEC and 10-Year Study Period. 242

Table B-10 1-Story Restaurant Summary Table for LEC and 10-Year Study Period. 242

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 sixteen states in the South 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 South Census Region have not yet adopted a state energy code for commercial buildings: Alabama, Mississippi, and Oklahoma. For these states, 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. The additional costs from implementing the energy efficiency measures overwhelm the future energy cost savings. *ASHRAE 90.1-2004* and *-2007* lead to greater reductions in energy use, energy costs, and carbon emissions than *ASHRAE 90.1-2001*, and are life-cycle cost-effective to adopt in two of the three states, with only Oklahoma realizing an increase in life-cycle costs.

Arkansas and West Virginia are the states in the South Census Region that have adopted *ASHRAE 90.1-2001* as their state energy code for commercial buildings. Both states would realize reductions in energy use, energy costs, and energy-related carbon emissions while realizing reductions in life-cycle costs from adopting *ASHRAE 90.1-2004* as their state energy code for commercial buildings. 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*.

Tennessee and South Carolina are the states in the South Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings. Both states would realize reductions in energy use, energy costs, and energy-related carbon emissions while realizing reductions in life-cycle costs from adopting *ASHRAE 90.1-2007*.

The adoption of the LEC design is analyzed for all sixteen 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 South 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 (20.1 %), energy costs (23.3 %), and carbon emissions (24.2 %), on average, while reducing life-cycle costs (1.3 %), on average, for a 10-year study period. Although the LEC design leads to reductions in energy use, energy costs, and carbon emissions for all states, the magnitude of the reductions varies according to each state's adopted energy code. The three states with no energy code realize the greatest percentage savings in energy use, energy costs, and carbon emissions. However, two of the three states realize percentage increases in life-cycle costs and the third state realizes a minimal percentage decrease. Meanwhile, the states that have already adopted *ASHRAE 90.1-2001*, *-2004*, or *-2007* realize percentage reductions in life-cycle costs.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 5 years to 15 years, the number of building types that are cost-effective increases from eight to all eleven considered. The study period is an important determinant of cost-effectiveness and size of 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 realize the smallest reductions while restaurants and 3- and 8-story office buildings realize the greatest reductions. The greatest percentage reductions in life-cycle costs 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 Texas than in Delaware because the amount of newly constructed floor area from 2003 to 2007 was 42 times greater in Texas.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy rates, and carbon emissions rates. The greatest 10-year reduction in energy use per unit of floor area resulting from adoption of the LEC design is realized by the three states that have no state energy code, ranging from 376 kWh/m^2 (119 kBtu/ft^2) to 551 kWh/m^2 (175 kBtu/ft^2), followed by the states that have adopted *ASHRAE 90.1-2001*, where the reduction ranges from 359 kWh/m^2 (114 kBtu/ft^2) to 370 kWh/m^2 (117 kBtu/ft^2). The states that have adopted *ASHRAE 90.1-2004* or *-2007* realize reductions ranging from 175 kWh/m^2 (56 kBtu/ft^2) to 247 kWh/m^2 (78 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 South Census Region. The results are analyzed for each state and across all states in the region to answer the following questions:

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

1.2 Literature Review

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

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

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

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

1.3 Approach

This study uses the BIRDS database to analyze the benefits and costs of increasing building energy efficiency for 71 cities located in the 16 states of the South 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 South 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, 71 cities across the sixteen states in the South Census Region of the United States, and 9 study period lengths.[1]

2.1 Building Types

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

Table 2-1 Building Characteristics

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

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

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

2.2 Building Designs

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

Table 2-2 shows the variation in commercial building energy codes across the sixteen states in the South Census Region.[3] Three states currently do not have a statewide energy code while two states, two states, and eight states have adopted *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, and *ASHRAE 90.1-2007*, respectively. One city in the South Census Region (Huntsville, AL) has adopted a newer edition of *ASHRAE 90.1* than has the state in which it is located.

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

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

State	City	Zone	Code
AL	Birmingham	3A	None
	Huntsville	3A	2001
	Mobile	2A	None
	Montgomery	3A	None
AR	Fort Smith	3A	2001
	Little Rock	3A	2001
DE	Wilmington	4A	2007
FL	Daytona Beach	2A	2007
	Jacksonville	2A	2007
	Key West	1	2007
	Miami	1	2007
	Tallahassee	2A	2007
	Tampa	2A	2007
	West Palm Beach	2A	2007
GA	Athens	3A	2007
	Atlanta	3A	2007
	Augusta	3A	2007
	Columbus	3A	2007
	Macon	3A	2007
	Savannah	2A	2007
KY	Covington	4A	2007
	Lexington	4A	2007
	Louisville	4A	2007
LA	Baton Rouge	2A	2007
	Lake Charles	2A	2007
	New Orleans	2A	2007
	Shreveport	3A	2007
MD	Baltimore	4A	2007
MS	Jackson	3A	None
	Meridian	3A	None
NC	Asheville	4A	2007
	Charlotte	3A	2007
	Greensboro	4A	2007
	Hatteras	3A	2007
	Raleigh	4A	2007
	Wilmington	3A	2007
OK	Oklahoma City	3A	None
	Tulsa	3A	None
SC	Charleston	3A	2004
	Columbia	3A	2004
	Greenville	3A	2004
TN	Bristol	4A	2004
	Chattanooga	4A	2004
	Knoxville	4A	2004
	Memphis	3A	2004
	Nashville	4A	2004
TX	Abilene	3B	2007
	Amarillo	4B	2007
	Austin	2A	2007
	Brownsville	2A	2007
	Corpus Christi	2A	2007
	Del Rio	2B	2007
	El Paso	3B	2007
	Fort Worth	3A	2007
	Houston	2A	2007
	Lubbock	3B	2007
	Lufkin	2A	2007
	Midland	3B	2007
	Port Arthur	2A	2007
	San Angelo	3B	2007
	San Antonio	2A	2007
	Victoria	2A	2007
	Waco	2A	2007
	Wichita Falls	3A	2007
VA	Lynchburg	4A	2007
	Norfolk	4A	2007
	Richmond	4A	2007
	Roanoke	4A	2007
WV	Charleston	4A	2001
	Elkins	5A	2001
	Huntington	4A	2001

The sixteen states, 71 cities, and 5 *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, Texas has eighteen cities while Delaware has one city. The climate zone(s) for each state vary across the South Census Region from *ASHRAE* Climate Zone 1 in Key West, Florida to Climate Zone 5 in Elkins, West Virginia. Almost the entire region is located in the “wet” (A) subzones except for western Texas and Oklahoma, which are located in the “dry” (B) subzones.

[4] State energy codes as of December 2011.

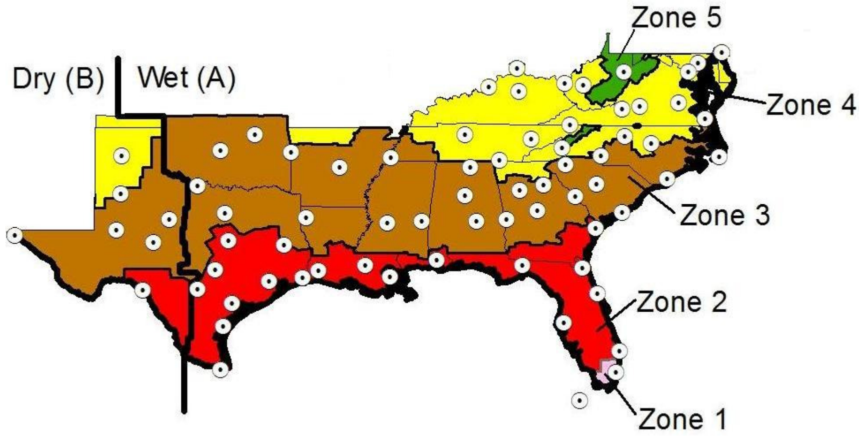

Figure 2-1 Cities and Climate Zones

2.3 Study Period Lengths

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

3 Cost Data

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

3.1 First Costs

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

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

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

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

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

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

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

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

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

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

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

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

The HVAC system size varies across the five building designs because changing the thermal characteristics of the building envelope alters the heating and cooling loads of the building. The *EnergyPlus* whole building energy simulations "autosize" the HVAC system to determine the appropriate system size to efficiently maintain the thermal comfort while dealing with ventilation requirements.[9] 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*.

[9] 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).[10] The UPV* values are used to discount future energy costs to equivalent present values. The discount factors vary by Census region, building sector, and fuel type.

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

4 Building Stock Data

Aggregating the savings for individual newly constructed commercial buildings to the state level requires new construction data for each building type within each state. This study uses the commercial building weighting factors reported in Jarnagin and Bandyopadhyay (2010) to estimate the total energy use savings, energy cost savings, life-cycle cost savings, and carbon emissions reduction resulting from adopting newer energy standard editions for each state. Jarnagin and Bandyopadhyay (2010) use two databases to generate the commercial building weighting factors: the 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 50.8 % of new commercial building stock floor area for 2003 through 2007 for the South 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 61.5 % of the new commercial building stock.

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

Category	Subcategory	Conditioned Floor Area 1000 m^2 (1000 ft^2)	Percentage in Category	Percentage of Total
Office	**Large**	**9425 (101 445)**	**22.2 %**	**2.8%**
Office	**Medium**	**17 151 (184 611)**	**40.4 %**	**5.0%**
Office	**Small**	**15 877 (170 902)**	**37.4 %**	**4.7%**
Retail		**41 494 (446 642)**	**72.9 %**	**12.2%**
Strip Mall		15 425 (166 035)	27.1 %	4.5%
School	Primary	14 698 (158 208)	32.5 %	4.3%
School	**Secondary**	**30 527 (328 585)**	**67.5 %**	**9.0%**
Hospital		8192 (88 179)	44.1 %	2.4%
Other Health Care		10 384 (111 773)	55.9 %	3.0%
Restaurant	**Sit Down**	**1872 (20 153)**	**52.9 %**	**0.5%**
Restaurant	Fast Food	1667 (17 944)	47.1 %	0.5%
Hotel	**Large**	**12 488 (134 417)**	**74.2 %**	**3.7%**
Hotel/Motel	Small	4342 (46 738)	25.8 %	1.3%
Warehouse		44 362 (477 511)		13.0%
Public Assembly		15 692 (168 905)		4.6%
Apartment	**High-rise**	**24 789 (266 827)**	**55.1 %**	**7.3%**
Apartment	**Mid-rise**	**20 200 (217 433)**	**44.9 %**	**5.9%**
No Prototype		51 999 (559 715)		15.3%
Total (2003 to 2007)		340 584 (3 666 018)		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 ta 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.[11] For this study, the design based on any *ASHRAE 90.1 Standard* edition that is newer than the standard edition required by the current state energy code is compared to the baseline state energy code compliant design to determine the changes in life-cycle costs.

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

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

5.3 Carbon Assessment

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

The assessment of cradle-to-grave energy-related carbon emissions considers a number of greenhouse gases for two types of energy consumption, electricity and natural gas. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the most prevalent. While carbon emissions from natural gas use can be assessed on a national average basis, those from electricity use are highly dependent upon the fuel mixes of regional electricity grids. For this reason, electricity emissions are assessed at the state-level using North American Electric Reliability Corporation (NERC) sub-region level data.[12] The life-cycle data sets for natural gas production and combustion as well as for all fuel sources in the electricity grid come from the U.S. Life-Cycle Inventory (LCI) database (LCI, 2012). The state-level average emissions rates per GWh (MBtu) of electricity generated are obtained from the 2007 Emissions and Generation Resource Integrated Database (eGRID2007), which is a collection of data from the EIA, the Federal Energy Regulatory Commission (FERC), and the Environmental Protection Agency (EPA).[13] 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.[14]

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

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

the GWP as carbon dioxide. The aggregated CO_2e is calculated by taking the amount of 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 Alabama

Alabama is located in the East South Central Census Division and spans two climate zones (Zone 2A and Zone 3A). 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 Alabama's simulated energy use keyed to building type 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 81 kWh/m^2 to 119 kWh/m^2 (26 kBtu/ft^2 to 38 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy for the *ASHRAE 90.1-1999* design at 189 kWh/m^2 (60 kBtu/ft^2) annually. The high school uses the greatest amount of energy for the LEC design at 130 kWh/m^2 (41 kBtu/ft^2) annually.

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

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	167	53	165	52	133	42	126	40	108	34
APART06	167	53	165	52	132	42	127	40	107	34
DORMI04	128	41	123	39	98	31	94	30	80	25
DORMI06	187	59	180	57	145	46	136	43	115	37
HOTEL15	150	48	148	47	117	37	122	39	104	33
HIGHS02	170	54	168	53	154	49	149	47	130	41
OFFIC03	128	41	124	39	109	34	103	33	81	26
OFFIC08	119	38	116	37	103	33	100	32	81	26
OFFIC16	143	45	141	45	125	40	129	41	109	35
RETAIL1	139	44	136	43	115	36	105	33	90	28
RSTRNT1	189	60	182	58	154	49	148	47	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.

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 Alabama.

6.1.1 Energy Use

Table 6-2 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 reductions in energy use of 3.0 % or less. There is a decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from -9.0 % to -22.9 % with an average of -17.3 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -9.1 % to -26.5 %, with an overall average of -19.9 %. The smallest reductions in energy use are realized by the 16-story office building and high school.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.9	-20.4	-24.3	-35.2
APART06	-0.9	-20.5	-23.7	-35.6
DORMI04	-2.7	-22.9	-25.6	-36.7
DORMI06	-3.0	-21.7	-26.5	-37.9
HOTEL15	-1.0	-21.5	-18.6	-30.3
HIGHS02	-0.6	-9.0	-12.3	-23.6
OFFIC03	-2.3	-14.4	-19.0	-36.3
OFFIC08	-2.4	-13.2	-15.3	-31.7
OFFIC16	-0.9	-12.1	-9.1	-23.3
RETAIL1	-2.0	-17.1	-23.7	-35.1
RSTRNT1	-2.9	-17.7	-21.0	-43.9
Average	**-1.8**	**-17.3**	**-19.9**	**-33.6**

For the high-rise buildings (15-story hotel and 16-story office building), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC requirement in Zone 2 and Zone 3 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 electricity 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 -23.3 % to -43.9 % with an average of -33.6 %.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.

6.1.2 Energy Costs

Table 6-3 shows a small percentage change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.7 % to -3.2 %), 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 -11.2 % to -26.2 % depending on the building type with an average of -19.4 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -9.4 % to -30.5 %, with an overall average of -21.9 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -25.1 % to -46.5 % with an average of -37.2 % overall.

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

Building Type	Standard Edition			
	2001	**2004**	**2007**	**LEC**
APART04	-1.0	-23.9	-27.9	-40.3
APART06	-1.0	-23.9	-27.6	-41.2
DORMI04	-2.9	-26.2	-29.4	-41.7
DORMI06	-3.2	-25.3	-30.5	-43.7
HOTEL15	-1.1	-25.1	-22.4	-36.2
HIGHS02	-0.7	-11.2	-14.4	-29.4
OFFIC03	-2.4	-14.6	-18.3	-36.6
OFFIC08	-2.5	-13.6	-15.3	-32.2
OFFIC16	-1.0	-12.3	-9.4	-25.1
RETAIL1	-2.1	-18.1	-23.6	-35.6
RSTRNT1	-3.0	-19.4	-22.1	-46.5
Average	**-1.9**	**-19.4**	**-21.9**	**-37.2**

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

6.1.3 Energy-related Carbon Emissions

The small changes in energy use lead to small percentage reductions (3.3 % or less) in cradle-to-grave energy-related carbon emissions from adopting 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 -12.3 % to -27.8 % with an average of -20.5 %. 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 -9.6 % to -32.5 % with an overall average of -22.9 %. The LEC design leads to the greatest average changes in carbon emissions, ranging from -26.0 % to -47.7 % depending on the building type with an average of -39.0 % across all building types.

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

Building Type	Standard Edition			
	2001	**2004**	**2007**	**LEC**
APART04	-1.0	-25.6	-29.8	-42.9
APART06	-1.0	-25.6	-29.5	-44.1
DORMI04	-3.0	-27.8	-31.2	-44.2
DORMI06	-3.3	-27.1	-32.5	-46.7
HOTEL15	-1.2	-26.9	-24.3	-39.2
HIGHS02	-0.7	-12.5	-15.6	-32.7
OFFIC03	-2.5	-14.7	-17.9	-36.8
OFFIC08	-2.5	-13.9	-15.3	-32.4
OFFIC16	-1.0	-12.3	-9.6	-26.0
RETAIL1	-2.2	-18.6	-23.5	-35.9
RSTRNT1	-3.1	-20.2	-22.6	-47.7
Average	**-2.0**	**-20.5**	**-22.9**	**-39.0**

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

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 8 of 11 building types over a 10-year study period. The current state energy code is never the lowest cost building design. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building designs for two and three building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -4.6 % to 2.5 % depending on the building type. The LEC design is the lowest cost building design for six building types, with the percentage change in life-cycle costs ranging from -4.9 % to -0.9 %. 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 6-5 Average Percentage Change in Life-Cycle Costs, 10-Year, Alabama

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.0	-3.0	**-3.6**	-3.4
APART06	-0.1	-3.1	**-3.6**	-3.5
DORMI04	3.4	-1.4	-1.2	**-2.9**
DORMI06	-0.4	-3.9	-4.6	**-4.9**
HOTEL15	-0.1	**-3.6**	-3.2	-3.0
HIGHS02	0.1	-1.5	-1.7	**-3.3**
OFFIC03	4.7	2.0	1.2	**-0.7**
OFFIC08	4.7	1.7	1.1	**-0.7**
OFFIC16	0.0	**-1.7**	-1.3	-1.0
RETAIL1	2.7	-0.5	**-1.2**	-0.9
RSTRNT1	6.5	2.5	1.5	**-3.4**
Average	**2.0**	**-1.1**	**-1.5**	**-2.5**

6.1.5 City Comparisons

Simulations are run for four cities located in Alabama: Mobile in Climate Zone 2A and Birmingham, Huntsville, and Montgomery in Climate Zone 3A. The results may vary across cities within Alabama for four 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. Finally, Huntsville has adopted a stricter building energy code than the state.

As can be seen in Table 6-6, average reductions in energy use for all building types from adopting newer energy standard editions vary across and within climate zones. Huntsville realizes smaller reductions in energy use than the other three cities for all building designs because it has adopted *ASHRAE 90.1-2001* as its state energy code. Excluding Huntsville, adopting *ASHRAE 90.1-2004* leads to reductions in energy use that range from 16.4 % to 22.8 %. Montgomery realizes the greatest reductions in energy use from adopting the *ASHRAE 90.1-2004, -2007,* and LEC designs. Excluding Huntsville, the city in Zone 2A (Mobile) realizes the greatest reduction for the *ASHRAE 90.1-2007* and LEC designs relative to *ASHRAE 90.1-2004*.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Mobile	2A	-2.6	-17.6	-23.9	-37.4
Birmingham	3A	-2.3	-16.4	-17.8	-31.9
Huntsville	3A	0.0	-12.4	-13.5	-26.8
Montgomery	3A	-2.3	-22.8	-24.5	-38.3
Average		**-1.8**	**-17.3**	**-19.9**	**-33.6**

The variations in energy costs across cities are a result of three factors, the reduction in energy use, the fuel source of the reduction, and the local energy code. Table 6-7 shows that Huntsville realizes the smallest reductions in energy costs because it has adopted *ASHRAE 90.1-2001*. Mobile and Montgomery realize similar reductions in energy costs for all building designs. The climate zone with the greatest reduction in energy use realizes the greatest reduction in energy costs for each of the building designs. Three of the four cities 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, a greater relative reduction in electricity leads to additional reductions in energy costs. Montgomery realizes slightly lower reductions in energy costs than reductions in energy use for the *ASHRAE 90.1-2004* and *-2007* designs because the percentage reduction in electricity consumption is less than the reduction in natural gas consumption.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Mobile	2A	-2.7	-20.0	-24.1	-39.1
Birmingham	3A	-2.4	-19.5	-21.5	-37.0
Huntsville	3A	0.0	-16.3	-18.1	-33.2
Montgomery	3A	-2.5	-21.8	-23.9	-39.3
Average		**-1.9**	**-19.4**	**-21.9**	**-37.2**

Table 6-8 reports changes in energy-related carbon emissions by city for Alabama. For all cities, the more stringent standard editions result in greater reductions in carbon emissions. Birmingham and Huntsville realize greater reductions in carbon emissions than reductions in energy use for all building designs. Meanwhile, Mobile and Montgomery realize smaller reductions in carbon emissions than energy use for two building designs.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Mobile	2A	-2.5	-20.2	-23.8	-39.9
Birmingham	3A	-2.3	-20.3	-22.7	-39.3
Huntsville	3A	0.0	-17.8	-20.1	-36.5
Montgomery	3A	-2.4	-20.9	-23.4	-39.9
Average		**-1.8**	**-19.8**	**-22.5**	**-38.9**

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*. Adoption of the *ASHRAE 90.1-2004* and *-2007* designs result in average reductions in life-cycle costs for three and four cities relative to *ASHRAE 90.1-1999*, respectively. Adoption of the LEC design realizes the greatest average percentage reductions in life-cycle costs for all cities in both climate zones. For the LEC design, buildings in Huntsville realize greater reductions in life-cycle costs than buildings in the other cities.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Mobile	2A	3.0	0.0	-0.8	-2.2
Birmingham	3A	2.5	-0.5	-0.7	-1.6
Huntsville	3A	0.0	-2.8	-3.0	-3.8
Montgomery	3A	2.3	-1.3	-1.6	-2.4
Average		**2.0**	**-1.1**	**-1.5**	**-2.5**

6.2 Total Savings

How much can Alabama 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.[15] 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.[16]

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

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-1.6	-0.5	-34.1	-10.8	-40.5	-12.9	-58.8	-18.6
APART06	-1.6	-0.5	-34.0	-10.8	-39.5	-12.5	-59.2	-18.8
DORMI04	-3.5	-1.1	-29.1	-9.2	-32.6	-10.3	-46.7	-14.8
DORMI06	-5.6	-1.8	-40.5	-12.9	-49.6	-15.7	-70.8	-22.4
HOTEL15	-1.6	-0.5	-32.3	-10.3	-28.1	-8.9	-45.5	-14.4
HIGHS02	-1.0	-0.3	-18.6	-5.9	-24.5	-7.8	-46.5	-14.8
OFFIC03	-3.0	-0.9	-15.0	-4.8	-20.5	-6.5	-39.5	-12.5
OFFIC08	-2.9	-0.9	-15.7	-5.0	-18.2	-5.8	-37.7	-11.9
OFFIC16	-1.3	-0.4	-17.4	-5.5	-13.0	-4.1	-33.3	-10.6
RETAIL1	-2.8	-0.9	-24.0	-7.6	-33.3	-10.5	-49.0	-15.5
RSTRNT1	-5.4	-1.7	-33.3	-10.6	-39.5	-12.5	-82.4	-26.1

The annual reduction in energy use shown in Table 6-11 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 3.2 GWh (10.9 GBtu), 33.8 GWh (115.4 GBtu), and 41.2 GWh (140.6 GBtu), respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 68.5 GWh (233.9 GBtu) of total energy use annually for one year's worth of new construction for these building types.

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

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

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 %	72	775	-112	-382	-2456	-8385	-2919	-9965	-4231	-14 446
APART06	55.1 %	88	949	-138	-472	-3001	-10 246	-3480	-11 881	-5217	-17 814
HOTEL15	100.0 %	171	1837	-265	-906	-5517	-18 838	-4790	-16 354	-7772	-26 536
HIGHS02	100.0 %	307	3303	-300	-1024	-4615	-15 756	-6286	-21 463	-12 109	-41 347
OFFIC03	37.4 %	113	1212	-337	-1151	-2100	-7169	-2763	-9432	-5237	-17 882
OFFIC08	40.4 %	121	1307	-355	-1212	-1902	-6493	-2208	-7539	-4572	-15 611
OFFIC16	22.2 %	67	719	-89	-305	-1159	-3959	-869	-2967	-2226	-7602
RETAIL1	100.0 %	497	5350	-1410	-4815	-11 924	-40 712	-16 530	-56 437	-24 346	-83 128
RSTRNT1	100.0 %	34	364	-183	-625	-1126	-3846	-1336	-4560	-2787	-9515
Total		**1469**	**15 815**	**-3190**	**-10 892**	**-33 799**	**-115 404**	**-41 178**	**-140 601**	**-68 498**	**-233 882**

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 65.2 % 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 the total statewide savings from adopting the LEC design in new commercial buildings to be 105.1 GWh (358.7 GBtu) per year. These savings imply 1.1 TWh (3.6 TBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 63.2 GWh (215.6 GBtu) annually or 631.6 GWh (2156.4 GBtu) over the 10-year study period.

The statewide change in energy use across the 9 building types with reported floor area data vary across and within the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2007*, and LEC designs. For the *ASHRAE 90.1-2001* design, the greatest reduction in energy use is realized by the retail store followed by the 8- and 3-story office buildings. Adopting *ASHRAE 90.1-2004* leads to the greatest reduction for the retail store followed by the hotel and high school. 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 33.8 % and 20.9 %, respectively, of the combined new construction in the state for the building types in this study. All other building types represent 11.6 % or less of new construction. For the LEC design, the amount of new construction overwhelms the relative percentage changes in energy use, with the retail store and high school ranked 7^{th} and 10^{th} 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, Alabama

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	-$1.24	-$0.12	-$29.56	-$2.75	-$34.53	-$3.21	-$49.87	-$4.63
APART06	-$1.25	-$0.12	-$29.58	-$2.75	-$34.11	-$3.17	-$50.97	-$4.74
DORMI04	-$2.78	-$0.26	-$24.97	-$2.32	-$28.03	-$2.60	-$39.72	-$3.69
DORMI06	-$4.48	-$0.42	-$35.13	-$3.26	-$42.32	-$3.93	-$60.59	-$5.63
HOTEL15	-$1.24	-$0.12	-$26.96	-$2.50	-$24.14	-$2.24	-$38.94	-$3.62
HIGHS02	-$2.39	-$0.22	-$14.22	-$1.32	-$17.84	-$1.66	-$35.57	-$3.30
OFFIC03	-$0.78	-$0.07	-$13.07	-$1.21	-$16.66	-$1.55	-$34.11	-$3.17
OFFIC08	-$2.33	-$0.22	-$12.62	-$1.17	-$14.12	-$1.31	-$29.75	-$2.76
OFFIC16	-$1.07	-$0.10	-$13.05	-$1.21	-$10.04	-$0.93	-$26.75	-$2.48
RETAIL1	-$2.26	-$0.21	-$19.01	-$1.77	-$24.80	-$2.30	-$37.32	-$3.47
RSTRNT1	-$4.31	-$0.40	-$27.29	-$2.54	-$31.10	-$2.89	-$65.41	-$6.08

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. All building types realize reductions in energy costs for all building designs. The *ASHRAE 90.1-2001* design realizes reductions in energy costs of $2.5 million. *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $27.7 million, $32.5 million, and $55.4 million respectively.

Assuming that the buildings considered in this study, which represent 65.2 % 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 *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide reductions in energy costs of $3.9 million, $42.5 million, $49.8 million, and $84.9 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2001	2004	2007	LEC
APART04	44.9 %	72	775	-\$89 128	-\$2 128 087	-\$2 485 667	-\$3 589 756
APART06	55.1 %	88	949	-\$110 147	-\$2 607 811	-\$3 007 728	-\$4 494 121
HOTEL15	100 %	171	1837	-\$211 628	-\$4 600 730	-\$4 118 738	-\$6 645 423
HIGHS02	100 %	307	3303	-\$238 982	-\$4 009 902	-\$5 112 524	-\$10 467 042
OFFIC03	37.4 %	113	1212	-\$268 779	-\$1 601 738	-\$2 008 743	-\$4 005 416
OFFIC08	40.4 %	121	1307	-\$283 014	-\$1 532 805	-\$1 714 809	-\$3 613 016
OFFIC16	22.2 %	67	719	-\$71 161	-\$871 948	-\$670 703	-\$1 786 908
RETAIL1	100 %	497	5350	-\$1 124 251	-\$9 449 092	-\$12 325 705	-\$18 548 214
RSTRNT1	100 %	34	364	-\$145 915	-\$923 287	-\$1 052 206	-\$2 213 315
Total		**1469**	**15 815**	**-\$2 543 006**	**-\$27 725 400**	**-\$32 496 823**	**-\$55 363 211**

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, Alabama

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	-13.2	-2.7	-325.8	-66.7	-377.8	-77.4	-544.8	-111.6
APART06	-13.3	-2.7	-326.3	-66.8	-375.5	-76.9	-560.3	-114.8
DORMI04	-29.6	-6.1	-274.0	-56.1	-307.9	-63.1	-434.5	-89.0
DORMI06	-47.7	-9.8	-387.1	-79.3	-463.5	-94.9	-664.4	-136.1
HOTEL15	-13.2	-2.7	-292.4	-59.9	-265.1	-54.3	-426.8	-87.4
HIGHS02	-8.3	-1.7	-144.2	-29.5	-178.8	-36.6	-375.5	-76.9
OFFIC03	-25.4	-5.2	-148.3	-30.4	-181.6	-37.2	-371.2	-76.0
OFFIC08	-24.8	-5.1	-134.9	-27.6	-148.4	-30.4	-315.3	-64.6
OFFIC16	-11.3	-2.3	-135.1	-27.7	-105.2	-21.5	-285.4	-58.4
RETAIL1	-24.1	-4.9	-201.7	-41.3	-255.6	-52.4	-388.7	-79.6
RSTRNT1	-45.9	-9.4	-293.8	-60.2	-329.0	-67.4	-694.6	-142.3

Table 6-15 applies the Table 6-14 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 for all building types. The adoption of *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* results in savings of

298 639 metric tons and 344 097 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 592 509 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 458 035 metric tons, 527 756 metric tons, and 908 756 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, Alabama – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	72	775	-948	-23 449	-27 198	-39 218
APART06	55.1 %	88	949	-1172	-28 767	-33 107	-49 401
HOTEL15	100.0 %	171	1837	-2251	-49 903	-45 243	-72 831
HIGHS02	100.0 %	307	3303	-2542	-44 232	-54 865	-115 215
OFFIC03	37.4 %	113	1212	-2859	-16 695	-20 445	-41 797
OFFIC08	40.4 %	121	1307	-3010	-16 384	-18 024	-38 281
OFFIC16	22.2 %	67	719	-757	-9026	-7029	-19 064
RETAIL1	100.0 %	497	5350	-11 959	-100 242	-127 054	-193 199
RSTRNT1	100.0 %	34	364	-1552	-9942	-11 133	-23 503
Total		**1469**	**15 815**	**-27 050**	**-298 639**	**-344 097**	**-592 509**

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, Alabama

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	-$0.22	-$0.02	-$29.02	-$2.70	-$34.68	-$3.22	-$32.82	-$3.05
APART06	-$0.64	-$0.06	-$29.49	-$2.74	-$34.31	-$3.19	-$33.68	-$3.13
DORMI04	$30.77	$2.86	-$12.81	-$1.19	-$11.55	-$1.07	-$26.26	-$2.44
DORMI06	-$4.04	-$0.38	-$38.92	-$3.62	-$46.02	-$4.27	-$49.08	-$4.56
HOTEL15	-$0.59	-$0.06	-$33.94	-$3.15	-$30.13	-$2.80	-$28.26	-$2.63
HIGHS02	$1.13	$0.11	-$11.49	-$1.07	-$13.15	-$1.22	-$25.57	-$2.38
OFFIC03	$35.03	$3.25	$15.14	$1.41	$8.59	$0.80	-$5.82	-$0.54
OFFIC08	$36.01	$3.35	$12.89	$1.20	$8.11	$0.75	-$6.40	-$0.59
OFFIC16	-$0.05	$0.00	-$12.70	-$1.18	-$9.47	-$0.88	-$6.95	-$0.65
RETAIL1	$17.00	$1.58	-$3.00	-$0.28	-$7.95	-$0.74	-$5.48	-$0.51
RSTRNT1	$80.02	$7.43	$29.39	$2.73	$16.66	$1.55	-$44.79	-$4.16

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 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 6 of 9 building types and increases total life-cycle costs by $19.6 million. The *ASHRAE 90.1-2004* and *-2007* designs result in a decrease in life-cycle costs for 6 of 9 building types, and decreases total life-cycle costs by $12.1 million and $16.8 million, respectively. The LEC design decreases life-cycle costs for all 9 building types, and decreases total life-cycle costs by $24.1 million. For a 10-year study period, it is cost-effective to adopt *ASHRAE 90.1-2004*, *-2007*, or the LEC design as Alabama'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 designs can be extrapolated to estimate statewide changes in life-cycle costs of $30.1 million, -$18.5 million, -$25.7 million, and -$37.0 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2001	2004	2007	LEC
APART04	44.9 %	72	775	-$16 187	-$2 088 867	-$2 496 460	-$2 362 203
APART06	55.1 %	88	949	-$56 386	-$2 599 670	-$3 025 054	-$2 969 767
HOTEL15	100.0 %	171	1837	-$101 118	-$5 791 083	-$5 141 870	-$4 821 976
HIGHS02	100.0 %	307	3303	$347 397	-$3 524 687	-$4 036 456	-$7 844 754
OFFIC03	37.4 %	113	1212	$3 944 651	$1 704 315	$967 514	-$655 088
OFFIC08	40.4 %	121	1307	$4 372 695	$1 565 333	$984 552	-$777 154
OFFIC16	22.2 %	67	719	-$3022	-$848 266	-$632 800	-$464 051
RETAIL1	100.0 %	497	5350	$8 447 106	-$1 489 371	-$3 952 577	-$2 725 771
RSTRNT1	100.0 %	34	364	$2 707 478	$994 305	$563 586	-$1 515 419
Total		**1469**	**15 815**	**$19 642 612**	**-$12 077 990**	**-$16 769 565**	**-$24 136 183**

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

6.3 State Summary

Alabama is one of three states in the South Census Region that have not yet adopted a state energy code for commercial buildings. On average, adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions, 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 631.6 GWh (2156.4 GBtu), energy cost savings of $49.8 million, and carbon emissions reductions of 527 756 metric tons while decreasing life-cycle costs by $25.7 million for one year's worth of commercial building construction. The adoption of the LEC design leads to even greater savings in 1.1 TWh (3.6 TBtu) of energy use, $84.9 million in energy costs, 908 756 metric tons of carbon emissions, and $37.0 million of life-cycle costs for one year's worth of commercial building construction.

7 Arkansas

Arkansas is one of two states in the South Census Region that have adopted *ASHRAE 90.1-2001* as their state energy code for commercial buildings, is located in the West South Central Census Division, and spans two climate zones (Zone 3A and Zone 4A). Table 7-1 provides an overview of Arkansas's simulated energy use keyed to building type 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 83 kWh/m^2 to 118 kWh/m^2 (26 kBtu/ft^2 to 37 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy for the *ASHRAE 90.1-2001* design at 188 kWh/m^2 (60 kBtu/ft^2) annually. The high school uses the greatest amount of energy for the LEC design at 154 kWh/m^2 (49 kBtu/ft^2) annually.

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

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	172	54	145	46	140	44	122	39
APART06	170	54	144	46	139	44	120	38
DORMI04	127	40	106	34	105	33	91	29
DORMI06	186	59	157	50	150	48	129	41
HOTEL15	150	48	126	40	136	43	118	37
HIGHS02	185	59	176	56	173	55	154	49
OFFIC03	121	39	110	35	107	34	85	27
OFFIC08	118	37	105	33	102	32	83	26
OFFIC16	143	46	130	41	138	44	117	37
RETAIL1	134	42	118	37	110	35	94	30
RSTRNT1	188	60	162	51	158	50	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 increasingly stringent energy codes. The results are reported in terms of average percentage savings on a statewide and city-by-city basis and as total savings on a statewide basis.

7.1 Percentage Savings

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

7.1.1 Energy Use

Table 7-2 shows that the average percentage changes in energy use from adopting the *ASHRAE 90.1-2004* design relative to *ASHRAE 90.1-2001* range from -4.9 % to -16.7 % depending on the building type, with an overall average of -12.8 %. The average percentage change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -3.5 % to -19.5 %, with an overall average of -13.9 %.

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

Building Type	Standard Edition		
	2004	2007	LEC
APART04	-15.5	-18.7	-29.0
APART06	-15.7	-18.4	-29.8
DORMI04	-16.7	-17.7	-28.8
DORMI06	-15.5	-19.5	-30.8
HOTEL15	-15.8	-9.1	-21.5
HIGHS02	-4.9	-6.4	-16.5
OFFIC03	-9.7	-12.2	-30.4
OFFIC08	-11.1	-13.8	-30.0
OFFIC16	-9.6	-3.5	-18.2
RETAIL1	-11.9	-17.5	-29.8
RSTRNT1	-14.0	-16.2	-39.8
Average	**-12.8**	**-13.9**	**-27.7**

For the high-rise buildings (15-story hotel and 16-story office building), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC requirement in Zone 2 and Zone 3 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 electricity consumption, such as increased roof insulation R-values.

The LEC design realizes the greatest percentage change in energy use relative to *ASHRAE 90.1-2001* with a range of -16.5 % to -39.8 % and an overall average of -27.7 %. Similar to the *ASHRAE 90.1-2007* design, the smallest 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 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 -8.7 % to -22.3 % depending on the building type, with an overall average of -16.5 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -7.9 % to -25.6 %, with an overall average of -18.3 %. 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. The LEC design realizes the greatest percentage changes in energy costs, with the average reduction by building type ranging from -23.8 % to -44.8 % and an overall average of -33.9 %.

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

Building Type	Standard Edition		
	2004	**2007**	**LEC**
APART04	-20.4	-24.5	-36.6
APART06	-20.5	-24.3	-37.9
DORMI04	-21.8	-24.5	-37.1
DORMI06	-20.3	-25.6	-39.1
HOTEL15	-22.3	-17.8	-32.1
HIGHS02	-8.7	-10.5	-25.0
OFFIC03	-11.4	-13.8	-33.0
OFFIC08	-12.3	-14.5	-31.4
OFFIC16	-12.0	-7.9	-23.8
RETAIL1	-14.0	-18.7	-31.8
RSTRNT1	-17.4	-19.6	-44.8
Average	**-16.5**	**-18.3**	**-33.9**

For all building designs, the average reductions in energy costs are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Adopting the *ASHRAE 90.1-2004*, *-2007*, and LEC designs increase natural gas consumption while decreasing electricity consumption for 11, 10, and 10 building types, respectively. 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

Table 7-4 shows significant changes in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -10.3 % to -24.6 % with an average of -17.8 %. The average change in carbon emissions from constructing buildings using *ASHRAE 90.1-2007* requirements is -19.9 % overall with the average change in carbon emissions varying across building types from -9.4 % to -27.8 %. The LEC design leads to the greatest average percentage changes in carbon emissions, ranging from -25.7 % to -46.5 % depending on the building type with an overall average of -36.1 % across all building types.

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

Building Type	Standard Edition		
	2004	2007	LEC
APART04	-22.2	-26.6	-39.4
APART06	-22.2	-26.4	-40.8
DORMI04	-23.5	-26.9	-40.0
DORMI06	-22.0	-27.8	-42.1
HOTEL15	-24.6	-21.0	-36.0
HIGHS02	-10.3	-12.1	-28.5
OFFIC03	-12.0	-14.3	-33.9
OFFIC08	-12.7	-14.7	-31.9
OFFIC16	-12.8	-9.4	-25.7
RETAIL1	-14.8	-19.1	-32.5
RSTRNT1	-18.6	-20.7	-46.5
Average	**-17.8**	**-19.9**	**-36.1**

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

7.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 7-5. The *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs realize the lowest life-cycle costs for two, five, and four 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 -10.3 % to 0.0 %. Based on the overall average percentage change of -3.3 %

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

Building Type	Standard Edition		
	2004	2007	LEC
APART04	-2.1	**-2.5**	-1.8
APART06	-2.1	**-2.5**	-1.9
DORMI04	-3.8	**-5.1**	-4.9
DORMI06	-2.6	**-3.2**	-2.9
HOTEL15	**-2.8**	-2.2	-1.6
HIGHS02	-0.9	-0.7	**-1.8**
OFFIC03	-2.9	-3.4	**-3.8**
OFFIC08	-3.0	-3.9	**-5.2**
OFFIC16	**-1.5**	-1.0	0.0
RETAIL1	-2.5	**-2.6**	-1.7
RSTRNT1	-2.5	-3.1	**-10.3**
Average	**-2.4**	**-2.7**	**-3.3**

7.1.5 City Comparisons

Simulations are run for two cities located in Arkansas, both of which are located in Climate Zone 3A: Fort Smith and Little Rock. 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 7-6, there is minimal variation in the average percentage reduction in energy use across cities in the state, with a difference of 0.4 to 0.6 percentage points depending on the building design.

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

Cities	Zone	Standard Edition		
		2004	2007	LEC
Fort Smith	3A	-12.6	-13.7	-27.4
Little Rock	3A	-13.0	-14.1	-28.0
Average		**-12.8**	**-13.9**	**-27.7**

Similar to energy use, Table 7-7 shows that the average percentage change in energy costs for all building types also varies minimally across cities, with a difference of less than 0.3 percentage points depending on the building design. For both 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.

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

Cities	Zone	Standard Edition		
		2004	2007	LEC
Fort Smith	3A	-16.3	-18.2	-33.7
Little Rock	3A	-16.6	-18.4	-34.0
Average		**-16.5**	**-18.3**	**-33.9**

Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally between cities. Table 7-8 shows that there is a 0.1 percentage point difference between cities for each building design. Similar to energy costs, reductions in carbon emissions are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption.

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

Cities	Zone	Standard Edition		
		2004	2007	LEC
Fort Smith	3A	-17.2	-19.5	-36.0
Little Rock	3A	-17.3	-19.6	-36.1
Average		**-17.2**	**-19.6**	**-36.1**

The data reported in Table 7-9 show that, over a 10-year period, the LEC design results in the lowest average life-cycle costs for both cities in the state. Reductions in life-cycle costs are similar across all cities in the state for each building design, with a variation of 0.1 percentage points between cities.

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

Cities	Zone	Standard Edition		
		2004	2007	LEC
Fort Smith	3A	-2.5	-2.8	**-3.3**
Little Rock	3A	-2.4	-2.7	**-3.2**
Average		**-2.4**	**-2.7**	**-3.3**

7.2 Total Savings

How much can Arkansas 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.[17] The reduction per m^2 (ft^2) is multiplied by the estimated annual m^2 (ft^2) of new construction of each building type, and Table 7-11 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[18]

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

Building Type	Standard Edition					
	2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-26.6	-8.5	-32.2	-10.2	-49.9	-15.8
APART06	-26.8	-8.5	-31.3	-9.9	-50.8	-16.1
DORMI04	-21.3	-6.7	-22.5	-7.1	-36.7	-11.6
DORMI06	-28.9	-9.2	-36.3	-11.5	-57.3	-18.2
HOTEL15	-23.6	-7.5	-13.6	-4.3	-32.2	-10.2
HIGHS02	-11.8	-3.7	-14.9	-4.7	-36.9	-11.7
OFFIC03	-9.0	-2.9	-11.9	-3.8	-30.5	-9.7
OFFIC08	-13.1	-4.2	-16.3	-5.2	-35.4	-11.2
OFFIC16	-13.7	-4.3	-5.0	-1.6	-26.1	-8.3
RETAIL1	-16.0	-5.1	-23.5	-7.4	-39.9	-12.7
RSTRNT1	-26.4	-8.4	-30.4	-9.7	-74.9	-23.8

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 11.6 GWh (39.8 GBtu) while adopting *ASHRAE 90.1-2007* saves 13.7 GWh (46.8 GBtu)

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

annually. The adoption of the LEC design as the state's energy code would save energy for all building types and 28.6 GWh (97.6 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, Arkansas

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition					
				2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	11	114	-283	-966	-342	-1 167	-530	-1 808
APART06	55.1 %	13	140	-348	-1 188	-407	-1 391	-661	-2 258
HOTEL15	100.0 %	97	1040	-2 282	-7 793	-1 316	-4 494	-3 113	-10 631
HIGHS02	100.0 %	259	2787	-2 333	-7 966	-3 077	-10 506	-7 908	-27 001
OFFIC03	37.4 %	48	521	-570	-1 948	-719	-2 456	-1 789	-6 108
OFFIC08	40.4 %	52	562	-685	-2 340	-853	-2 913	-1 850	-6 317
OFFIC16	22.2 %	29	309	-394	-1 345	-145	-494	-749	-2 558
RETAIL1	100.0 %	272	2925	-4 346	-14 838	-6 380	-21 782	-10 836	-37 000
RSTRNT1	100.0 %	15	166	-406	-1 386	-469	-1 600	-1 154	-3 941
Total		**796**	**8564**	**-11 648**	**-39 771**	**-13 707**	**-46 802**	**-28 591**	**-97 621**
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 67.1 % 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 use savings to be 42.6 GWh (145.5 GBtu) annually. These savings imply 426.1 GWh (1454.9 GBtu) in energy savings over the 10-year study period. In comparison, *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* would save 17.4 GWh (59.3 GBtu) and 20.4 GWh (69.7 GBtu) annually, or 173.6 GWh (592.7 GBtu) and 204.3 GWh (697.5 GBtu) over the 10-year study period, respectively.

The variation in the statewide change in energy use across the 9 building types with reported floor area data are consistent across building designs. Building types that represent the greatest amount of new floor area realize the largest changes in aggregate energy use. The greatest reductions across all building designs are realized by retail stores followed by high schools and hotels. The smallest reductions are realized by the 4- and 6-story apartments and 16-story office buildings. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. For example, the building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and high schools -- rank 6th and 11th in percentage reduction, respectively, among the 11 building types, 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, energy cost rates, and energy price escalation rates as defined in Section 3.2.

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

Building Type	Standard Edition					
	2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$18.88	-$1.75	-$22.64	-$2.10	-$33.84	-$3.14
APART06	-$18.93	-$1.76	-$22.42	-$2.08	-$35.01	-$3.25
DORMI04	-$15.28	-$1.42	-$17.18	-$1.60	-$26.02	-$2.42
DORMI06	-$20.48	-$1.90	-$25.84	-$2.40	-$39.45	-$3.67
HOTEL15	-$17.99	-$1.67	-$14.37	-$1.33	-$25.94	-$2.41
HIGHS02	-$7.98	-$0.74	-$9.60	-$0.89	-$23.03	-$2.14
OFFIC03	-$7.93	-$0.74	-$9.51	-$0.88	-$22.72	-$2.11
OFFIC08	-$8.50	-$0.79	-$9.99	-$0.93	-$21.62	-$2.01
OFFIC16	-$9.76	-$0.91	-$6.42	-$0.60	-$19.32	-$1.80
RETAIL1	-$10.49	-$0.97	-$13.95	-$1.30	-$23.74	-$2.21
RSTRNT1	-$18.32	-$1.70	-$20.60	-$1.91	-$47.16	-$4.38

Table 7-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. Overall, reductions in energy costs are greater for the more energy efficient building designs: $8.5 million, $9.7 million, and $19.2 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 $12.6 million, $14.4 million, and $28.6 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition		
				2004	2007	LEC
APART04	44.9 %	11	114	-$200 540	-$240 462	-$359 499
APART06	55.1 %	13	140	-$246 323	-$291 728	-$455 580
HOTEL15	100.0 %	97	1040	-$1 737 230	-$1 387 818	-$2 505 465
HIGHS02	100.0 %	259	2787	-$2 053 821	-$2 462 032	-$5 881 930
OFFIC03	37.4 %	48	521	-$386 274	-$464 768	-$1 114 838
OFFIC08	40.4 %	52	562	-$443 853	-$521 460	-$1 129 016
OFFIC16	22.2 %	29	309	-$280 371	-$184 387	-$555 117
RETAIL1	100.0 %	272	2925	-$2 849 372	-$3 791 847	-$6 451 060
RSTRNT1	100.0 %	15	166	-$282 204	-$317 349	-$726 487
Total		**796**	**8564**	**-$8 479 988**	**-$9 661 851**	**-$19 178 992**

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, Arkansas

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	-249.8	-51.2	-299.0	-61.2	-442.7	-90.7
APART06	-250.4	-51.3	-297.5	-60.9	-459.9	-94.2
DORMI04	-202.8	-41.5	-231.6	-47.4	-344.3	-70.5
DORMI06	-270.9	-55.5	-342.2	-70.1	-518.1	-106.1
HOTEL15	-242.2	-49.6	-206.0	-42.2	-353.7	-72.4
HIGHS02	-110.2	-22.6	-129.5	-26.5	-304.2	-62.3
OFFIC03	-104.3	-21.4	-123.9	-25.4	-294.0	-60.2
OFFIC08	-109.8	-22.5	-126.8	-26.0	-274.3	-56.2
OFFIC16	-129.3	-26.5	-94.6	-19.4	-258.5	-52.9
RETAIL1	-135.9	-27.8	-175.6	-36.0	-298.9	-61.2
RSTRNT1	-241.2	-49.4	-269.4	-55.2	-604.0	-123.7

Table 7-15 applies the Table 7-14 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 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs all decrease carbon emissions. The adoption of *ASHRAE 90.1-2004* results in savings of 112 965 metric tons while adopting *ASHRAE 90.1-2007* saves 127 666 metric tons over a 10-year study period. The adoption of the LEC design as the state's energy code decreases carbon emissions by 250 112 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 *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide reductions in carbon emissions of 168 353 metric tons, 190 262 metric tons, and 372 746 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, Arkansas – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition		
				2004	2007	LEC
APART04	44.9 %	11	114	-2653	-3176	-4703
APART06	55.1 %	13	140	-3258	-3871	-5984
HOTEL15	100.0 %	97	1040	-23 391	-19 900	-34 161
HIGHS02	100.0 %	259	2787	-28 528	-33 527	-78 766
OFFIC03	37.4 %	48	521	-5050	-5998	-14 235
OFFIC08	40.4 %	52	562	-5732	-6619	-14 324
OFFIC16	22.2 %	29	309	-3714	-2716	-7427
RETAIL1	100.0 %	272	2925	-36 924	-47 710	-81 209
RSTRNT1	100.0 %	15	166	-3716	-4149	-9304
Total		**796**	**8564**	**-112 965**	**-127 666**	**-250 112**

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, Arkansas

Building Type	Standard Edition					
	2004		2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$19.01	-$1.77	-$23.10	-$2.15	-$16.36	-$1.52
APART06	-$19.27	-$1.79	-$22.83	-$2.12	-$17.09	-$1.59
DORMI04	-$34.05	-$3.16	-$46.10	-$4.28	-$43.58	-$4.05
DORMI06	-$24.70	-$2.29	-$29.71	-$2.76	-$27.38	-$2.54
HOTEL15	-$24.95	-$2.32	-$19.86	-$1.84	-$14.39	-$1.34
HIGHS02	-$6.70	-$0.62	-$4.95	-$0.46	-$13.44	-$1.25
OFFIC03	-$21.86	-$2.03	-$25.88	-$2.40	-$28.91	-$2.69
OFFIC08	-$23.34	-$2.17	-$30.56	-$2.84	-$40.67	-$3.78
OFFIC16	-$10.19	-$0.95	-$6.60	-$0.61	$0.26	$0.02
RETAIL1	-$15.44	-$1.43	-$16.08	-$1.49	-$10.54	-$0.98
RSTRNT1	-$31.59	-$2.93	-$39.25	-$3.65	-$130.62	-$12.13

Table 7-17 applies the Table 7-16 results to one year's worth of new building construction in the state to estimate the 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 *ASHRAE 90.1-2007* and realizes an increase in life-cycle costs for the LEC design. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in similar total reductions in life-cycle costs for the building types considered in this study ($11.8 million each). The LEC design leads to the greatest total reductions in life-cycle costs of $13.7 million. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide changes in life-cycle costs of $17.7 million, $17.5 million, and $20.4 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition		
				2004	**2007**	**LEC**
APART04	44.9 %	11	114	-$201 958	-$245 401	-$173 778
APART06	55.1 %	13	140	-$250 744	-$296 999	-$222 395
HOTEL15	100.0 %	97	1040	-$2 409 963	-$1 918 016	-$1 389 520
HIGHS02	100.0 %	259	2787	-$1 736 035	-$1 282 081	-$3 479 349
OFFIC03	37.4 %	48	521	-$1 058 473	-$1 252 947	-$1 399 758
OFFIC08	40.4 %	52	562	-$1 218 597	-$1 595 671	-$2 123 465
OFFIC16	22.2 %	29	309	-$292 835	-$189 489	$7495
RETAIL1	100.0 %	272	2925	-$4 194 606	-$4 369 646	-$2 863 397
RSTRNT1	100.0 %	15	166	-$486 547	-$604 645	-$2 011 969
Total		**796**	**8564**	**-$11 849 757**	**-$11 754 894**	**-$13 656 136**
Note: Dormitories are excluded because no such floor area category is reported in the construction						

7.3 State Summary

Arkansas is one of two states that have adopted *ASHRAE 90.1-2001* as their state energy code for commercial buildings. 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, 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 for commercial buildings would lead to energy use savings of 204.3 GWh (697.5 GBtu), energy cost savings of $14.4 million, and 190 262 metric tons of carbon emissions reductions while saving $17.5 million in life-cycle costs for one year's worth of commercial building construction. Adopting the LEC design would lead to even greater impacts with savings of 426.1 GWh (1454.9 GBtu), $28.6 million in energy costs, 372 746 metric tons of carbon emissions, and life-cycle cost savings of $20.4 million.

8 Delaware

Delaware has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, and is located in the South Atlantic Census Division and Climate Zone 4A. Table 8-1 provides an overview of Delaware'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 99 kWh/m^2 (25 kBtu/ft^2 to 31 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 197 kWh/m^2 to 210 kWh/m^2 (62 kBtu/ ft^2 to 67 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	152	48	136	43
APART06	150	48	133	42
DORMI04	112	36	98	31
DORMI06	165	52	146	46
HOTEL15	154	49	134	42
HIGHS02	210	67	197	62
OFFIC03	106	34	85	27
OFFIC08	99	31	79	25
OFFIC16	148	47	124	39
RETAIL1	113	36	97	31
RSTRNT1	160	51	116	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. There is no within-state variation to consider for this state since only one city is simulated for the state (Wilmington).

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 Delaware.

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

There is significant variation in the change in energy use for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -6.4 % to -27.7 % depending on the building type with an overall average of -14.8 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

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

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-10.4	-15.0	-16.0	-0.2
APART06	-11.2	-17.0	-18.2	-0.4
DORMI04	-12.3	-16.3	-17.2	-0.5
DORMI06	-11.3	-16.9	-18.0	-0.8
HOTEL15	-13.1	-17.6	-18.5	-0.6
HIGHS02	-6.4	-13.3	-14.8	-1.8
OFFIC03	-20.0	-22.7	-23.2	-3.4
OFFIC08	-19.7	-21.1	-21.3	-3.2
OFFIC16	-16.0	-19.4	-19.9	-1.0
RETAIL1	-14.2	-16.7	-17.1	-0.8
RSTRNT1	-27.7	-32.2	-33.0	-8.5
Average	**-14.8**	**-18.9**	**-19.7**	**-1.9**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -13.3 % to -32.2 % depending on the building type with an average of -18.9 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 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 44.6 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over two times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -14.8 % to -33.0 % with an average of -19.7 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 8 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -8.5 % to -0.2 % for a 10-year study period. Since all 11 building types realize reductions in life-cycle costs, the LEC design is cost-effective for the state to adopt as its state energy code for commercial buildings.

8.2 Total Savings

How much can Delaware 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 8-3 reports the average per unit change in annual energy use by building type and building design in the state.[19] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 8-4 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[20]

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

Table 8-3 Average Per Unit Change in Annual Energy Use, Delaware

Building Type	Standard Edition LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-15.7	-5.0
APART06	-16.9	-5.4
DORMI04	-13.8	-4.4
DORMI06	-18.6	-5.9
HOTEL15	-20.1	-6.4
HIGHS02	-21.1	-6.7
OFFIC03	-13.5	-4.3
OFFIC08	-19.5	-6.2
OFFIC16	-23.7	-7.5
RETAIL1	-16.1	-5.1
RSTRNT1	-44.3	-14.1

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 3.4 GWh (11.5 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 55.9 % 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 6.0 GWh (20.5 GBtu) per year. These savings imply 60.1 GWh (205.3 GBtu) in energy use savings over the 10-year study period.

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 greatest total reductions are realized by high schools and retail stores because they represent 30.2 % and 24.5 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 13.0 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- high schools and retail stores -- only rank 11th and 5th in percentage reduction, respectively, among the 11 building types, as reported in Table 8-2.

Table 8-4 Statewide Change in Annual Energy Use for One Year of Construction, Delaware

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	kBtu
APART04	44.9 %	6	68	-99 049	-338 196
APART06	55.1 %	8	83	-130 376	-445 161
HOTEL15	100.0 %	25	266	-496 289	-1 694 545
HIGHS02	100.0 %	58	625	-785 128	-2 680 765
OFFIC03	37.4 %	17	180	-354 464	-1 210 293
OFFIC08	40.4 %	18	195	-352 850	-1 204 782
OFFIC16	22.2 %	10	107	-235 479	-804 028
RETAIL1	100.0 %	47	510	-764 433	-2 610 103
RSTRNT1	100.0 %	3	35	-142 399	-486 211
Total		**192**	**2069**	**-3 360 468**	**-11 474 083**

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

8.2.2 Energy Costs

Table 8-5 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 8-5 Average Per Unit Change in Energy Costs, 10-Year, Delaware

Building Type	Standard Edition LEC $/m^2$	$/ft^2$
APART04	-$16.19	-$1.50
APART06	-$18.32	-$1.70
DORMI04	-$13.47	-$1.25
DORMI06	-$19.96	-$1.85
HOTEL15	-$19.58	-$1.82
HIGHS02	-$20.85	-$1.94
OFFIC03	-$18.53	-$1.72
OFFIC08	-$18.92	-$1.76
OFFIC16	-$23.87	-$2.22
RETAIL1	-$15.58	-$1.45
RSTRNT1	-$41.84	-$3.89

Table 8-6 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 $3.6 million for 10 years of building operation.

Assuming that the buildings considered in this study, which represent 55.9 % 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 $6.5 million over the 10-year study period.

Table 8-6 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Delaware

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	6	68	-$102 070
APART06	55.1 %	8	83	-$141 520
HOTEL15	100.0 %	25	266	-$483 773
HIGHS02	100.0 %	58	625	-$1 076 378
OFFIC03	37.4 %	17	180	-$349 528
OFFIC08	40.4 %	18	195	-$341 994
OFFIC16	22.2 %	10	107	-$237 330
RETAIL1	100.0 %	47	510	-$738 614
RSTRNT1	100.0 %	3	35	-$134 485
Total		**192**	**2069**	**-$3 605 692**

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

8.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-112.5	-23.0
APART06	-128.3	-26.3
DORMI04	-92.9	-19.0
DORMI06	-139.5	-28.6
HOTEL15	-135.0	-27.7
HIGHS02	-133.2	-27.3
OFFIC03	-144.1	-29.5
OFFIC08	-130.4	-26.7
OFFIC16	-165.4	-33.9
RETAIL1	-107.3	-22.0
RSTRNT1	-287.2	-58.8

Table 8-8 applies the Table 8-7 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The adoption of the LEC design decreases carbon emissions for all building types and results in total savings of 25 198 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the statewide reductions in carbon emissions of 45 078 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	6	68	-709
APART06	55.1 %	8	83	-990
HOTEL15	100.0 %	25	266	-3337
HIGHS02	100.0 %	58	625	-7735
OFFIC03	37.4 %	17	180	-2415
OFFIC08	40.4 %	18	195	-2357
OFFIC16	22.2 %	10	107	-1645
RETAIL1	100.0 %	47	510	-5088
RSTRNT1	100.0 %	3	35	-923
Total		**192**	**2069**	**-25 198**

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

8.2.4 Life-Cycle Costs

Table 8-9 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

Table 8-9 Average Per Unit Change in Life-Cycle Costs, 10-Year, Delaware

Building Type	Standard Edition LEC $/m^2$	$/ft^2$
APART04	-$2.26	-$0.21
APART06	-$4.06	-$0.38
DORMI04	-$4.86	-$0.45
DORMI06	-$7.35	-$0.68
HOTEL15	-$5.12	-$0.48
HIGHS02	-$13.74	-$1.28
OFFIC03	-$26.17	-$2.43
OFFIC08	-$25.02	-$2.32
OFFIC16	-$7.19	-$0.67
RETAIL1	-$5.22	-$0.49
RSTRNT1	-$112.91	-$10.49

Table 8-10 applies the Table 8-9 results to one year's worth of new building construction in the state to estimate change in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building types, with all 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $2.5 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 decrease in life-cycle costs ($798 270, $452 159, and $438 620, 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 $4.5 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	6	68	-$14 278
APART06	55.1 %	8	83	-$31 373
HOTEL15	100.0 %	25	266	-$126 570
HIGHS02	100.0 %	58	625	-$798 270
OFFIC03	37.4 %	17	180	-$438 620
OFFIC08	40.4 %	18	195	-$452 159
OFFIC16	22.2 %	10	107	-$71 527
RETAIL1	100.0 %	47	510	-$247 565
RSTRNT1	100.0 %	3	35	-$362 959
Total		**192**	**2069**	**-$2 543 321**

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

8.3 State Summary

Delaware has adopted *ASHRAE 90.1-2007* as its state commercial building energy code. On average, adopting the LEC design reduces energy use, energy costs and energy-related carbon emissions, and does so in a cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to statewide energy use savings of 60.1 GWh (205.3 GBtu), energy cost savings of $6.5 million, and carbon emissions reductions of 45 078 metric tons while decreasing life-cycle costs by $4.5 million for one year's worth of commercial building construction.

9 Florida

Florida has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the South Atlantic Census Division, and spans two climate zones (Zone 1 and Zone 2A). Table 9-1 provides an overview of Florida's simulated energy use keyed to building type and energy standard edition. Average energy use varies across building types and building designs. The 4-story dormitory uses the least amount of energy at 79 kWh/m^2 to 95 kWh/m^2 (25 kBtu/ft^2 to 30 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy at 108 kWh/m^2 to 155 kWh/m^2 (34 kBtu/ft^2 to 49 kBtu/ ft^2) annually.

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

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

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

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 the LEC design for the state of Florida.

9.1.1 Statewide Building Comparison

Table 9-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*. The LEC design realizes changes in energy use ranging from -16.6 % to -30.5 %, with an average of -19.8 %. The lowest reduction in energy use for the LEC design occurs in the 4-story apartment building and hotel while the greatest reduction in energy use occurs in restaurants.

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

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

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

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

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

9.1.2 City Comparisons

Simulations are run for seven cities located in Florida: Key West and Miami in Climate Zone 1, and Daytona Beach, Jacksonville, Tallahassee, Tampa, and West Palm Beach in Climate Zone 2A. The results may vary across cities within the state for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zones and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

As can be seen in Table 9-3, the average reduction in energy use for all building types from adopting the LEC design is slightly greater for the cities located in Zone 1 than in Zone 2. For the LEC design, Zone 1 realizes an average change in energy use of -21.2 % compared to -19.6 % for Zone 2. The average percentage change in energy use varies minimally within Zone 2, -17.6 % to -20.3 %, because of climate variation within the subzone. The cities located furthest north in the state, Jacksonville and Tallahassee, realize the smallest reductions in energy use.

Table 9-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Florida

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

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

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

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

9.2 Total Savings

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

9.2.1 Energy Use

Table 9-4 reports the average per unit change in annual energy use by building type for the LEC design in the state.[21] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 9-5 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.[22]

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

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

Table 9-4 Average Per Unit Change in Annual Energy Use, Florida

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

The annual reduction in energy use shown in Table 9-5 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 246.4 GWh (841.3 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 65.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate total statewide savings to be 379.0 GWh (1294.2 GBtu) per year. These savings imply 3.8 TWh (12.9 TBtu) in energy savings over the 10-year study period.

Table 9-5 Statewide Change in Annual Energy Use for One Year of Construction, Florida

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	1923	20 704	-41 125 439	-140 419 934
APART06	55.1 %	2356	25 359	-53 670 927	-183 255 624
HOTEL15	100.0 %	596	6414	-10 823 497	-36 956 072
HIGHS02	100.0 %	1552	16 705	-41 416 445	-141 413 553
OFFIC03	37.4 %	676	7277	-18 492 215	-63 140 373
OFFIC08	40.4 %	729	7848	-15 950 755	-54 462 735
OFFIC16	22.2 %	401	4318	-8 971 492	-30 632 532
RETAIL1	100.0 %	2381	25 627	-49 516 636	-169 071 088
RSTRNT1	100.0 %	136	1460	-6 413 952	-21 899 992
Total		**10 750**	**115 711**	**-246 381 359**	**-841 251 902**

Note: Dormitories are excluded because no 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 -- 6-story apartment buildings and retail stores -- only rank 9th and 5th in percentage reduction, respectively, among the 11 building types, as reported in Table 9-2.

9.2.2 Energy Costs

Table 9-6 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 9-6 Average Per Unit Change in Energy Costs, 10-Year, Florida

Building Type	Standard Edition LEC $/m^2$	Standard Edition LEC $/ft^2$
APART04	-$18.85	-$1.75
APART06	-$20.25	-$1.88
DORMI04	-$14.60	-$1.36
DORMI06	-$22.97	-$2.13
HIGHS02	-$16.63	-$1.55
HOTEL15	-$24.03	-$2.23
OFFIC03	-$23.50	-$2.18
OFFIC08	-$18.64	-$1.73
OFFIC16	-$19.69	-$1.83
RETAIL1	-$17.79	-$1.65
RSTRNT1	-$40.76	-$3.79

Table 9-7 reports the statewide changes in total energy costs by building type, which account for one year's worth of new construction evaluated over 10 years of building operation. Overall, the reduction in energy costs totals $216.4 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 apartment buildings, retail stores, and high schools. The smallest reductions in energy costs are realized by restaurants and 16-story office buildings. Assuming that the buildings considered in this study, which represent 65.0 % of all new floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $333.0 million over the 10-year study period.

Table 9-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Florida

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

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

9.2.3 Energy-related Carbon Emissions

Table 9-8 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 9-8 Average Per Unit Change in Carbon Emissions, 10-Year, Florida

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

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

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

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

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

9.2.4 Life-Cycle Costs

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

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

Table 9-11 applies the Table 9-10 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 decreases total life-cycle costs by

$91.4 million, and reduces costs for all 9 building types. Hotels and high-rise office buildings realize the smallest reductions in life-cycle costs. Assuming that the buildings considered in this study are generally representative of the entire new building stock in the state, the results for the LEC design can be extrapolated to estimate an increase in total statewide life-cycle costs of $151.3 million over the 10-year study period.

Table 9-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Florida

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

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

9.3 State Summary

Florida 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 significantly decreasing life-cycle costs. Based on the average annual new commercial construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code for commercial buildings would lead to energy savings of 3.8 TWh (12.9 TBtu), energy cost savings of $333.0 million, and carbon emissions savings of 3.2 million metric tons, and life-cycle cost savings of $151.3 million for one year's worth of commercial building construction.

10 Georgia

Georgia has adopted *ASHRAE 90.1-2007* as its state energy code, is located in the South Atlantic Census Division, and spans two climate zones (Zone 2A and Zone 3A). Table 10-1 provides an overview of Georgia'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 80 kWh/m^2 to 100 kWh/m^2 (25 kBtu/ft^2 to 32 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 129 kWh/m^2 to 148 kWh/m^2 (41 kBtu/ft^2 to 47 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	124	39	106	34
APART06	124	39	105	33
DORMI04	93	30	79	25
DORMI06	135	43	114	36
HOTEL15	121	38	104	33
HIGHS02	148	47	129	41
OFFIC03	102	32	80	25
OFFIC08	100	32	80	25
OFFIC16	130	41	109	34
RETAIL1	104	33	88	28
RSTRNT1	148	47	103	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.

10.1 Percentage Savings

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

10.1.1 Statewide Building Comparison

Table 10-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*. There is significant variation in the change in energy use for the LEC design relative to

ASHRAE 90.1-2007, ranging from -12.6 % to -30.0 % depending on the building type with an overall average of -17.3 %. High schools realize the lowest reductions in energy use while restaurants realize the greatest reductions in energy use.

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

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-14.3	-17.7	-18.8	0.4
APART06	-15.5	-19.5	-20.9	0.3
DORMI04	-15.1	-18.1	-19.1	-1.2
DORMI06	-15.5	-19.7	-21.2	-0.1
HOTEL15	-14.5	-18.5	-19.9	0.4
HIGHS02	-12.6	-18.2	-20.3	-1.6
OFFIC03	-21.6	-22.9	-23.3	-1.2
OFFIC08	-19.5	-20.2	-20.4	-1.7
OFFIC16	-16.5	-18.4	-19.1	0.5
RETAIL1	-15.5	-16.5	-16.8	0.5
RSTRNT1	-30.0	-32.7	-33.6	-4.9
Average	**-17.3**	**-20.2**	**-21.2**	**-0.8**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.5 % to -32.7 % depending on the building type with an average of -20.2 % 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 all 11 building types. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 24.8 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 44 % greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 2 and Zone 3, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.8 % to -33.6 % with an average of -21.2 %. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for all 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to greater reductions in carbon emissions than reductions in energy use.

The percentage change in life-cycle costs varies across building types, ranging from -4.9 % 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 -0.8 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

10.1.2 City Comparisons

Simulations are run for six cities located in Georgia: Savannah in Zone 2A and Athens, Atlanta, Augusta, Columbus, and Macon in Zone 3A. The results may vary across cities within Georgia 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 10-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design vary minimally across cities, ranging from -16.6 % to -18.1 % with an overall average of -17.3 %. There is no significant difference between cities located in Zone 2A relative to cities in Zone 3A.

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

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Savannah	2A	-17.2	-20.0	-21.2	-0.8
Athens	3A	-17.5	-20.5	-21.9	-0.7
Atlanta	3A	-16.7	-19.9	-21.4	-0.6
Augusta	3A	-16.6	-19.8	-21.2	-0.8
Columbus	3A	-18.1	-20.6	-21.7	-1.0
Macon	3A	-17.9	-20.5	-21.6	-0.8
Average		**-17.3**	**-20.2**	**-21.5**	**-0.8**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -19.8 % to -20.6 % for 10 years of operation. For all cities, percentage reductions in energy costs are greater than percentage reductions in energy use because electricity consumption decreases while natural gas consumption increases. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -21.2 % to -21.9 %. Reductions in life-cycle costs for all building types vary minimally across cities, ranging from -0.6 % to -1.0 %.

10.2 Total Savings

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

10.2.1 Energy Use

Table 10-4 reports the average per unit change in annual energy use by building type and building design in the state.[23] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 10-5 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[24]

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

Building Type	Standard Edition LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-17.72	-5.62
APART06	-19.28	-6.11
DORMI04	-14.09	-4.47
DORMI06	-20.86	-6.62
HOTEL15	-17.61	-5.59
HIGHS02	-22.04	-6.99
OFFIC03	-18.57	-5.89
OFFIC08	-19.48	-6.18
OFFIC16	-21.55	-6.83
RETAIL1	-16.09	-5.10
RSTRNT1	-44.19	-14.02

[23] A simple average for a state is used because no data for a weighted average is available regarding the amount of new construction on a city-by-city basis.
[24] 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 76.8 GWh (262.4 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 57.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate statewide savings to be 134.8 GWh (460.3 GBtu) per year. These savings imply 1.3 TWh (4.6 TBtu) 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 27.0 % and 28.6 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 9.9 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and high schools -- only rank 7th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 10-2.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	332	3576	-5 887 666	-20 103 022
APART06	55.1 %	407	4380	-7 843 401	-26 780 745
HOTEL15	100.0 %	302	3251	-5 319 574	-18 163 313
HIGHS02	100.0 %	1116	12 012	-20 728 878	-70 777 302
OFFIC03	37.4 %	272	2925	-5 990 308	-20 453 489
OFFIC08	40.4 %	293	3154	-5 709 765	-19 495 594
OFFIC16	22.2 %	161	1736	-3 474 048	-11 861 895
RETAIL1	100.0 %	1179	12 686	-18 957 555	-64 729 243
RSTRNT1	100.0 %	66	713	-2 925 702	-9 989 605
Total		**4128**	**44 433**	**-76 836 897**	**-262 354 207**

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

10.2.2 Energy Costs

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

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

Building Type	Standard Edition LEC $/m^2	$/ft^2
APART04	-$13.43	-$1.25
APART06	-$14.90	-$1.38
DORMI04	-$10.49	-$0.97
DORMI06	-$16.23	-$1.51
HOTEL15	-$13.33	-$1.24
HIGHS02	-$15.87	-$1.47
OFFIC03	-$15.58	-$1.45
OFFIC08	-$13.95	-$1.30
OFFIC16	-$15.77	-$1.46
RETAIL1	-$11.44	-$1.06
RSTRNT1	-$31.48	-$2.92

Table 10-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $58.4 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 57.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide energy cost savings of $102.5 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	332	3576	-$4 462 271
APART06	55.1 %	407	4380	-$6 062 625
HOTEL15	100.0 %	302	3251	-$4 027 231
HIGHS02	100.0 %	1116	12 012	-$17 384 927
OFFIC03	37.4 %	272	2925	-$4 312 175
OFFIC08	40.4 %	293	3154	-$4 088 695
OFFIC16	22.2 %	161	1736	-$2 542 103
RETAIL1	100.0 %	1179	12 686	-$13 480 042
RSTRNT1	100.0 %	66	713	-$2 084 174
Total		**4128**	**44 433**	**-58 444 243**

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

10.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition LEC	
	kg/m^2	lb/ft^2
APART04	-163.6	-33.5
APART06	-182.4	-37.4
DORMI04	-127.1	-26.0
DORMI06	-199.1	-40.8
HOTEL15	-162.4	-33.3
HIGHS02	-194.6	-39.9
OFFIC03	-190.6	-39.0
OFFIC08	-167.3	-34.3
OFFIC16	-190.2	-39.0
RETAIL1	-136.9	-28.0
RSTRNT1	-376.9	-77.2

Table 10-9 applies the Table 10-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs and is highly correlated with the total reduction in energy use. The LEC design decreases carbon emissions for all building types. The adoption of the LEC design results in savings of 712 622 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 1.3 million metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	332	3576	-54 357
APART06	55.1 %	407	4380	-74 236
HOTEL15	100.0 %	302	3251	-49 043
HIGHS02	100.0 %	1116	12 012	-217 226
OFFIC03	37.4 %	272	2925	-51 787
OFFIC08	40.4 %	293	3154	-49 029
OFFIC16	22.2 %	161	1736	-30 671
RETAIL1	100.0 %	1179	12 686	-161 317
RSTRNT1	100.0 %	66	713	-24 955
Total		**4128**	**44 433**	**-712 622**

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

10.2.4 Life-Cycle Costs

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

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

Building Type	Standard Edition LEC $/$m^2$	Standard Edition LEC $/$ft^2$
APART04	$3.82	$0.35
APART06	$2.68	$0.25
DORMI04	-$10.91	-$1.01
DORMI06	-$0.86	-$0.08
HOTEL15	$3.44	$0.32
HIGHS02	-$12.10	-$1.12
OFFIC03	-$8.79	-$0.82
OFFIC08	-$13.43	-$1.25
OFFIC16	$3.47	$0.32
RETAIL1	$3.09	$0.29
RSTRNT1	-$60.97	-$5.66

Table 10-11 applies the Table 10-10 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 $16.3 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools realize the greatest statewide decreases in life-cycle costs ($13.5 million) while the retail stores realize the greatest increases in life-cycle costs ($3.6 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 $28.5 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	332	3576	$1 268 257
APART06	55.1 %	407	4380	$1 090 901
HOTEL15	100.0 %	302	3251	$1 040 169
HIGHS02	100.0 %	1116	12 012	-$13 508 986
OFFIC03	37.4 %	272	2925	-$2 389 100
OFFIC08	40.4 %	293	3154	-$3 936 111
OFFIC16	22.2 %	161	1736	$559 388
RETAIL1	100.0 %	1179	12 686	$3 646 333
RSTRNT1	100.0 %	66	713	-$4 036 321
Total		**4128**	**44 433**	**-$16 265 471**

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

10.3 State Summary

Georgia 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 1.3 TWh (4.6 TBtu), energy cost savings of $102.5 million, and carbon emissions reductions of 1.3 million metric tons while decreasing life-cycle costs by $28.5 million for one year's worth of commercial building construction.

11 Kentucky

Kentucky has adopted *ASHRAE 90.1-2007* as its state energy code, and is located in the East South Central Census Division and Climate Zone 4A. Table 11-1 provides an overview of Kentucky'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 81 kWh/m^2 to 101 kWh/m^2 (26 kBtu/ft^2 to 32 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 192 kWh/m^2 to 209 kWh/m^2 (61 kBtu/ft^2 to 66 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	151	48	134	43
APART06	151	48	131	41
DORMI04	114	36	100	32
DORMI06	165	52	143	45
HOTEL15	153	49	132	42
HIGHS02	209	66	192	61
OFFIC03	109	34	87	28
OFFIC08	101	32	81	26
OFFIC16	151	48	126	40
RETAIL1	115	37	98	31
RSTRNT1	164	52	119	38

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 Kentucky.

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 -8.0 % to -27.9 % depending on the building type with an overall average of -15.5 %. 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, Kentucky

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-11.5	-15.6	-17.9	0.7
APART06	-13.4	-18.6	-21.4	0.5
DORMI04	-12.9	-16.4	-18.3	-1.0
DORMI06	-12.9	-17.9	-20.6	0.2
HOTEL15	-13.7	-17.6	-19.8	0.6
HIGHS02	-8.0	-14.1	-17.8	-0.9
OFFIC03	-19.8	-22.4	-23.5	-2.4
OFFIC08	-19.5	-20.8	-21.4	-2.4
OFFIC16	-16.2	-19.3	-20.7	0.7
RETAIL1	-14.9	-17.2	-18.3	0.5
RSTRNT1	-27.9	-32.3	-34.3	-5.4
Average	**-15.5**	**-19.3**	**-21.3**	**-0.8**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -14.1 % to -32.3 % depending on the building type with an average of -19.3 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 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 35.4 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 76.3 % greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -17.8 % to -34.3 % with an average of -21.3 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 10 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -5.4 % to 0.7 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs, with restaurants realizing the greatest percentage reduction while 16-story office buildings and 4-story apartment buildings realize the largest increases in life-cycle costs (0.7 %). Based on the overall average percentage change of -0.8 % in life-cycle costs, the LEC design may be cost-effective for the state to adopt as its state energy code.

11.1.2 City Comparisons

Simulations are run for three cities located in Kentucky, all of which are located in Zone 4A: Covington, Lexington, and Louisville. While the three 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 11-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design varies minimally across cities, ranging from -14.9 % to -16.3 % with an overall average of -15.5 %.

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

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Covington	4A	-14.9	-18.9	-21.2	-0.8
Lexington	4A	-15.3	-19.2	-21.5	-0.8
Louisville	4A	-16.3	-19.8	-21.8	-0.9
Average		**-15.5**	**-19.3**	**-21.5**	**-0.8**

The average percentage change in energy costs for all building types varies minimally across cities, ranging from -18.9 % to -19.8 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -21.2 % to -21.8 %. Changes in life-cycle costs for all building types vary minimally across cities, with the percentage change in life-cycle costs ranging from -0.8 % to -0.9 %.

11.2 Total Savings

How much can Kentucky 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.[25] 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.[26]

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

Building Type	Standard Edition	
	LEC	
	kWh/m²	kBtu/ft²
APART04	-17.4	-5.5
APART06	-20.1	-6.4
DORMI04	-14.7	-4.7
DORMI06	-21.2	-6.7
HOTEL15	-20.9	-6.6
HIGHS02	-21.5	-6.8
OFFIC03	-16.6	-5.3
OFFIC08	-19.6	-6.2
OFFIC16	-24.4	-7.7
RETAIL1	-17.2	-5.5
RSTRNT1	-45.9	-14.5

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

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 19.9 GWh (68.0 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 52.7 % 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 37.8 GWh (129.1 GBtu) per year. These savings imply 378.0 GWh (1290.8 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 32.3 % and 24.6 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 12.5 % 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 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, Kentucky

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	24	260	-419 589	-1 432 658
APART06	55.1 %	30	318	-594 651	-2 030 394
HOTEL15	100.0 %	129	1384	-2 693 623	-9 197 188
HIGHS02	100.0 %	254	2734	-4 214 129	-14 388 848
OFFIC03	37.4 %	87	940	-1 878 787	-6 414 985
OFFIC08	40.4 %	94	1014	-1 844 372	-6 297 480
OFFIC16	22.2 %	52	558	-1 262 947	-4 312 245
RETAIL1	100.0 %	333	3588	-5 745 573	-19 617 856
RSTRNT1	100.0 %	28	298	-1 268 604	-4 331 561
Total		**1031**	**11094**	**-19 922 276**	**-68 023 215**

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, Kentucky

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$11.10	-$1.03
APART06	-$13.23	-$1.23
DORMI04	-$8.95	-$0.83
DORMI06	-$13.94	-$1.29
HOTEL15	-$12.77	-$1.19
HIGHS02	-$13.46	-$1.25
OFFIC03	-$12.87	-$1.20
OFFIC08	-$12.10	-$1.12
OFFIC16	-$15.48	-$1.44
RETAIL1	-$10.48	-$0.97
RSTRNT1	-$27.57	-$2.56

Table 11-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with statewide reductions in energy costs of $12.9 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 52.7 % 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 $24.6 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	24	260	-$267 838
APART06	55.1 %	30	318	-$390 794
HOTEL15	100.0 %	129	1384	-$1 642 428
HIGHS02	100.0 %	254	2734	-$3 270 162
OFFIC03	37.4 %	87	940	-$1 175 470
OFFIC08	40.4 %	94	1014	-$1 139 281
OFFIC16	22.2 %	52	558	-$802 153
RETAIL1	100.0 %	333	3588	-$3 494 781
RSTRNT1	100.0 %	28	298	-$762 826
Total		**1031**	**11094**	**-$12 945 734**

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, Kentucky

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-153.3	-31.4
APART06	-184.4	-37.8
DORMI04	-121.4	-24.9
DORMI06	-194.2	-39.8
HOTEL15	-173.4	-35.5
HIGHS02	-188.6	-38.6
OFFIC03	-184.5	-37.8
OFFIC08	-165.0	-33.8
OFFIC16	-213.3	-43.7
RETAIL1	-142.2	-29.1
RSTRNT1	-372.5	-76.3

Table 11-9 applies the Table 11-8 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of the LEC design. The total 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 179 794 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 341 165 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	24	260	-3 697
APART06	55.1 %	30	318	-5 448
HOTEL15	100.0 %	129	1384	-22 303
HIGHS02	100.0 %	254	2734	-47 919
OFFIC03	37.4 %	87	940	-16 112
OFFIC08	40.4 %	94	1014	-15 544
OFFIC16	22.2 %	52	558	-11 053
RETAIL1	100.0 %	333	3588	-47 413
RSTRNT1	100.0 %	28	298	-10 305
Total		**1031**	**11094**	**-179 794**

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 costs 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, Kentucky

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$6.57	$0.61
APART06	$4.85	$0.45
DORMI04	-$9.27	-$0.86
DORMI06	$1.97	$0.18
HOTEL15	$5.27	$0.49
HIGHS02	-$6.94	-$0.64
OFFIC03	-$19.99	-$1.86
OFFIC08	-$19.91	-$1.85
OFFIC16	$5.23	$0.49
RETAIL1	$3.07	$0.29
RSTRNT1	-$74.26	-$6.90

Table 11-11 applies the Table 11-10 results to one year's worth of new building construction in the state to estimate changes in statewide life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $5.2 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Restaurants, 8-story office buildings, high schools, and 3-story office buildings realize the greatest statewide decreases in life-cycle costs ($2.1 million, $1.9 million, $1.8 million, and $1.7 million, respectively) while retail stores realize the largest increase in life-cycle costs of $1.0 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 LEC design can be extrapolated to estimate a statewide decrease in life-cycle costs of $9.8 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	24	260	$158 367
APART06	55.1 %	30	318	$143 268
HOTEL15	100.0 %	129	1384	$677 778
HIGHS02	100.0 %	254	2734	-$1 762 636
OFFIC03	37.4 %	87	940	-$1 745 687
OFFIC08	40.4 %	94	1014	-$1 874 970
OFFIC16	22.2 %	52	558	$270 809
RETAIL1	100.0 %	333	3588	$1 024 294
RSTRNT1	100.0 %	28	298	-$2 054 629
Total		**1031**	**11094**	**-$5 163 407**

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

11.3 State Summary

Kentucky 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 378.0 GWh (1290.8 GBtu), energy cost savings of $24.6 million, and carbon emissions reductions of 341 165 metric tons while decreasing life-cycle costs by $9.8 million for one year’s worth of commercial building construction.

12 Louisiana

Louisiana has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the West South Central Census Division, and spans two climate zones (Zone 2A and Zone 3A). Table 12-1 provides an overview of Louisiana'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 78 kWh/m^2 to 92 kWh/m^2 (25 kBtu/ft^2 to 29 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy for the *ASHRAE 90.1-2007* design at 148 kWh/m^2 (47 kBtu/ft^2) annually. The high school uses the greatest amount of energy for the LEC design at 114 kWh/m^2 (36 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	125	40	106	34
APART06	127	40	106	34
DORMI04	92	29	78	25
DORMI06	135	43	113	36
HOTEL15	115	37	98	31
HIGHS02	135	43	114	36
OFFIC03	104	33	81	26
OFFIC08	103	33	83	26
OFFIC16	128	41	107	34
RETAIL1	105	33	89	28
RSTRNT1	148	47	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.

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 Louisiana.

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 -14.5 % to -29.3 % depending on the building type with an overall average of -17.9 %. Hotels realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

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

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-15.4	-17.6	-18.3	0.5
APART06	-16.5	-19.1	-20.0	0.4
DORMI04	-15.5	-17.8	-18.5	-0.8
DORMI06	-16.7	-19.6	-20.6	0.0
HOTEL15	-14.5	-18.1	-19.3	0.6
HIGHS02	-15.4	-19.5	-21.0	-0.8
OFFIC03	-21.9	-22.7	-23.0	-0.3
OFFIC08	-19.9	-20.2	-20.3	-1.8
OFFIC16	-16.6	-18.3	-18.8	0.7
RETAIL1	-15.0	-15.5	-15.7	0.7
RSTRNT1	-29.3	-31.3	-31.9	-6.0
Average	**-17.9**	**-20.0**	**-20.7**	**-0.6**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.5 % to -31.3% depending on the building type with an average of -20.0 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. In fact, 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 19.4 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 27 % greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 2 and Zone 3, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -15.7 % to -31.9 % with an average of -20.7 %. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for all 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to greater reductions in carbon emissions than reductions in energy use.

The percentage change in life-cycle costs varies across building types, ranging from -6.0 % to 0.7 % for a 10-year study period. Five of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -0.6 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

12.1.2 City Comparisons

Simulations are run for four cities located in Louisiana: Baton Rouge, Lake Charles, and New Orleans in Zone 2A and Shreveport in Zone 3A. The results vary across cities within Louisiana 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 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 vary minimally across cities, ranging from -17.1 % to -18.0 %. Any variation across and within climate zones appears to have minimal effects on energy consumption.

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

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Baton Rouge	2A	-18.0	-20.2	-21.1	-0.7
Lake Charles	2A	-17.1	-19.3	-20.4	-0.8
New Orleans	2A	-18.4	-20.2	-21.2	-0.3
Shreveport	3A	-18.0	-20.2	-21.3	-0.6
Average		**-17.9**	**-20.0**	**-21.0**	**-0.6**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -19.3 % to -20.2 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -20.4 % to -21.3 %. Percentage changes in life-cycle costs for all building types vary across cities, ranging from -0.3 % to -0.8 %, with New Orleans realizing the smallest reduction in life-cycle costs.

12.2 Total Savings

How much can Louisiana 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.[27] 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.[28]

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

Building Type	Standard Edition	
	LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-19.3	-6.1
APART06	-20.8	-6.6
DORMI04	-14.3	-4.5
DORMI06	-22.6	-7.2
HOTEL15	-16.7	-5.3
HIGHS02	-22.8	-7.2
OFFIC03	-20.6	-6.5
OFFIC08	-20.5	-6.5
OFFIC16	-21.3	-6.8
RETAIL1	-15.8	-5.0
RSTRNT1	-43.3	-13.7

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

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 18.6 GWh (63.4 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 57.2 % 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 32.5 GWh (110.8 GBtu) per year. These savings imply 324.6 GWh (1108.3 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 35.7 % and 17.3 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 16.5 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 10th and 9th 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, Louisiana

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	15	164	-293 762	-1 003 028
APART06	55.1 %	19	201	-388 654	-1 327 031
HOTEL15	100.0 %	161	1738	-2 702 869	-9 228 758
HIGHS02	100.0 %	168	1812	-3 470 485	-11 849 727
OFFIC03	37.4 %	88	947	-2 005 327	-6 847 047
OFFIC08	40.4 %	95	1021	-1 947 962	-6 651 179
OFFIC16	22.2 %	52	562	-1 113 583	-3 802 250
RETAIL1	100.0 %	347	3736	-5 474 143	-18 691 077
RSTRNT1	100.0 %	27	291	-1 170 372	-3 996 152
Total		**973**	**10 471**	**-18 567 155**	**-63 396 250**

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, Louisiana

Building Type	Standard Edition LEC	
	$/m²	$/ft²
APART04	-$12.43	-$1.15
APART06	-$13.62	-$1.27
DORMI04	-$9.29	-$0.86
DORMI06	-$14.89	-$1.38
HOTEL15	-$11.37	-$1.06
HIGHS02	-$14.14	-$1.31
OFFIC03	-$14.20	-$1.32
OFFIC08	-$12.54	-$1.16
OFFIC16	-$13.73	-$1.28
RETAIL1	-$9.64	-$0.90
RSTRNT1	-$26.96	-$2.51

Table 12-7 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years. All building types realize energy cost savings for the LEC design, with a statewide reduction in energy costs of $11.9 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 57.2 % 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 $20.8 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	15	164	-$189 248
APART06	55.1 %	19	201	-$253 961
HOTEL15	100.0 %	161	1738	-$1 835 737
HIGHS02	100.0 %	168	1812	-$2 390 533
OFFIC03	37.4 %	88	947	-$1 243 545
OFFIC08	40.4 %	95	1021	-$1 189 203
OFFIC16	22.2 %	52	562	-$716 778
RETAIL1	100.0 %	347	3736	-$3 346 337
RSTRNT1	100.0 %	27	291	-$728 466
Total		**973**	**10 471**	**-$11 893 808**

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, Louisiana

Building Type	Standard Edition LEC	
	kg/m^2	lb/ft^2
APART04	-161.5	-33.1
APART06	-177.6	-36.4
DORMI04	-120.9	-24.8
DORMI06	-194.6	-39.9
HOTEL15	-149.7	-30.7
HIGHS02	-187.7	-38.4
OFFIC03	-181.8	-37.2
OFFIC08	-160.5	-32.9
OFFIC16	-178.4	-36.5
RETAIL1	-123.4	-25.3
RSTRNT1	-347.0	-71.1

Table 12-9 applies the Table 12-8 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building designs, and is highly correlated with 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 154 275 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 269 711 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	15	164	-2 458
APART06	55.1 %	19	201	-3 312
HOTEL15	100.0 %	161	1738	-24 177
HIGHS02	100.0 %	168	1812	-31 594
OFFIC03	37.4 %	88	947	-15 986
OFFIC08	40.4 %	95	1021	-15 220
OFFIC16	22.2 %	52	562	-9 309
RETAIL1	100.0 %	347	3736	-42 844
RSTRNT1	100.0 %	27	291	-9 375
Total		**973**	**10 471**	**-154 275**

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, Louisiana

Building Type	Standard Edition	
	LEC	
	$/m^2	$/ft^2
APART04	$4.56	$0.42
APART06	$3.45	$0.32
DORMI04	-$7.36	-$0.68
DORMI06	-$0.07	-$0.01
HOTEL15	$5.43	$0.50
HIGHS02	-$5.65	-$0.52
OFFIC03	-$1.95	-$0.18
OFFIC08	-$14.45	-$1.34
OFFIC16	$5.08	$0.47
RETAIL1	$4.20	$0.39
RSTRNT1	-$77.04	-$7.16

Table 12-11 applies the Table 12-10 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of the LEC design. Total changes in life-cycle costs over the 10-year study period vary across building type, with 4 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $1.8 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Restaurants and 8-story office buildings realize the greatest reductions in life-cycle costs ($2.1 million and $1.4 million, respectively). Retail stores realize the greatest increase in life-cycle costs ($1.5 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 $3.2 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	15	164	$69 450
APART06	55.1 %	19	201	$64 410
HOTEL15	100.0 %	161	1738	$876 528
HIGHS02	100.0 %	168	1812	-$950 911
OFFIC03	37.4 %	88	947	-$171 540
OFFIC08	40.4 %	95	1021	-$1 370 216
OFFIC16	22.2 %	52	562	$264 871
RETAIL1	100.0 %	347	3736	$1 457 483
RSTRNT1	100.0 %	27	291	-$2 081 379
Total		**973**	**10 471**	**-$1 841 303**

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

12.3 State Summary

Louisiana 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 324.6 GWh (1108.3 GBtu), energy cost savings of $20.8 million, and carbon emissions reductions of 269 711 metric tons while decreasing life-cycle costs by $3.2 million for one year's worth of commercial building construction.

13 Maryland

Maryland is located in the South Atlantic Census Division and primarily in Climate Zone 4A, with the northwestern portion of the state located in Zone 5A. Only one city, Baltimore, is simulated for this study and is located in Zone 4A. While Maryland is now the first state to adopt *ASHRAE 90.1-2010*, at the time of this study the state had adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. Table 13-1 provides an overview of Maryland's simulated energy use keyed to building types and energy codes. Average energy use varies across building types. The 8-story office building uses the least amount of energy at 80 kWh/m^2 to 100 kWh/m^2 (25 kBtu/ft^2 to 32 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 192 kWh/m^2 to 207 kWh/m^2 (61 kBtu/ft^2 to 66 kBtu/ ft^2) annually.

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

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

The detailed analysis for this state reports the changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs from adoption of the LEC design. The results are reported in terms of average percentage savings and total savings on a statewide basis. There is no within-state variation to consider for this state since only one city is simulated for the state (Baltimore).

13.1 Percentage Savings

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

Table 13-2 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007*. The LEC design realizes changes in energy use ranging from -7.2 % to -27.7 % with an average of -15.1 % relative to the *ASHRAE 90.1-2007* design. The greatest reduction in energy use for the LEC design occurs in restaurants followed by the small and mid-sized office buildings. The smallest reductions occur in the high school followed by the apartments and dormitories.

Table 13-2 Average Percentage Change from Adoption of a Newer Code, 10-Year, Maryland

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

The LEC design realizes average changes in energy costs from -16.9 % to -33.5 % depending on the building type, with an average of -20.6 % overall over 10 years of operation. The high school and 4-story apartment building realize the smallest average reductions in energy costs while the restaurant realizes the greatest average reductions in energy use. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 10 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 40.6 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is over twice the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

The LEC design leads to average changes in carbon emissions ranging from -15.6 % to -32.9 % depending on the building type, with an average of -20.0 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. 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 average change in life-cycle costs for the LEC design over a 10-year study period ranges from -9.0 % to 0.2 %. The 4-story apartment building is the only building type that realizes a percentage increase in life-cycle costs. The restaurant, 3-story office building, and 8-story office building are the building types that realize the greatest reductions in average life-cycle costs. Given that 10 of 11 buildings types realize an average percentage decrease in life-cycle costs, the LEC design is likely to be cost-effective if the state adopted it as its state energy code for commercial buildings.

13.2 Total Savings

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

13.2.1 Energy Use

Table 13-3 reports the average per unit change in annual energy use by building type for the LEC design in the state.[29] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 13-4 reports the estimated average annual floor area of new construction and the total annual reduction in energy use for each building type. The weightings within a category (e.g., small, medium, and

[29] 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.

large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[30]

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

Building Type	Standard Edition LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-16.4	-5.2
APART06	-18.0	-5.7
DORMI04	-14.0	-4.4
DORMI06	-19.7	-6.3
HOTEL15	-20.5	-6.5
HIGHS02	-21.3	-6.8
OFFIC03	-14.9	-4.7
OFFIC08	-19.6	-6.2
OFFIC16	-23.6	-7.5
RETAIL1	-16.2	-5.2
RSTRNT1	-44.6	-14.2

The annual reduction in energy use shown in Table 13-4 ranges widely across building types with reported floor area data, but the LEC design decreases overall energy use across the state. The adoption of the LEC design as the state's energy code would save energy for all building types and 37.3 GWh (127.5 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 60.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings to be 62.2 GWh (212.4 GBtu) per year. These savings imply 622 GWh (2124.5 GBtu) in energy savings over the 10-year study period.

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

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

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

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

The relative reduction in energy use varies across the 9 building types with reported floor area data for the LEC design relative to *ASHRAE 90.1-2007*. The greatest reductions are for 6-story apartment buildings followed by retail stores, 4-story apartment buildings, high schools, and 3- and 8-story office buildings. The smallest reductions are for restaurants followed by the high-rise buildings. Building types that represent a greater amount of new floor area realize the largest changes in energy use. The building types that have the greatest percentage reductions in energy use are not always the same buildings that lead to the greatest total reductions for the state. The building types that lead to the greatest estimated reductions in energy use -- retail stores and 6- and 4-story apartment buildings-- only rank 5th, 8th, and 10th in percentage reduction, respectively, among the 11 building types, as reported in Table 13-2.

13.2.2 Energy Costs

Table 13-5 reports the average per unit change in energy costs by building type. Energy costs are calculated using the annual energy use, state average energy cost rates, and regional energy price escalation rates as defined in Section 3.2.

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

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$17.00	-$1.58
APART06	-$19.83	-$1.84
DORMI04	-$13.62	-$1.27
DORMI06	-$21.45	-$1.99
HOTEL15	-$19.85	-$1.84
HIGHS02	-$20.88	-$1.94
OFFIC03	-$21.12	-$1.96
OFFIC08	-$19.05	-$1.77
OFFIC16	-$23.97	-$2.23
RETAIL1	-$15.57	-$1.45
RSTRNT1	-$41.93	-$3.90

Table 13-6 reports the statewide changes in total energy costs by building type, which account for one year's worth of new construction evaluated over 10 years of building operation. All building types realize energy cost savings for the LEC design, with the energy cost savings being highly correlated with energy use savings. Any variation is a result of the greater percentage reduction in electricity consumption relative to the reduction in natural gas consumption. Overall, reductions in energy costs total $37.4 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study, which represent 60.0 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total energy cost savings of $62.4 million over the 10-year study period.

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

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

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

13.2.3 Energy-related Carbon Emissions

Table 13-7 reports the average reduction in energy-related carbon emissions over 10 years, per m^2 (ft^2), by building type. The carbon emissions estimation approach is defined in Section 5.3.

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

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

Table 13-8 applies the Table 13-7 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of a more energy efficient code. The total reduction in carbon emissions ranges widely across building types, and is correlated with each building's total reductions in energy use. However, there is not a perfect correlation because the magnitude of the offsetting natural gas increase for 10 of 11 building types varies. The adoption of the LEC design as the state's energy code decreases carbon emissions by 269 357 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 448 928 metric tons over the 10-year study period.

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

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

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

13.2.4 Life-Cycle Costs

Table 13-9 reports the average change in life-cycle cost over 10 years, per m^2 (ft^2), by building type. As discussed in Section 5.2, life-cycle costs include construction costs, maintenance, repair, and replacement costs, energy costs, and residual values.

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

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

Table 13-10 applies the Table 13-9 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of more energy-efficient codes. The change in life-cycle costs varies widely across building types, with 8 of 9 building types realizing reductions in life-cycle costs. Three-story and 8-story office buildings realize total reductions in life-cycle costs of greater than \$5.5 million. The LEC design leads to statewide reductions in life-cycle costs of \$17.3 million relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total statewide life-cycle cost increases of \$28.8 million over the 10-year study period.

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

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

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

13.3 State Summary

As of December 2011, Maryland had adopted *ASHRAE 90.1-2007* as its energy code for commercial buildings. The adoption of the LEC design, which goes beyond *ASHRAE 90.1-2007*, leads to impressive energy use, energy cost, and energy-related carbon emissions reductions in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code would lead to energy savings of 622 GWh (2124.5 GBtu), energy cost savings of \$62.4 million, and carbon emissions reductions of 448 928 metric tons while decreasing life-cycle costs by \$28.8 million for one year's worth of commercial building construction.

14 Mississippi

Mississippi is located in the East South Central Census Division and primarily in Climate Zone 3A with the southern (Gulf Coast) counties of the state located in Zone 2A. All cities simulated for this study are located in Zone 3A. The state does not have a commercial building energy code, and is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements. Table 14-1 provides an overview of Mississippi's simulated energy use keyed to building type 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 81 kWh/m^2 to 120 kWh/m^2 (26 kBtu/ft^2 to 38 kBtu/ft^2) annually. The restaurant uses the greatest amount of energy for the *ASHRAE 90.1-1999* design at 197 kWh/m^2 (62 kBtu/ft^2) annually. The high school uses the greatest amount of energy for the LEC design at 132 kWh/m^2 (42 kBtu/ft^2) annually.

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

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	171	54	169	54	135	43	127	40	110	35
APART06	170	54	168	53	134	43	127	40	109	34
DORMI04	133	42	129	41	102	32	94	30	81	26
DORMI06	190	60	183	58	150	47	137	43	117	37
HOTEL15	163	52	162	51	126	40	122	39	107	34
HIGHS02	180	57	179	57	160	51	150	47	132	42
OFFIC03	139	44	135	43	115	37	102	32	81	26
OFFIC08	120	38	116	37	104	33	101	32	81	26
OFFIC16	151	48	149	47	131	42	130	41	110	35
RETAIL1	151	48	147	47	121	38	105	33	90	28
RSTRNT1	197	62	190	60	160	51	148	47	106	34

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

14.1 Percentage Savings

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

14.1.1 Energy Use

Table 14-2 shows a small change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999*, with all 11 building types having a reduction in energy use of 3.7 % or less. There is a significant decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change ranging from -10.9 % to -23.8 % with an average of -18.4 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -14.1 % to -30.5 %, with an overall average of -23.7 %. The smallest reductions in energy use are realized by high schools and 8- and 16-story office buildings for the *ASHRAE 90.1-2004* and *-2007* designs. Unlike most states that have not yet adopted *ASHRAE 90.1-2007*, the percentage decrease in energy use for cities in Mississippi is greater for adopting *ASHRAE 90.1-2007* than *ASHRAE 90.1-2004* for the high-rise buildings.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-1.1	-20.9	-25.5	-35.7
APART06	-1.2	-21.0	-25.3	-36.2
DORMI04	-3.3	-23.8	-29.2	-39.0
DORMI06	-3.7	-21.2	-27.7	-38.2
HOTEL15	-1.0	-22.9	-25.0	-34.4
HIGHS02	-0.7	-10.9	-16.8	-26.7
OFFIC03	-2.8	-17.1	-26.4	-41.9
OFFIC08	-3.0	-13.2	-15.8	-32.4
OFFIC16	-1.0	-13.1	-14.1	-27.3
RETAIL1	-2.5	-19.8	-30.5	-40.6
RSTRNT1	-3.4	-18.8	-24.8	-46.0
Average	**-2.2**	**-18.4**	**-23.7**	**-36.2**

The LEC design realizes the greatest reductions in energy use, with the change in energy use relative to *ASHRAE 90.1-1999* ranging from -26.7 % to -46.0 % with an average of -36.2 %. The smallest reduction in energy use for the LEC design occurs in the high school and 16-story office building.

14.1.2 Energy Costs

Table 14-3 shows a small percentage change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.9 % to -4.1 %), 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 -9.8 % to -28.1 % depending on the building type with an average of -20.0 %. The average chagne in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -7.9 % to -32.2 %, with an overall average of -23.4 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -24.8 % to -47.7 % with an average of -38.9 % overall.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-1.3	-25.7	-29.7	-42.4
APART06	-1.3	-25.7	-29.5	-43.3
DORMI04	-3.7	-28.1	-32.0	-44.2
DORMI06	-4.1	-26.5	-32.2	-45.6
HOTEL15	-1.3	-23.8	-22.9	-37.0
HIGHS02	-0.9	-12.7	-17.4	-33.1
OFFIC03	-3.1	-15.4	-21.1	-39.1
OFFIC08	-3.1	-13.1	-14.5	-32.0
OFFIC16	-1.2	-9.8	-7.9	-24.8
RETAIL1	-2.8	-20.1	-27.3	-38.8
RSTRNT1	-3.8	-19.5	-23.1	-47.7
Average	**-2.4**	**-20.0**	**-23.4**	**-38.9**

Adoption of the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs leads to average reductions in energy costs that are lower than the reductions in energy use for four, six, and four building types, respectively. Each of these building types realizes a greater percentage reduction in natural gas consumption than electricity consumption. Since electricity is more expensive than natural gas on a per unit of energy basis, the overall reduction in energy costs is decreased for the building. The remaining building types realize a greater percentage reduction in electricity consumption than natural gas consumption.

14.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small percentage reductions (4.1 % or less) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 14-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -9.7 % to -28.2 % with an average of -20.1 %. 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 -7.6 % to -32.4 % with an overall average of -23.4 %. The LEC design leads to the greatest average changes in carbon emissions, ranging from -24.7 % to -47.7 % depending on the building type with an average of -39.0 % across all building types.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-1.3	-25.9	-29.9	-42.6
APART06	-1.3	-25.8	-29.7	-43.5
DORMI04	-3.7	-28.2	-32.1	-44.4
DORMI06	-4.1	-26.7	-32.4	-45.9
HOTEL15	-1.3	-23.8	-22.8	-37.1
HIGHS02	-0.9	-12.7	-17.4	-33.4
OFFIC03	-3.1	-15.3	-20.9	-39.0
OFFIC08	-3.2	-13.1	-14.5	-31.9
OFFIC16	-1.2	-9.7	-7.6	-24.7
RETAIL1	-2.8	-20.1	-27.2	-38.8
RSTRNT1	-3.8	-19.5	-23.0	-47.7
Average	**-2.4**	**-20.1**	**-23.4**	**-39.0**

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

14.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 14-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for 7 of 11 building types over a 10-year study period. The current state energy code is the lowest cost option for two building types. *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building design for two and three building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -4.5 % to 4.9 % depending on building type. The LEC design is the lowest cost building design for four building types and realizes a reduction in life-cycle costs for 9 of 11 building types, with the percentage change in life-cycle costs ranging from -4.7 % to 1.1 %. Based on the overall average percentage reduction in life-cycle costs of 1.9 %, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-0.0	-3.0	**-3.6**	-3.3
APART06	-0.1	-3.1	**-3.6**	-3.4
DORMI04	4.5	-0.5	-1.0	**-1.8**
DORMI06	-0.5	-3.8	-4.5	**-4.7**
HOTEL15	-0.1	**-3.3**	-3.1	-2.8
HIGHS02	0.2	-1.7	-2.3	**-3.4**
OFFIC03	6.0	3.5	1.7	0.4
OFFIC08	6.0	3.5	3.1	1.1
OFFIC16	0.0	**-1.2**	-0.9	-0.5
RETAIL1	3.6	-0.0	**-1.3**	-0.3
RSTRNT1	8.4	4.9	3.6	**-1.9**
Average	**2.6**	**-0.4**	**-1.1**	**-1.9**

14.1.5 City Comparisons

Simulations are run for two cities located in Mississippi, both of which are located in Zone 3A: Jackson and Meridian. There are no significant population centers in the area of Mississippi located in Zone 2A. While the 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 14-6, average reductions in energy use for all building types from adopting newer energy standard editions varies within the climate zone. Jackson realizes slightly greater reductions in energy use than Meridian from adoption of the *ASHRAE 90.1-2001* design. Meridian realizes slightly greater reductions in energy use than Jackson for the *ASHRAE 90.1-2007* and LEC designs, and significantly greater reductions for the *ASHRAE 90.1-2004* design (22.8 % versus 14.0 %).

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Jackson	3A	-2.2	-14.0	-23.1	-35.0
Meridian	3A	-2.1	-22.8	-24.3	-37.5
Average		**-2.2**	**-18.4**	**-23.7**	**-36.2**

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 14-7 shows that Jackson realizes larger percentage reductions in energy costs than percentage reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Since electricity is more expensive than natural gas on a per unit basis, the shift in energy use leads to additional reductions in energy costs. Meanwhile, Meridian realizes smaller percentage reductions in energy costs than percentage reductions in energy use because the percentage reduction in electricity consumption is less than the reduction in natural gas consumption from adoption of the ASHRAE *90.1-2004*, and *-2007* designs.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Jackson	3A	-2.5	-18.7	-23.2	-38.3
Meridian	3A	-2.4	-21.4	-23.6	-39.5
Average		**-2.4**	**-20.0**	**-23.4**	**-38.9**

Table 14-8 reports changes in energy-related carbon emissions by city for Mississippi. For both cities, the more stringent standard editions result in greater reductions in carbon emissions. Jackson realizes greater reductions in carbon emissions than reductions in energy use for the ASHRAE *90.1-2001*, *-2004*, and LEC designs. Meridian realizes greater reductions in carbon emissions than reductions in energy use for the *ASHRAE 90.1-2001* and LEC designs.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Jackson	3A	-2.3	-18.0	-23.0	-38.5
Meridian	3A	-2.2	-21.0	-23.4	-39.6
Average		**-2.2**	**-19.5**	**-23.2**	**-39.1**

The data reported in Table 14-9 show that, over a 10-year period, average life-cycle costs increase for both cities for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999*. Adoption of the *ASHRAE 90.1-2004*, *-2007*, and LEC designs results in average reductions in life-cycle costs for both cities relative to *ASHRAE 90.1-1999*. Adoption of the LEC design realizes the greatest average percentage reductions in life-cycle costs for both cities. There is minimal variation across cities in the percentage reduction in life-cycle costs.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Jackson	3A	2.5	-0.1	-1.2	**-1.8**
Meridian	3A	2.6	-0.7	-1.0	**-1.9**
Average		**2.6**	**-0.4**	**-1.1**	**-1.9**

14.2 Total Savings

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

14.2.1 Energy Use

Table 14-10 reports the average per unit change in annual energy use by building type and building design in the state.[31] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 14-11 reports the 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.[32]

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

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

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	-2.0	-0.6	-35.6	-11.3	-43.5	-13.8	-60.9	-19.3
APART06	-2.0	-0.6	-35.8	-11.3	-43.1	-13.7	-61.6	-19.5
DORMI04	-4.4	-1.4	-31.7	-10.0	-38.9	-12.3	-51.9	-16.5
DORMI06	-7.0	-2.2	-40.1	-12.7	-52.5	-16.7	-72.3	-22.9
HOTEL15	-1.6	-0.5	-37.4	-11.9	-40.8	-12.9	-56.2	-17.8
HIGHS02	-1.2	-0.4	-23.6	-7.5	-36.7	-11.6	-58.2	-18.5
OFFIC03	-3.8	-1.2	-19.5	-6.2	-30.3	-9.6	-48.1	-15.2
OFFIC08	-3.6	-1.1	-15.8	-5.0	-18.9	-6.0	-38.8	-12.3
OFFIC16	-1.5	-0.5	-19.7	-6.3	-21.3	-6.7	-41.1	-13.0
RETAIL1	-3.8	-1.2	-29.7	-9.4	-46.0	-14.6	-61.3	-19.4
RSTRNT1	-6.7	-2.1	-36.9	-11.7	-48.7	-15.5	-90.6	-28.7

The annual reduction in energy use shown in Table 14-11 ranges widely across building designs, but all building designs decrease overall energy use across the state relative to *ASHRAE 90.1-1999*. Adopting the *ASHRAE 90.1-2001, ASHRAE 90.1-2004*, and *ASHRAE 90.1-2007* designs result in annual decreases of 1.8 GWh (6.0 GBtu), 17.3 GWh (59.2 GBtu), and 24.2 GWh (82.7 GBtu), respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and 35.5 GWh (121.3 GBtu) of total energy use annually for one year's worth of new construction for these building types.

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

Building Type	Subcat. Weight.	m² (1000s)	ft² (1000s)	Standard Edition							
				2001		2004		2007		LEC	
				MWh	MBtu	MWh	MBtu	MWh	MBtu	MWh	MBtu
APART04	44.9 %	13	145	-26	-90	-480	-1638	-586	-2000	-820	-2799
APART06	55.1 %	17	178	-33	-111	-590	-2014	-711	-2428	-1016	-3470
HOTEL15	100.0 %	96	1031	-158	-538	-3577	-12 214	-3902	-13 323	-5381	-18 374
HIGHS02	100.0 %	149	1600	-183	-626	-2901	-9906	-4499	-15 362	-7142	-24 387
OFFIC03	37.4 %	47	508	-181	-617	-1113	-3801	-1733	-5918	-2749	-9385
OFFIC08	40.4 %	51	548	-183	-626	-805	-2748	-960	-3279	-1974	-6739
OFFIC16	22.2 %	28	302	-42	-142	-552	-1886	-596	-2034	-1152	-3934
RETAIL1	100.0 %	233	2510	-889	-3036	-6924	-23 642	-10 717	-36 591	-14 290	-48 793
RSTRNT1	100.0 %	11	117	-73	-250	-403	-1374	-531	-1814	-988	-3374
Total		**645**	**6938**	**-1768**	**-6036**	**-17 345**	**-59 224**	**-24 235**	**-82 749**	**-35 513**	**-121 256**

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 51.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the total statewide savings from adopting the LEC design in new commercial buildings to be 69.0 GWh (235.4 GBtu) per year. These savings imply 689.6 GWh (2354.5 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 47.1 GWh (160.7 GBtu) annually or 470.6 GWh (1606.8 GBtu) over the 10-year study period.

The statewide change in energy use across the 9 building types with reported floor area data vary across and within building designs. As the building design becomes more energy efficient, 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 reduction. For the *ASHRAE 90.1-2007* and LEC designs, the greatest total reductions are realized by retail stores and high schools because they represent 36.1 % and 23.1 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 14.9 % 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. The building types that lead to the greatest estimated reduction in energy use for the LEC design -- retail stores and high schools -- rank 3rd and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 14-2.

14.2.2 Energy Costs

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

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

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	-$1.48	-$0.14	-$29.43	-$2.73	-$34.05	-$3.16	-$48.54	-$4.51
APART06	-$1.49	-$0.14	-$29.43	-$2.73	-$33.85	-$3.14	-$49.63	-$4.61
DORMI04	-$3.35	-$0.31	-$25.29	-$2.35	-$28.83	-$2.68	-$39.82	-$3.70
DORMI06	-$5.26	-$0.49	-$33.92	-$3.15	-$41.16	-$3.82	-$58.29	-$5.42
HOTEL15	-$1.24	-$0.12	-$22.99	-$2.14	-$22.13	-$2.06	-$35.83	-$3.33
HIGHS02	-$2.88	-$0.27	-$14.34	-$1.33	-$19.74	-$1.83	-$36.54	-$3.39
OFFIC03	-$0.93	-$0.09	-$13.56	-$1.26	-$18.65	-$1.73	-$35.50	-$3.30
OFFIC08	-$2.71	-$0.25	-$11.33	-$1.05	-$12.50	-$1.16	-$27.56	-$2.56
OFFIC16	-$1.12	-$0.10	-$9.51	-$0.88	-$7.65	-$0.71	-$24.05	-$2.23
RETAIL1	-$2.87	-$0.27	-$20.40	-$1.89	-$27.76	-$2.58	-$39.43	-$3.66
RSTRNT1	-$5.06	-$0.47	-$25.75	-$2.39	-$30.45	-$2.83	-$62.96	-$5.85

Table 14-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. 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 ($1.3 million). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $11.7 million, $14.5 million, and $23.9 million, respectively. Assuming that the buildings considered in this study, which represent 51.5 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of $2.6 million, $22.6 million, $28.1 million, and $46.3 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	13	145	-$19 902	-$396 430	-$458 723	-$653 813
APART06	55.1 %	17	178	-$24 547	-$485 560	-$558 513	-$818 906
HOTEL15	100.0 %	96	1031	-$118 715	-$2 201 477	-$2 119 091	-$3 430 744
HIGHS02	100.0 %	149	1600	-$138 131	-$2 016 077	-$2 771 504	-$5 276 822
OFFIC03	37.4 %	47	508	-$136 126	-$676 833	-$931 896	-$1 725 280
OFFIC08	40.4 %	51	548	-$138 091	-$576 697	-$636 276	-$1 403 016
OFFIC16	22.2 %	28	302	-$31 348	-$266 445	-$214 305	-$673 758
RETAIL1	100.0 %	233	2510	-$670 136	-$4 756 391	-$6 473 300	-$9 196 011
RSTRNT1	100.0 %	11	117	-$55 206	-$280 870	-$332 115	-$686 663
Total		**645**	**6938**	**-$1 332 203**	**-$11 656 780**	**-$14 495 721**	**-$23 865 012**

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

14.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kg/m²	lb/ft²	kg/m²	lb/ft²	kg/m²	lb/ft²	kg/m²	lb/ft²
APART04	-14.9	-3.1	-297.5	-60.9	-343.7	-70.4	-490.2	-100.4
APART06	-15.0	-3.1	-297.5	-60.9	-341.7	-70.0	-501.4	-102.7
DORMI04	-33.8	-6.9	-255.4	-52.3	-290.5	-59.5	-401.7	-82.3
DORMI06	-53.0	-10.9	-343.2	-70.3	-415.5	-85.1	-588.9	-120.6
HOTEL15	-12.5	-2.6	-230.0	-47.1	-220.1	-45.1	-358.9	-73.5
HIGHS02	-9.4	-1.9	-136.3	-27.9	-186.5	-38.2	-357.6	-73.3
OFFIC03	-29.1	-6.0	-143.3	-29.4	-196.2	-40.2	-365.8	-74.9
OFFIC08	-27.3	-5.6	-114.0	-23.3	-125.4	-25.7	-277.2	-56.8
OFFIC16	-11.3	-2.3	-94.0	-19.3	-74.2	-15.2	-240.0	-49.2
RETAIL1	-29.0	-5.9	-204.9	-42.0	-277.4	-56.8	-395.2	-80.9
RSTRNT1	-51.0	-10.5	-258.9	-53.0	-304.8	-62.4	-632.8	-129.6

Table 14-15 applies the Table 14-14 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 117 015 metric tons and 144 819 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 239 566 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 227 214 metric tons, 281 202 metric tons, and 465 176 metric tons over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	13	145	-201	-4008	-4630	-6603
APART06	55.1 %	17	178	-247	-4909	-5638	-8273
HOTEL15	100.0 %	96	1031	-1197	-22 021	-21 077	-34 367
HIGHS02	100.0 %	149	1600	-1392	-20 264	-27 724	-53 156
OFFIC03	37.4 %	47	508	-1372	-6767	-9264	-17 272
OFFIC08	40.4 %	51	548	-1392	-5803	-6384	-14 114
OFFIC16	22.2 %	28	302	-316	-2634	-2079	-6724
RETAIL1	100.0 %	233	2510	-6755	-47 786	-64 699	-92 155
RSTRNT1	100.0 %	11	117	-556	-2823	-3324	-6902
Total		**645**	**6938**	**-13 429**	**-117 015**	**-144 819**	**-239 566**

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

14.2.4 Life-Cycle Costs

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

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

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	-$0.16	-$0.02	-$29.19	-$2.71	-$34.53	-$3.21	-$31.73	-$2.95
APART06	-$0.72	-$0.07	-$29.48	-$2.74	-$34.41	-$3.20	-$32.53	-$3.02
DORMI04	$40.38	$3.75	-$4.29	-$0.40	-$9.31	-$0.86	-$16.49	-$1.53
DORMI06	-$4.73	-$0.44	-$37.44	-$3.48	-$44.86	-$4.17	-$46.60	-$4.33
HOTEL15	-$0.49	-$0.05	-$30.43	-$2.83	-$29.25	-$2.72	-$25.77	-$2.39
HIGHS02	$1.60	$0.15	-$13.13	-$1.22	-$17.78	-$1.65	-$26.63	-$2.47
OFFIC03	$45.25	$4.20	$26.40	$2.45	$13.07	$1.21	$3.26	$0.30
OFFIC08	$45.93	$4.27	$27.11	$2.52	$23.71	$2.20	$8.45	$0.78
OFFIC16	$0.12	$0.01	-$8.97	-$0.83	-$6.85	-$0.64	-$3.96	-$0.37
RETAIL1	$22.47	$2.09	-$0.05	-$0.01	-$8.37	-$0.78	-$1.88	-$0.17
RSTRNT1	$102.28	$9.50	$60.49	$5.62	$43.43	$4.04	-$23.39	-$2.17

Table 14-17 applies the Table 14-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. Total 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 6 of 9 building types and increases total life-cycle costs by $11.0 million. The *ASHRAE 90.1-2004* and *-2007* designs result in a decrease in life-cycle costs for 6 of 9 building types, and decrease total life-cycle costs by $2.7 million and $6.3 million, respectively. The LEC design decreases life-cycle costs for 7 of 9 building types, and decreases total life-cycle costs by $7.6 million. For a 10-year study period, it is cost-effective to adopt *ASHRAE 90.1-2004*, *-2007*, and LEC designs as Mississippi'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 $21.4 million, -$5.3 million, -$12.3 million, and -$14.8 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	13	145	-$2195	-$393 237	-$465 184	-$427 414
APART06	55.1 %	17	178	-$11 871	-$486 406	-$567 761	-$536 740
HOTEL15	100.0 %	96	1031	-$46 876	-$2 913 791	-$2 800 348	-$2 467 519
HIGHS02	100.0 %	149	1600	$237 422	-$1 951 522	-$2 642 060	-$3 957 339
OFFIC03	37.4 %	47	508	$2 136 492	$1 246 614	$617 131	$153 846
OFFIC08	40.4 %	51	548	$2 338 314	$1 380 147	$1 207 215	$430 178
OFFIC16	22.2 %	28	302	$3379	-$251 187	-$191 980	-$110 947
RETAIL1	100.0 %	233	2510	$5 240 363	-$12 706	-$1 952 354	-$438 251
RSTRNT1	100.0 %	11	117	$1 115 583	$659 787	$473 737	-$255 104
Total		**645**	**6938**	**$11 010 611**	**-$2 722 302**	**-$6 321 605**	**-$7 609 290**

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

14.3 State Summary

Mississippi is one of three states in the South Census Region that has not yet adopted a state energy code for commercial buildings. On average, adopting *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007* leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions, 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 470.6 GWh (1606.8 GBtu), energy cost savings of $28.1 million, and 281 202 metric tons of carbon emissions reductions while decreasing life-cycle costs by $12.3 million for one year's worth of commercial building construction. Adopting the LEC design would lead to even greater impacts than adopting

ASHRAE 90.1-2007, with savings of 689.6 GWh (2354.5 GBtu), $46.3 million of energy costs, and 465 176 metric tons of carbon emissions while decreasing life-cycle cost by $14.8 million for one year's worth of commercial building construction. Even though both cities in Mississippi simulated in this study are located in the same climate zone, there is significant variation in their results.

15 North Carolina

North Carolina is located in the South Atlantic Census Division and has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings. North Carolina spans three climate zones with the southern portion of the state located in Zone 3A, the central and northeast portions in Zone 4A, and the northwest portion in Zone 5A. All cities simulated for this study are located in Zone 3A and Zone 4A. Table 15-1 provides an overview of North Carolina's simulated energy use keyed to building types and energy codes. Average energy use varies across building types. The 8-story office building uses the least amount of energy at 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 146 kWh/m^2 to 163 kWh/m^2 (46 kBtu/ft^2 to 52 kBtu/ft^2) annually.

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

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	129	41	112	35
APART06	129	41	110	35
DORMI04	95	30	81	26
DORMI06	141	45	121	38
HOTEL15	129	41	110	35
HIGHS02	163	52	146	46
OFFIC03	101	32	79	25
OFFIC08	98	31	78	25
OFFIC16	135	43	112	35
RETAIL1	104	33	88	28
RSTRNT1	148	47	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.

15.1 Percentage Savings

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

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*. The LEC design realizes changes in energy use ranging from -10.5 % to -30.2 % with an average of -17.1 % relative to the *ASHRAE 90.1-2007* design. The greatest reduction in energy use for the LEC design occurs for the restaurant while the smallest reductions occur for the high school.

Table 15-2 Average Percentage Change from Adoption of a Newer Code, 10-Year, North Carolina

Building Type	LEC			
	Energy Use	**Energy Cost**	**Carbon**	**LCC**
APART04	-13.5	-17.0	-18.1	0.4
APART06	-14.8	-19.2	-20.6	0.2
DORMI04	-14.8	-17.7	-18.5	-0.7
DORMI06	-14.7	-19.1	-20.4	-0.1
HOTEL15	-14.9	-18.4	-19.4	0.3
HIGHS02	-10.5	-16.2	-18.1	-1.1
OFFIC03	-21.9	-23.3	-23.7	-2.1
OFFIC08	-20.2	-20.9	-21.1	-1.9
OFFIC16	-17.2	-19.1	-19.6	0.4
RETAIL1	-15.8	-17.2	-17.6	0.1
RSTRNT1	-30.2	-33.0	-33.8	-4.8
Average	**-17.1**	**-20.1**	**-21.0**	**-0.9**

The LEC design realizes average changes in energy costs from -16.2 % to -33.0 % depending on the building type, with an average of -20.1 % overall over 10 years of operation. The high school realizes the smallest average reduction in energy costs while the restaurant realizes the greatest average reduction in energy costs. 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 32.3 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 1.5 times greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4 and Zone 5, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

The LEC design leads to average changes in carbon emissions ranging from -17.6 % to -33.8 % depending on the building type, with an average of -21.0 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 8 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The average change in life-cycle costs for the LEC design over a 10-year study period ranges from -4.8 % to 0.4 %. The 4-story apartment building and 16-story office building realize the largest increases in life-cycle costs while the restaurant, 3-story office building, and 8-story office building are the building types that realize the greatest reductions in average life-cycle costs. Given that 6 of 11 buildings types realize an average percentage decrease in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

15.1.2 City Comparisons

Simulations are run for six cities in North Carolina located across two climate zones: Cape Hatteras, Charlotte, and Wilmington located in Zone 3A and Asheville, Greensboro, and Raleigh located in Zone 4A. There are no significant population centers in the area of North Carolina located in Zone 5A. The results may vary across cities within North Carolina for three reasons. First, the cities in 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.

Table 20-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design vary across cities, ranging from -15.9 % to -18.0 %. There is variation within both zones while there is not a significant difference when comparing across climate zones. Cities located closer to the coast (Raleigh, Cape Hatteras, and Wilmington) tend to realize greater reductions than cities located further inland (Asheville, Charlotte, and Greensboro).

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

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Cape Hatteras	3A	-17.8	-20.2	-21.2	-0.7
Charlotte	3A	-15.9	-19.1	-20.3	-0.6
Wilmington	3A	-17.3	-19.7	-20.7	-0.7
Asheville	4A	-16.6	-20.3	-21.7	-1.0
Greensboro	4A	-17.1	-20.4	-21.7	-1.1
Raleigh	4A	-18.0	-20.9	-22.1	-1.0
Average		**-17.1**	**-20.1**	**-21.3**	**-0.9**

The average percentage change in energy costs for all building types also varies across cities, ranging from -19.1 % to -20.9 % 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 across cities, ranging from -20.3 % to -22.1 %. Cities located in Zone 4A realize slightly greater reductions in energy costs and carbon emissions than cities in Zone 3A. All cities realize average percentage reductions in life-cycle costs, ranging from -0.6 % to -1.1 %. Cities located in Zone 4A realize greater reductions in life-cycle costs than cities in Zone 3, which is likely driven by variation in local construction costs.

15.2 Total Savings

How much can North Carolina 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 for the LEC design in the state.[33] 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

[33] 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.

large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[34]

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

Building Type	Standard Edition LEC kWh/m^2	Standard Edition LEC kBtu/ft^2
APART04	-17.4	-5.5
APART06	-19.2	-6.1
DORMI04	-14.0	-4.4
DORMI06	-20.8	-6.6
HOTEL15	-19.2	-6.1
HIGHS02	-22.1	-7.0
OFFIC03	-17.0	-5.4
OFFIC08	-19.8	-6.3
OFFIC16	-23.2	-7.3
RETAIL1	-16.5	-5.2
RSTRNT1	-44.7	-14.2

The annual reduction in energy use shown in Table 15-5 ranges widely across building types with reported floor area data, but the LEC design decreases overall energy use across the state for all building types. The adoption of the LEC design as the state's energy code would save 53.2 GWh (181.8 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 64.3 % 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 total statewide savings to be 82.8 GWh (282.7 GBtu) per year. These savings imply 827.9 GWh (2826.8 GBtu) in energy use savings over the 10-year study period.

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

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC	
				kWh	kBtu
APART04	44.9 %	144	1555	-2 507 392	-8 561 315
APART06	55.1 %	177	1904	-3 392 978	-11 585 086
HOTEL15	100.0 %	236	2536	-4 526 469	-15 455 313
HIGHS02	100.0 %	684	7359	-11 607 850	-39 634 192
OFFIC03	37.4 %	252	2714	-5 569 110	-19 015 336
OFFIC08	40.4 %	272	2926	-5 382 197	-18 377 134
OFFIC16	22.2 %	150	1610	-3 464 422	-11 829 028
RETAIL1	100.0 %	894	9628	-14 722 109	-50 267 611
RSTRNT1	100.0 %	46	496	-2 061 248	-7 037 985
Total		**2855**	**30 727**	**-53 233 776**	**-181 763 001**

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

The relative reduction in energy use varies across the 9 building types with reported floor area data for the LEC design relative to *ASHRAE 90.1-2007*. The greatest reductions are realized by the retail store followed by the high school. The smallest reductions are realized by the restaurant and 4-story apartment buildings. Building types that represent a greater amount of new floor area realize the largest changes in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 31.3 % and 24.0 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 9.5 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. The building types that lead to the greatest estimated reduction in energy use -- retail stores and high schools -- only rank 5th and 11th 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, North Carolina

Building Type	Standard Edition LEC $/m^2	$/ft^2
APART04	-$11.75	-$1.09
APART06	-$13.34	-$1.24
DORMI04	-$9.14	-$0.85
DORMI06	-$14.44	-$1.34
HOTEL15	-$12.60	-$1.17
HIGHS02	-$14.25	-$1.32
OFFIC03	-$13.33	-$1.24
OFFIC08	-$12.68	-$1.18
OFFIC16	-$15.12	-$1.40
RETAIL1	-$10.52	-$0.98
RSTRNT1	-$28.22	-$2.62

Table 15-7 reports the statewide changes in total energy costs by building type, which account for one year's worth of new construction evaluated over 10 years of building operation. All building types realize energy cost savings for the LEC design, with the energy cost savings being highly correlated with energy use savings. Any variation is a result of the greater percentage reduction in electricity consumption relative to the reduction in natural gas consumption. Overall, the reduction in energy costs totals $36.2 million for adopting the LEC design relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study, which represent 64.3 % 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 LEC design can be extrapolated to estimate the total energy cost savings of $56.2 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	144	1555	-$1 697 106
APART06	55.1 %	177	1904	-$2 360 570
HOTEL15	100.0 %	236	2536	-$2 967 443
HIGHS02	100.0 %	684	7359	-$9 114 778
OFFIC03	37.4 %	252	2714	-$3 592 282
OFFIC08	40.4 %	272	2926	-$3 446 037
OFFIC16	22.2 %	150	1610	-$2 261 251
RETAIL1	100.0 %	894	9628	-$9 409 644
RSTRNT1	100.0 %	46	496	-$1 301 041
Total		**2855**	**30 727**	**-$36 150 151**

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

15.2.3 Energy-related Carbon Emissions

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

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

Building Type	Standard Edition	
	LEC	
	kg/m²	lb/ft²
APART04	-122.2	-25.0
APART06	-139.6	-28.6
DORMI04	-94.2	-19.3
DORMI06	-151.0	-30.9
HOTEL15	-130.0	-26.6
HIGHS02	-143.0	-29.3
OFFIC03	-146.5	-30.0
OFFIC08	-130.1	-26.6
OFFIC16	-155.9	-31.9
RETAIL1	-107.9	-22.1
RSTRNT1	-288.6	-59.1

Table 15-9 applies the Table 15-8 results to one year's worth of new building construction in the state to estimate statewide reductions in carbon emissions from adoption of the LEC design. The total reduction in carbon emissions ranges widely across building types, and is correlated with each building's total reduction in energy use. However, there is not a perfect correlation because the magnitude of the offsetting natural gas increase varies across building types. The adoption of the LEC design as the state's energy code decreases carbon emissions by 376 144 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 584 982 metric tons over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	144	1555	-17 645
APART06	55.1 %	177	1904	-24 695
HOTEL15	100.0 %	236	2536	-30 626
HIGHS02	100.0 %	684	7359	-97 737
OFFIC03	37.4 %	252	2714	-36 932
OFFIC08	40.4 %	272	2926	-35 365
OFFIC16	22.2 %	150	1610	-23 314
RETAIL1	100.0 %	894	9628	-96 525
RSTRNT1	100.0 %	46	496	-13 305
Total		**2855**	**30 727**	**-376 144**

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, North Carolina

Building Type	Standard Edition LEC $\$/m^2$	Standard Edition LEC $\$/ft^2$
APART04	$3.12	$0.29
APART06	$1.89	$0.18
DORMI04	-$6.04	-$0.56
DORMI06	-$1.01	-$0.09
HOTEL15	$2.41	$0.22
HIGHS02	-$7.73	-$0.72
OFFIC03	-$14.33	-$1.33
OFFIC08	-$13.79	-$1.28
OFFIC16	$2.38	$0.22
RETAIL1	$0.50	$0.05
RSTRNT1	-$56.27	-$5.23

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 the LEC design. The change in life-cycle costs varies widely across building types, with 4 of 9 building types realizing a reduction in life-cycle costs. High schools realize the greatest decrease in life-cycle costs ($5.3 million) followed by 8- and 3-story office buildings ($3.7 million and $3.6 million, respectively). The hotel realizes the greatest increase in life-cycle costs ($568 540). Adopting the LEC design leads to a reduction in statewide life-cycle costs of $13.1 million relative to *ASHRAE 90.1-2007*. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate the total decrease in statewide life-cycle costs of $20.3 million over the 10-year study period.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	144	1555	$450 059
APART06	55.1 %	177	1904	$333 549
HOTEL15	100.0 %	236	2536	$568 540
HIGHS02	67.5 %	684	7359	-$5 286 568
OFFIC03	37.4 %	252	2714	-$3 612 534
OFFIC08	40.4 %	272	2926	-$3 747 879
OFFIC16	22.2 %	150	1610	$356 321
RETAIL1	100.0 %	894	9628	$448 045
RSTRNT1	100.0 %	46	496	-$2 593 950
Total		**2855**	**30 727**	**-$13 084 418**

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

15.3 State Summary

North Carolina has adopted *ASHRAE 90.1-2007* as its energy code for commercial buildings. The adoption of the LEC design, which goes beyond *ASHRAE 90.1-2007*, leads to reductions in energy use, energy costs, and energy-related carbon emissions in a life-cycle cost-effective manner. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting the LEC design as the state's energy code would lead to energy use savings of 827.9 GWh (2826.8 GBtu), energy cost savings of $56.2 million, and carbon emissions reductions of 584 982 metric tons while decreasing life-cycle costs by $20.3 million for one year's worth of commercial building construction.

16 Oklahoma

Oklahoma is located in the West South Central Census Division and spans two climate zones, Zone 2A across most of the state and Zone 3B in the western "panhandle." The state does not have a commercial building energy code, and is assumed to build to the current minimum industry practices represented by *ASHRAE 90.1-1999* requirements. Table 16-1 provides an overview of Oklahoma's simulated energy use keyed to building type 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 85 kWh/m^2 to 123 kWh/m^2 (27 kBtu/ft^2 to 39 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 168 kWh/m^2 to 198 kWh/m^2 (53 kBtu/ft^2 to 63 kBtu/ft^2) annually.

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

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	174	55	172	55	149	47	144	46	126	40
APART06	172	55	171	54	148	47	143	45	124	39
DORMI04	134	42	130	41	112	36	111	35	97	31
DORMI06	191	61	185	59	161	51	154	49	134	43
HOTEL15	156	50	154	49	132	42	144	46	125	40
HIGHS02	198	63	197	62	189	60	186	59	168	53
OFFIC03	127	40	124	39	113	36	110	35	88	28
OFFIC08	123	39	119	38	107	34	104	33	85	27
OFFIC16	149	47	147	47	135	43	145	46	123	39
RETAIL1	141	45	138	44	123	39	114	36	98	31
RSTRNT1	198	63	192	61	168	53	164	52	120	38

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

16.1 Percentage Savings

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

16.1.1 Energy Use

Table 16-2 shows a small change in energy use from adopting *ASHRAE 90.1-2001* relative to *ASHRAE 90.1-1999* with all 11 building types having reductions in energy use of 3.3 % or less. There is a decrease in energy use for all 11 building types for *ASHRAE 90.1-2004*, with the percentage change in energy use ranging from -4.6 % to -16.4 % with an average of -13.0 %. The average change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -2.9 % to -19.3 %, with an overall average of -13.9 %.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-1.0	-14.2	-17.4	-27.2
APART06	-1.0	-14.4	-17.0	-28.1
DORMI04	-3.1	-16.4	-16.8	-27.6
DORMI06	-3.3	-15.7	-19.3	-29.9
HOTEL15	-1.3	-15.3	-7.9	-19.7
HIGHS02	-0.6	-4.6	-6.0	-15.0
OFFIC03	-2.8	-11.3	-13.8	-30.8
OFFIC08	-3.1	-13.2	-16.0	-31.2
OFFIC16	-1.3	-9.7	-2.9	-17.3
RETAIL1	-2.0	-12.9	-19.1	-30.5
RSTRNT1	-3.1	-15.5	-17.3	-39.7
Average	**-2.0**	**-13.0**	**-13.9**	**-27.0**

For the high-rise buildings (15-story hotel and 16-story office building), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC requirement in Zone 2 and Zone 3 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 electricity 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 -15.0 % to -39.7 % with an average of -27.0 %. Similar to the *ASHRAE 90.1-2007* design, the lowest reduction in energy use for the LEC design occurs in the buildings with the greatest window-to-wall ratios due to the less strict window SHGC requirement. 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.

16.1.2 Energy Costs

Table 16-3 shows a small change in energy costs over 10 years from adopting *ASHRAE 90.1-2001* (-0.7 % to -3.6 %), 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 -8.2 % to -22.1 % depending on the building type, with an average of -17.0 %. The average chagne in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -7.3 % to -25.8 %, with an overall average of -18.5 %. The LEC design realizes the greatest change in energy costs, with the average change by building type ranging from -22.8 % to -45.1 % with an average of -33.3 % overall.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-1.1	-19.5	-23.5	-35.1
APART06	-1.1	-19.6	-23.3	-36.5
DORMI04	-3.4	-22.1	-24.2	-36.1
DORMI06	-3.6	-21.0	-25.8	-38.5
HOTEL15	-1.4	-21.5	-16.3	-29.9
HIGHS02	-0.7	-8.2	-9.8	-22.8
OFFIC03	-2.9	-13.4	-15.6	-33.7
OFFIC08	-3.2	-14.7	-16.9	-32.9
OFFIC16	-1.4	-12.2	-7.3	-23.0
RETAIL1	-2.2	-15.3	-20.3	-32.6
RSTRNT1	-3.3	-19.1	-21.0	-45.1
Average	**-2.2**	**-17.0**	**-18.5**	**-33.3**

For all building designs, the average reductions in energy costs are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. For 10 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.

16.1.3 Energy-related Carbon Emissions

Minimal change in energy use leads to small changes (3.9 % or less) in cradle-to-grave energy-related carbon emissions for the *ASHRAE 90.1-2001* design across all building types. Table 16-4 shows a significant change in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -11.4 % to -26.1 % with an average of -19.8 %. 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 -10.4 % to -30.5 % with an overall average of -21.9 %. The LEC design leads to the greatest average carbon emissions changes, ranging from -26.9 % to -48.8 % depending on the building type with an average of -37.9 % across all building types.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	-1.2	-23.4	-28.0	-40.8
APART06	-1.2	-23.4	-27.9	-42.6
DORMI04	-3.6	-26.1	-29.4	-42.2
DORMI06	-3.9	-24.8	-30.5	-44.8
HOTEL15	-1.6	-26.1	-22.5	-37.5
HIGHS02	-0.8	-11.4	-13.1	-29.7
OFFIC03	-3.0	-14.7	-16.8	-35.7
OFFIC08	-3.3	-15.7	-17.4	-34.0
OFFIC16	-1.5	-13.8	-10.4	-26.9
RETAIL1	-2.3	-17.0	-21.1	-34.0
RSTRNT1	-3.5	-21.7	-23.6	-48.8
Average	**-2.3**	**-19.8**	**-21.9**	**-37.9**

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

16.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 16-5. Life-cycle costs increase for the *ASHRAE 90.1-2001* design compared to *ASHRAE 90.1-1999* for 7 of 11 building types over a 10-year study period. *ASHRAE 90.1-1999* is the lowest cost building design for three building types while *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* are the lowest cost building design for two and four building types, respectively. The change in life-cycle costs for *ASHRAE 90.1-2004* and *-2007* range from -2.9 % to 4.7 % depending on building type. The LEC design is the lowest cost building design for 2 of 11 building types, with the percentage change in life-cycle costs ranging from -3.1 % to 2.0 %. Given that the adoption of the LEC design decreases life-cycle costs for 7 of 11 building types, it may be cost-effective to adopt the LEC design as the state's energy code for commercial buildings.

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

Building Type	Standard Edition			
	2001	2004	2007	LEC
APART04	0.0	-1.6	**-2.0**	-1.3
APART06	-0.0	-1.7	**-2.1**	-1.5
DORMI04	4.5	1.0	**-0.3**	-0.0
DORMI06	-0.3	-2.4	**-2.9**	-2.6
HOTEL15	-0.1	**-2.5**	-1.8	-1.2
HIGHS02	0.2	-0.5	-0.3	**-1.3**
OFFIC03	6.1	3.1	2.6	2.0
OFFIC08	6.3	3.2	2.4	0.9
OFFIC16	-0.0	**-1.2**	-0.6	0.3
RETAIL1	3.6	1.5	1.4	1.9
RSTRNT1	7.3	4.7	4.2	**-3.1**
Average	**2.5**	**0.3**	**0.0**	**-0.5**

16.1.5 City Comparisons

Simulations are run for two cities located in Oklahoma: Oklahoma City and Tulsa in Climate Zone 2A. There are no significant population centers located in Zone 3B. While the two cities in Oklahoma selected for this study are located in the same climate zone, the results may still vary across cities within the state 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 16-6, the average reduction in energy use for all building types from adopting newer energy standard editions varies minimally between cities. The difference in the percentage reductions is 0.4 percentage points.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Oklahoma City	3A	-2.0	-13.2	-14.0	-27.1
Tulsa	3A	-2.1	-12.8	-13.9	-26.9
Average		**-2.0**	**-13.0**	**-13.9**	**-27.0**

The variations in energy costs between cities are a result of two factors, the reduction in energy use and the fuel source of the reduction. Table 16-7 shows that the average reduction in energy costs for all building types varies minimally. The percentage change in energy costs is greater than the percentage change in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Oklahoma City	3A	-2.2	-17.1	-18.6	-33.4
Tulsa	3A	-2.3	-16.8	-18.5	-33.1
Average		**-2.2**	**-17.0**	**-18.5**	**-33.3**

Table 16-8 shows that the average percentage changes in energy-related carbon emissions vary minimally between cities. For both, the more stringent standard editions result in greater reductions in carbon emissions. The percentage change in carbon emissions is greater than the percentage change in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Oklahoma City	3A	-2.1	-19.2	-21.5	-37.9
Tulsa	3A	-2.2	-19.0	-21.3	-37.5
Average		**-2.2**	**-19.1**	**-21.4**	**-37.7**

The data reported in Table 16-9 show that, over a 10-year period, average life-cycle costs increase for both cities for the *ASHRAE 90.1-2001*, *-2004*, and *-2007* designs compared to *ASHRAE 90.1-1999*. Adopting the LEC design decreases average life-cycle costs for both cities, with Tulsa realizing slightly greater reductions.

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

Cities	Zone	Standard Edition			
		2001	2004	2007	LEC
Oklahoma City	3A	2.5	0.3	0.0	-0.4
Tulsa	3A	2.5	0.3	0.0	-0.7
Average		**2.5**	**0.3**	**0.0**	**-0.5**

16.2 Total Savings

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

16.2.1 Energy Use

Table 16-10 reports the average per unit change in annual energy use by building type and building design in the state.[35] The reduction per m^2 (ft^2) is multiplied by the estimated m^2 (ft^2) of new construction of each building type, and Table 16-11 reports the estimated average annual floor area of new construction and the total annual change in energy use for each building type. The weightings within a category (e.g., small, medium, and large office buildings) are based on the national average percentage of new building construction for the category that is represented by each subcategory.[36]

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

Building Type	Standard Edition							
	2001		2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-1.7	-0.5	-24.6	-7.8	-30.1	-9.6	-47.3	-15.0
APART06	-1.8	-0.6	-24.9	-7.9	-29.4	-9.3	-48.5	-15.4
DORMI04	-4.2	-1.3	-21.9	-6.9	-22.5	-7.1	-36.9	-11.7
DORMI06	-6.3	-2.0	-30.1	-9.6	-36.9	-11.7	-57.3	-18.2
HOTEL15	-2.0	-0.6	-23.9	-7.6	-12.4	-3.9	-30.8	-9.8
HIGHS02	-1.1	-0.4	-14.4	-4.6	-17.5	-5.6	-39.3	-12.5
OFFIC03	-3.5	-1.1	-9.0	-2.9	-11.9	-3.8	-29.7	-9.4
OFFIC08	-3.8	-1.2	-16.3	-5.2	-19.7	-6.2	-38.4	-12.2
OFFIC16	-1.9	-0.6	-14.5	-4.6	-4.3	-1.4	-25.8	-8.2
RETAIL1	-2.8	-0.9	-18.1	-5.7	-26.8	-8.5	-42.9	-13.6
RSTRNT1	-6.1	-1.9	-30.7	-9.7	-34.3	-10.9	-78.8	-25.0

The total annual reduction in energy use ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs all decrease overall energy use across the state. Adopting *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, and *ASHRAE 90.1-2007* result in annual decreases of 2.0 GWh (6.7 GBtu), 13.3 GWh (45.3 GBtu), and 15.4 GWh (52.6 GBtu) annually, respectively. The adoption of the LEC design as the state's energy code would save energy for all building types and

[35] 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.
[36] State-level subcategory data are not available.

30.7 GWh (104.8 GBtu) of total energy use annually for one year's worth of new construction for these building types.

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

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 %	10	112	-18	-61	-255	-872	-312	-1067	-490	-1674
APART06	55.1 %	13	137	-22	-76	-316	-1080	-373	-1275	-616	-2105
HOTEL15	100.0 %	102	1102	-206	-704	-2444	-8344	-1269	-4334	-3150	-10 754
HIGHS02	100.0 %	236	2538	-264	-901	-2131	-7277	-2807	-9584	-7002	-23 909
OFFIC03	37.4 %	57	615	-202	-690	-825	-2817	-1002	-3420	-2244	-7663
OFFIC08	40.4 %	62	663	-235	-802	-1003	-3425	-1213	-4140	-2367.5	-8084
OFFIC16	22.2 %	34	365	-66	-225	-490	-1674	-147	-501	-876	-2990
RETAIL1	100.0 %	273	2937	-770	-2629	-4938	-16 862	-7320	-24 993	-11 704	-39 963
RSTRNT1	100.0 %	28	305	-172	-588	-868	-2 963	-970	-3313	-2230	-7614
Total		**815**	**8774**	**-1956**	**-6677**	**-13 272**	**-45 315**	**-15 413**	**-52 628**	**-30 680**	**-104 756**
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 51.3 % 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 total statewide savings from adopting the LEC design in new commercial buildings to be 59.8 GWh (204.2 GBtu) per year. These savings imply 598.1 GWh (2042.0 GBtu) in energy use savings over the 10-year study period. In comparison, *ASHRAE 90.1-2007* would save 30.0 GWh (102.6 GBtu) annually or 300.5 GWh (1025.9 GBtu) over the 10-year study period.

The statewide change in energy use varies across building types within a building design. Building types that represent a greater amount of new floor area realize the largest changes in aggregate energy use. The greatest total reductions are realized by retail stores and high schools because they represent 33.5 % and 29.0 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 12.5 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that have the greatest percentage reduction in energy use are not always the same buildings that lead to the greatest total reductions for the state. 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 6th and 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 16-2.

16.2.2 Energy Costs

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

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

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	-$0.93	-$0.09	-$16.21	-$1.51	-$19.53	-$1.81	-$29.17	-$2.71
APART06	-$0.94	-$0.09	-$16.32	-$1.52	-$19.40	-$1.80	-$30.38	-$2.82
DORMI04	-$2.23	-$0.21	-$14.48	-$1.35	-$15.86	-$1.47	-$23.71	-$2.20
DORMI06	-$3.38	-$0.31	-$19.44	-$1.81	-$23.90	-$2.22	-$35.68	-$3.31
HOTEL15	-$1.08	-$0.10	-$16.06	-$1.49	-$12.17	-$1.13	-$22.33	-$2.07
HIGHS02	-$1.90	-$0.18	-$8.66	-$0.80	-$10.09	-$0.94	-$21.86	-$2.03
OFFIC03	-$0.60	-$0.06	-$7.12	-$0.66	-$8.50	-$0.79	-$19.75	-$1.84
OFFIC08	-$2.04	-$0.19	-$9.38	-$0.87	-$10.76	-$1.00	-$20.98	-$1.95
OFFIC16	-$1.04	-$0.10	-$9.09	-$0.84	-$5.49	-$0.51	-$17.21	-$1.60
RETAIL1	-$1.51	-$0.14	-$10.60	-$0.99	-$14.06	-$1.31	-$22.59	-$2.10
RSTRNT1	-$3.27	-$0.30	-$18.84	-$1.75	-$20.70	-$1.92	-$44.40	-$4.12

Table 16-13 reports the statewide changes in total energy costs by building type and building design, which account for one year's worth of new construction evaluated over 10 years of building operation. The *ASHRAE 90.1-2001* design realizes the smallest reductions in energy costs ($1.0 million). *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design realize decreases in energy costs of $8.5 million, $9.5 million, and $18.2 million, respectively. Assuming that the buildings considered in this study, which represent 51.3 % 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 *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and the LEC design can be extrapolated to estimate statewide reductions in energy costs of $2.0 million, $16.6 million, $18.6 million, and $35.4 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	10	112	-$9600	-$168 182	-$202 620	-$302 589
APART06	55.1 %	13	137	-$11 979	-$207 388	-$246 445	-$385 931
HOTEL15	100 %	102	1102	-$110 602	-$1 644 061	-$1 245 807	-$2 286 560
HIGHS02	100 %	236	2538	-$141 459	-$1 679 254	-$2 003 375	-$4 658 311
OFFIC03	37.4 %	57	615	-$108 437	-$495 076	-$576 539	-$1 248 905
OFFIC08	40.4 %	62	663	-$125 945	-$578 068	-$663 135	-$1 292 756
OFFIC16	22.2 %	34	365	-$35 327	-$308 152	-$186 236	-$583 524
RETAIL1	100 %	273	2937	-$412 876	-$2 893 448	-$3 837 337	-$6 164 769
RSTRNT1	100 %	28	305	-$92 401	-$533 198	-$585 762	-$1 256 369
Total		**815**	**8774**	**-$1 048 625**	**-$8 506 828**	**-$9 547 255**	**-$18 179 715**

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

16.2.3 Energy-related Carbon Emissions

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

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

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	-16.8	-3.4	-326.9	-66.9	-391.1	-80.1	-570.5	-116.8
APART06	-17.1	-3.5	-328.5	-67.3	-391.6	-80.2	-598.3	-122.5
DORMI04	-40.4	-8.3	-292.5	-59.9	-329.2	-67.4	-472.9	-96.9
DORMI06	-61.2	-12.5	-388.3	-79.5	-478.2	-97.9	-701.0	-143.6
HOTEL15	-19.6	-4.0	-326.8	-66.9	-281.4	-57.6	-469.0	-96.1
HIGHS02	-10.9	-2.2	-154.1	-31.6	-177.2	-36.3	-400.1	-81.9
OFFIC03	-34.4	-7.0	-167.1	-34.2	-190.3	-39.0	-404.6	-82.9
OFFIC08	-37.0	-7.6	-177.1	-36.3	-197.2	-40.4	-384.0	-78.7
OFFIC16	-18.9	-3.9	-179.3	-36.7	-134.6	-27.6	-348.8	-71.4
RETAIL1	-27.4	-5.6	-201.9	-41.4	-251.0	-51.4	-404.5	-82.8
RSTRNT1	-59.1	-12.1	-367.7	-75.3	-400.4	-82.0	-827.6	-169.5

Table 16-15 applies the Table 16-14 results to one year's worth of new building construction in the state to estimate the statewide reduction in carbon emissions from adoption of more energy efficient codes. The total reduction in carbon emissions ranges widely across building designs, but the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs decrease carbon emissions overall. The adoption of *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* result in savings of 169 419 metric tons and 187 059 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 348 290 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide reductions in carbon emissions of 330 251 metric tons, 364 637 metric tons, and 678 928 metric tons over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	10	112	-174	-3390	-4057	-5917
APART06	55.1 %	13	137	-217	-4174	-4975	-7601
HOTEL15	100.0 %	102	1102	-2002	-33 463	-28 816	-48 020
HIGHS02	100.0 %	236	2538	-2561	-36 346	-41 791	-94 349
OFFIC03	37.4 %	57	615	-1963	-9546	-10 874	-23 116
OFFIC08	40.4 %	62	663	-2280	-10 911	-12 149	-23 663
OFFIC16	22.2 %	34	365	-640	-6080	-4563	-11 827
RETAIL1	100.0 %	273	2937	-7475	-55 104	-68 503	-110 379
RSTRNT1	100.0 %	28	305	-1673	-10 405	-11 330	-23 419
Total		**815**	**8774**	**-18 985**	**-169 419**	**-187 059**	**-348 290**

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

16.2.4 Life-Cycle Costs

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

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

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	$0.21	$0.02	-$14.59	-$1.36	-$18.24	-$1.69	-$11.97	-$1.11
APART06	-$0.31	-$0.03	-$15.49	-$1.44	-$18.60	-$1.73	-$13.26	-$1.23
DORMI04	$37.40	$3.47	$8.52	$0.79	-$2.47	-$0.23	-$0.27	-$0.02
DORMI06	-$3.00	-$0.28	-$22.45	-$2.09	-$26.45	-$2.46	-$23.81	-$2.21
HOTEL15	-$0.58	-$0.05	-$21.42	-$1.99	-$15.96	-$1.48	-$10.50	-$0.98
HIGHS02	$1.50	$0.14	-$3.80	-$0.35	-$1.91	-$0.18	-$9.37	-$0.87
OFFIC03	$42.20	$3.92	$21.15	$1.96	$17.69	$1.64	$13.49	$1.25
OFFIC08	$45.19	$4.20	$23.03	$2.14	$16.90	$1.57	$6.63	$0.62
OFFIC16	-$0.10	-$0.01	-$8.29	-$0.77	-$4.29	-$0.40	$2.11	$0.20
RETAIL1	$20.46	$1.90	$8.77	$0.81	$7.96	$0.74	$10.83	$1.01
RSTRNT1	$83.22	$7.73	$54.04	$5.02	$47.87	$4.45	-$35.05	-$3.26

Table 16-17 applies the Table 16-16 results to one year's worth of new building construction in the state to estimate statewide changes in life-cycle costs from adoption of more energy-efficient state energy codes for commercial buildings. 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 6 of 9 building types and increases total statewide life-cycle costs by $13.4 million. The *ASHRAE 90.1-2004* and *-2007* designs result in an increase in life-cycle costs for 4 of 9 building types, with total life-cycle costs increasing by $2.8 million for *ASHRAE 90.1-2004* and $2.9 million for *ASHRAE 90.1-2007*. The LEC design decreases life-cycle costs for 5 of 9 building types, and decreases total life-cycle costs by $363 368. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide changes in life-cycle costs of $26.2 million, $5.5 million, $5.7 million, and -$708 320 over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2001	2004	2007	LEC
APART04	44.9 %	10	112	$2203	-$151 345	-$189 229	-$124 201
APART06	55.1 %	13	137	-$3989	-$196 735	-$236 357	-$168 433
HOTEL15	100.0 %	102	1102	-$59 008	-$2 193 613	-$1 634 180	-$1 075 136
HIGHS02	100.0 %	236	2538	$352 687	-$895 760	-$449 264	-$2 210 012
OFFIC03	37.4 %	57	615	$2 411 480	$1 208 267	$1 010 853	$770 658
OFFIC08	40.4 %	62	663	$2 784 385	$1 419 248	$1 041 514	$408 420
OFFIC16	22.2 %	34	365	-$3444	-$281 194	-$145 273	$71 518
RETAIL1	100.0 %	273	2937	$5 581 905	$2 392 822	$2 171 871	$2 955 614
RSTRNT1	100.0 %	28	305	$2 354 890	$1 529 327	$1 354 595	-$991 795
Total		**815**	**8774**	**$13 421 108**	**$2 831 018**	**$2 924 530**	**-$363 368**

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

16.3 State Summary

Oklahoma is one of the three states in the South Census Region that has no state energy code for commercial buildings. Adopting the *ASHRAE 90.1-2001*, *-2004*, and *-2007* designs lead to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions, but not in a life-cycle cost-effective manner, costing $26.2 million, $5.5 million, and $5.7 million, respectively. Oklahoma is one of the few states for which adopting *ASHRAE 90.1-2007* is not life-cycle cost effective. On average, adopting the LEC design leads to reductions in energy use, energy costs, and cradle-to-grave energy-related carbon emissions at negative life-cycle costs. Based on the average annual new construction in the state from 2003 to 2007 and a 10-year study period, adopting *ASHRAE 90.1-2007* as the state's energy code for commercial buildings would lead to energy use savings of 300.5 GWh (1025.9 GBtu), energy cost savings of $29.1 million, and 502 267 metric tons of carbon emissions reductions while adding $5.7 million in life-cycle costs for one year's worth of commercial building construction. Adopting the LEC design would lead to even greater impactsthan adopting *ASHRAE 90.1-2007*, with savings of 598.1 GWh (2042.0 GBtu), $35.4 million of energy costs, 678 928 metric tons of carbon emissions while decreasing life-cycle costs by $708 320 for one year's worth of commercial building construction.

17 South Carolina

South Carolina is one of two states in the South Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings, and is located in the South Atlantic Census Division and Climate Zone 3A. Table 17-1 provides an overview of South Carolina'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 78 kWh/m^2 to 94 kWh/m^2 (25 $kBtu/ft^2$ to 30 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 133 kWh/m^2 to 153 kWh/m^2 (42 $kBtu/ft^2$ to 49 $kBtu/ft^2$) annually.

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

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	131	41	124	39	107	34
APART06	130	41	125	40	105	33
DORMI04	94	30	92	29	78	25
DORMI06	144	46	136	43	115	36
HOTEL15	114	36	123	39	105	33
HIGHS02	153	49	151	48	133	42
OFFIC03	103	33	101	32	79	25
OFFIC08	101	32	98	31	79	25
OFFIC16	123	39	130	41	108	34
RETAIL1	110	35	104	33	88	28
RSTRNT1	151	48	147	47	103	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 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.

17.1 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 South Carolina.

17.1.1 Energy Use

Table 17-2 shows a large variation in the percentage change in energy use for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 7.4 % to -5.9 % with an average of -1.8 %. 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 3A for buildings with fenestration accounting for greater than 40 % of wall surface area is less stringent for *ASHRAE 90.1-2007* than *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-values.

Table 17-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, South Carolina

Building Type	Standard Edition	
	2007	LEC
APART04	-4.7	-18.0
APART06	-4.1	-18.9
DORMI04	-2.0	-16.9
DORMI06	-5.9	-20.2
HOTEL15	7.4	-8.5
HIGHS02	-1.7	-13.8
OFFIC03	-2.6	-23.8
OFFIC08	-2.6	-21.7
OFFIC16	5.6	-12.1
RETAIL1	-5.9	-20.2
RSTRNT1	-2.8	-32.0
Average	**-1.8**	**-18.7**

The LEC design realizes percentage changes in energy use relative to *ASHRAE 90.1-2004,* ranging from -8.5 % to -32.0 % with an average of -18.7 %. 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.

17.1.2 Energy Costs

Table 17-3 shows significant variation in the percentage changes in average energy costs for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 5.0 % to -8.0 % depending on the building type, with an average of -2.7 %. 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. The percentage reductions in energy costs are smaller than the reductions in energy use for 3 of 11 building types because adopting the *ASHRAE 90.1-2007* design decreases natural gas consumption by a greater percentage than electricity consumption. Since natural gas is cheaper than electricity on a per unit basis, the greater relative reduction in natural gas consumption leads to a smaller percentage reduction in energy costs, on average, than the percentage reduction in total energy use for these three building types.

Table 17-3 Average Percentage Change in Energy Costs, 10-Year, South Carolina

Building Type	Standard Edition	
	2007	LEC
APART04	-6.1	-22.6
APART06	-5.9	-24.4
DORMI04	-4.4	-21.7
DORMI06	-8.0	-26.0
HOTEL15	5.0	-14.6
HIGHS02	-2.0	-19.8
OFFIC03	-2.4	-24.9
OFFIC08	-2.1	-21.9
OFFIC16	3.7	-15.5
RETAIL1	-4.9	-20.5
RSTRNT1	-2.8	-34.7
Average	**-2.7**	**-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 -14.6 % to -34.7 % 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. For these building types, the percentage reduction in electricity consumption is greater than the reduction in natural gas, which leads to additional reductions in energy costs.

17.1.3 Energy-related Carbon Emissions

Table 17-4 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 4.7 % to -8.2 % with an average of -2.9 %. The LEC design leads to significant changes in average carbon emissions, ranging from -15.4 % to -35.1 % depending on the building type with an average of -22.9 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. However, the carbon emissions reductions are smaller than the energy use reductions for 3 of 11 building types for the *ASHRAE 90.1-2007* design because natural gas consumption is decreased by a greater percentage than electricity consumption.

Table 17-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, South Carolina

Building Type	Standard Edition	
	2007	LEC
APART04	-6.3	-23.2
APART06	-6.1	-25.1
DORMI04	-4.7	-22.3
DORMI06	-8.2	-26.8
HOTEL15	4.7	-15.4
HIGHS02	-2.1	-20.6
OFFIC03	-2.4	-25.0
OFFIC08	-2.1	-22.0
OFFIC16	3.5	-15.9
RETAIL1	-4.8	-20.5
RSTRNT1	-2.8	-35.1
Average	**-2.9**	**-22.9**

17.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 17-5. 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 the lowest life-cycle costs for the hotel and 16-story office building.

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

The LEC design results in reductions in life-cycle costs for 8 of the 11 building types for a 10-year study period. The percentage change in life-cycle costs ranges from -4.2 % to 1.0 %. Based on the overall average percentage change of -0.9 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

Table 17-5 Average Percentage Change in Life-Cycle Costs, 10-Year, South Carolina

Building Type	Standard Edition	
	2007	LEC
APART04	**-0.6**	-0.1
APART06	**-0.5**	-0.2
DORMI04	-0.5	**-1.3**
DORMI06	-0.7	**-0.7**
HOTEL15	0.6	0.9
HIGHS02	0.2	**-1.3**
OFFIC03	-0.6	**-2.0**
OFFIC08	-0.7	**-2.2**
OFFIC16	0.5	1.0
RETAIL1	**-0.1**	0.2
RSTRNT1	-0.5	**-4.2**
Average	**-0.3**	**-0.9**

17.1.5 City Comparisons

Simulations are run for three cities located in South Carolina, all of which are located in Zone 3A: Charleston, Columbia, and Greenville. While the three 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 17-6, the average reduction in energy use for all building types from adopting newer energy standard editions varies across cities. For the *ASHRAE 90.1-2007* design, the percentage change in average energy use ranges minimally from -1.3 % to -2.2 %. For the LEC design, the percentage change in average energy use ranges from -17.2 % to -20.2 %. The closer a city is to the coastline, the greater the percentage reduction in energy use.

Table 17-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, South Carolina

Cities	Zone	Standard Edition	
		2007	LEC
Charleston	3A	-2.2	-20.2
Columbia	3A	-1.8	-18.8
Greenville	3A	-1.3	-17.2
Average		**-1.8**	**-18.7**

The variations in energy costs across cities are a result of two factors, the reduction in energy use and the fuel source of the reduction. Table 17-7 shows that the average reduction in energy costs for all building types varies marginally across cities. For the *ASHRAE 90.1-2007* design, the percentage change in average energy costs ranges from -2.4 % to -3.0 % with an average of -2.7 %. For the LEC design, the percentage change in average energy costs ranges from -21.6 % to -23.1 % with an average of -22.4 %.

Table 17-7 Average Percentage Change in Energy Costs by City, 10-Year, South Carolina

Cities	Zone	Standard Edition	
		2007	LEC
Charleston	3A	-3.0	-23.1
Columbia	3A	-2.8	-22.5
Greenville	3A	-2.4	-21.6
Average		**-2.7**	**-22.4**

Table 17-8 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 average percentage change in carbon emissions varies minimally across cities.

Table 17-8 Average Percentage Change in Carbon Emissions by City, South Carolina

Cities	Zone	Standard Edition	
		2007	LEC
Charleston	3A	-3.1	-23.4
Columbia	3A	-3.3	-23.9
Greenville	3A	-2.8	-22.7
Average		**-3.1**	**-23.3**

The data reported in Table 17-9 show that adoption of the *ASHRAE 90.1-2007* design decreases life-cycle costs across all cities, with changes in life-cycle costs ranging minimally from -0.2 % to -0.3 %. The LEC design realizes the greatest reduction in life-cycle costs across all cities in the state. Charleston realizes smaller reductions in life-cycle costs from adopting the LEC design than does Greenville or Columbia.

Table 17-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, South Carolina

Cities	Zone	Standard Edition	
		2007	LEC
Charleston	3A	-0.3	-0.6
Columbia	3A	-0.2	-1.1
Greenville	3A	-0.2	-1.0
Average		**-0.3**	**-0.9**

17.2 Total Savings

How much can South Carolina 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 17-10 reports the average per unit change in annual energy use by building type and building design in the state.[37] 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 17-11 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.[38]

[37] 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.
[38] State-level subcategory data are not available.

Table 17-10 Average Per Unit Change in Annual Energy Use, South Carolina

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	kBtu/ft^2	kWh/m^2	kBtu/ft^2
APART04	-6.1	-1.9	-23.5	-7.5
APART06	-5.3	-1.7	-24.5	-7.8
DORMI04	-1.9	-0.6	-15.9	-5.0
DORMI06	-8.5	-2.7	-29.1	-9.2
HOTEL15	8.4	2.7	-9.6	-3.1
HIGHS02	-2.7	-0.8	-24.5	-7.8
OFFIC03	-2.6	-0.8	-21.0	-6.7
OFFIC08	-2.7	-0.8	-21.9	-6.9
OFFIC16	6.9	2.2	-14.9	-4.7
RETAIL1	-6.5	-2.1	-22.3	-7.1
RSTRNT1	-4.3	-1.4	-48.4	-15.3

The annual reduction in energy use shown in Table 17-11 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 6.2 GWh (21.0 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 retail stores realizing the greatest reduction. The adoption of the LEC design as the state's energy code for commercial buildings would save 39.7 GWh (135.6 GBtu) of total statewide energy use annually for one year's worth of new construction for these building types.

Table 17-11 Statewide Change in Annual Energy Use for One Year of Construction, South Carolina

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition			
				2007		LEC	
				kWh	kBtu	kWh	kBtu
APART04	44.9 %	178	1917	-1 080 991	-3 690 967	-4 187 110	-14 296 595
APART06	55.1 %	218	2348	-1 165 791	-3 980 513	-5 352 445	-18 275 548
HOTEL15	100.0 %	113	1211	947 358	3 234 687	-1 082 794	-3 697 126
HIGHS02	100.0 %	444	4784	-1 175 449	-4 013 487	-9 326 327	-31 844 092
OFFIC03	37.4 %	115	1240	-305 956	-1 044 666	-2 824 215	-9 643 083
OFFIC08	40.4 %	124	1337	-332 088	-1 133 892	-2 717 279	-9 277 959
OFFIC16	22.2 %	68	736	470 275	1 605 720	-1 016 146	-3 469 559
RETAIL1	100.0 %	520	5597	-3 370 718	-11 509 082	-11 580 978	-39 542 437
RSTRNT1	100.0 %	34	362	-143 765	-490 876	-1 626 635	-5 554 033
Total		**1814**	**19 531**	**-6 157 126**	**-21 023 076**	**-39 713 929**	**-135 600 432**

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

Assuming that the buildings considered in this study, which represent 66.8 % 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 statewide savings to be 9.2 GWh (31.5 GBtu) and 59.5 GWh (203.0 GBtu) per year for adoption of the *ASHRAE 90.1-2007* and LEC designs, respectively. These savings imply 92.2 GWh (314.7 GBtu) and 594.5 GWh (2029.9 GBtu) in energy use savings over the 10-year study period.

The relative reduction in energy use across building types is consistent across building designs. The greatest total reductions are realized by retail stores and high schools because they represent 28.7 % and 24.5 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent less than 12.0 %. 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 -- rank 4th and 9th in percentage reduction, respectively, among the 11 building types, as reported in Table 17-2.

17.2.2 Energy Costs

Table 17-12 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 17-12 Average Per Unit Change in Energy Costs, 10-Year, South Carolina

Building Type	Standard Edition			
	2007		LEC	
	$/m^2	$/ft^2	$/m^2	$/ft^2
APART04	-$4.80	-$0.45	-$17.76	-$1.65
APART06	-$4.64	-$0.43	-$19.19	-$1.78
DORMI04	-$2.54	-$0.24	-$12.66	-$1.18
DORMI06	-$6.93	-$0.64	-$22.63	-$2.10
HOTEL15	$3.34	$0.31	-$9.82	-$0.91
HIGHS02	-$1.67	-$0.15	-$17.02	-$1.58
OFFIC03	-$1.74	-$0.16	-$16.96	-$1.58
OFFIC08	-$1.46	-$0.14	-$14.93	-$1.39
OFFIC16	$2.96	$0.28	-$12.46	-$1.16
RETAIL1	-$3.48	-$0.32	-$14.45	-$1.34
RSTRNT1	-$2.68	-$0.25	-$33.18	-$3.08

Table 17-13 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: $4.3 million and $29.3 million for adopting *ASHRAE 90.1-2007* and LEC, respectively. The increase in energy use for the high-rise buildings leads to an increase in energy costs for those buildings for *ASHRAE 90.1-2007*. All building types realize energy cost savings for the LEC design. The energy cost savings are highly correlated with the energy use savings. Assuming that the buildings considered in this study, which represent 66.8 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC design can be extrapolated to estimate the total statewide energy cost savings of $6.5 million and $43.8 million over the 10-year study period, respectively.

Table 17-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, South Carolina

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	178	1917	-$854 237	-$3 161 825
APART06	55.1 %	218	2348	-$1 012 813	-$4 184 680
HOTEL15	100.0 %	113	1211	$376 368	-$1 104 759
HIGHS02	100.0 %	444	4784	-$771 184	-$7 538 010
OFFIC03	37.4 %	115	1240	-$192 046	-$1 960 790
OFFIC08	40.4 %	124	1337	-$181 043	-$1 854 863
OFFIC16	22.2 %	68	736	$202 524	-$851 553
RETAIL1	100.0 %	520	5597	-$1 809 081	-$7 515 956
RSTRNT1	100.0 %	34	362	-$90 132	-$1 115 740
Total		**1814**	**19 531**	**-$4 331 644**	**-$29 288 176**

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

17.2.3 Energy-related Carbon Emissions

Table 17-14 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 17-14 Average Per Unit Change in Carbon Emissions, 10-Year, South Carolina

Building Type	Standard Edition			
	2007		LEC	
	kg/m^2	lb/ft^2	kg/m^2	lb/ft^2
APART04	-45.4	-9.3	-167.4	-34.3
APART06	-44.4	-9.1	-181.5	-37.2
DORMI04	-25.0	-5.1	-120.0	-24.6
DORMI06	-65.8	-13.5	-214.0	-43.8
HOTEL15	28.7	5.9	-95.0	-19.5
HIGHS02	-16.1	-3.3	-161.0	-33.0
OFFIC03	-15.4	-3.2	-159.1	-32.6
OFFIC08	-13.2	-2.7	-139.3	-28.5
OFFIC16	25.8	5.3	-118.7	-24.3
RETAIL1	-31.5	-6.4	-134.0	-27.5
RSTRNT1	-24.7	-5.1	-309.6	-63.4

Table 17-15 applies the Table 17-14 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 40 540 metric tons over a 10-year study period. The adoption of the LEC design decreases carbon emissions by 275 489 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 60 689 metric tons and 412 409 metric tons over the 10-year study period, respectively.

Table 17-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, South Carolina – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition	
				2007	LEC
APART04	44.9 %	178	1917	-8091	-29 813
APART06	55.1 %	218	2348	-9676	-39 594
HOTEL15	100.0 %	113	1211	3225	-10 691
HIGHS02	100.0 %	444	4784	-7160	-71 548
OFFIC03	37.4 %	115	1240	-1774	-18 324
OFFIC08	40.4 %	124	1337	-1641	-17 302
OFFIC16	22.2 %	68	736	1764	-8110
RETAIL1	100.0 %	520	5597	-16 356	-69 696
RSTRNT1	100.0 %	34	362	-832	-10 413
Total		**1814**	**19 531**	**-40 540**	**-275 489**

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

17.2.4 Life-Cycle Costs

Table 17-16 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 17-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, South Carolina

Building Type	Standard Edition			
	2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²
APART04	-$5.05	-$0.47	-$0.64	-$0.06
APART06	-$4.66	-$0.43	-$1.46	-$0.14
DORMI04	-$4.08	-$0.38	-$10.84	-$1.01
DORMI06	-$6.54	-$0.61	-$6.81	-$0.63
HOTEL15	$4.69	$0.44	$8.10	$0.75
HIGHS02	$1.68	$0.16	-$9.48	-$0.88
OFFIC03	-$4.54	-$0.42	-$14.73	-$1.37
OFFIC08	-$5.11	-$0.47	-$16.54	-$1.54
OFFIC16	$3.33	$0.31	$6.90	$0.64
RETAIL1	-$0.34	-$0.03	$1.20	$0.11
RSTRNT1	-$6.12	-$0.57	-$51.43	-$4.78

Table 17-17 applies the Table 17-16 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 $2.0 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 $8.1 million, while reducing life-cycle costs for 6 of 9 building types. The *ASHRAE 90.1-2007* and the LEC designs both lead to an increase in life-cycle costs for hotels and 16-story office buildings. The LEC design also increases life-cycle costs for retail stores. 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 $2.9 million and $12.2 million over the 10-year study period, respectively.

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

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition 2007	Standard Edition LEC
APART04	44.9 %	178	1917	-$899 772	-$113 854
APART06	55.1 %	218	2348	-$1 015 642	-$319 135
HOTEL15	100.0 %	113	1211	$528 024	$911 168
HIGHS02	100.0 %	444	4784	$745 786	-$4 212 504
OFFIC03	37.4 %	115	1240	-$523 144	-$1 696 577
OFFIC08	40.4 %	124	1337	-$634 651	-$2 054 774
OFFIC16	22.2 %	68	736	$227 732	$471 565
RETAIL1	100.0 %	520	5597	-$178 253	$626 409
RSTRNT1	100.0 %	34	362	-$205 810	-$1 729 530
Total		**1814**	**19 531**	**-$1 955 729**	**-$8 117 233**

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

17.3 State Summary

South Carolina is one of two states in the South 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. 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 92.2 GWh (314.7 GBtu), energy cost savings of $6.5 million, carbon emissions reductions of 60 689 metric tons, and life-cycle cost savings of $2.9 million. The LEC design would lead to even greater impactswith savings of 594.5 GWh (2029.9 GBtu), energy cost savings of $43.8 million, carbon emissions reductions of 412 409 metric tons for one year's worth of commercial building construction while decreasing life-cycle costs by $12.2 million.

18 Tennessee

Tennessee is one of two states in the South Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings, is located in the East South Central Census Division, and spans two climate zones (Zone 3A and Zone 4A). Table 18-1 provides an overview of Tennessee's simulated energy use keyed to building type and energy standard edition. Average energy use varies across building types and building designs. The 8-story office building uses the least amount of energy at 80 kWh/m^2 to 104 kWh/m^2 (25 kBtu/ ft^2 to 33 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 157 kWh/m^2 to 180 kWh/m^2 (50 kBtu/ ft^2 to 57 $kBtu/ft^2$) annually.

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

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	141	45	136	43	118	37
APART06	139	44	135	43	115	37
DORMI04	104	33	100	32	86	27
DORMI06	152	48	148	47	127	40
HOTEL15	127	40	135	43	115	37
HIGHS02	180	57	175	55	157	50
OFFIC03	109	35	104	33	81	26
OFFIC08	104	33	100	32	80	25
OFFIC16	131	42	139	44	115	36
RETAIL1	118	37	108	34	90	29
RSTRNT1	161	51	154	49	108	34

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

18.1 Percentage Savings

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

18.1.1 Energy Use

Table 18-2 shows a large variation in percentage changes in energy use for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 6.4 % to -8.4 % with an average of -2.3 %. For the high-rise, 100 % glazed buildings (16-story office building and 15-story hotel), *ASHRAE 90.1-2007* is actually less energy efficient than *ASHRAE 90.1-2004* because the maximum window U-factor and SHGC requirements in Zone 3A and Zone 4A 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 18-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, Tennessee

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

The LEC design realizes greater percentage changes in energy use relative to *ASHRAE 90.1-2004,* ranging from -9.6 % to -32.9 % with an average of -18.8 %. Similar to the *ASHRAE 90.1-2007* design, the smallest reductions in energy use for the LEC design occur in the 16-story office building and hotel. 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.

18.1.2 Energy Costs

Table 18-3 shows significant variation in the percentage changes in average energy costs for *ASHRAE 90.1-2007* relative to *ASHRAE 90.1-2004*, ranging from 6.8 % to -5.3 % depending on the building type, with an average of -1.2 %. As with energy use savings, adopting *ASHRAE 90.1-2007* results in an increase in energy costs relative to *ASHRAE 90.1-2004* for the two high-rise buildings. For these two building types, the percentage increase in energy costs is larger than the increase in energy use because electricity consumption increases while decreasing natural gas consumption. The offset of natural gas with electricity increases energy costs because electricity is more expensive per unit of energy. Eight of the remaining nine building types realize smaller percentage reductions in energy costs than the reductions in energy use because adopting the *ASHRAE 90.1-2007* design decreases natural gas consumption by a greater percentage than electricity consumption. Only the 6-story dormitory realizes a slightly greater reduction in energy costs than its reduction in energy use because electricity consumption decreases by a greater percentage than natural gas consumption.

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

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

The LEC design realizes greater reductions in energy costs than the *ASHRAE 90.1-2007* design, with the average percentage change by building type ranging from -13.6 % to -35.6 % with an overall average of -21.9 % for 10 years of building operation. The reductions in energy costs are greater than the reductions in energy use for 9 of 11 building types. For these building types, electricity consumption is decreased by a greater percentage than natural gas consumption, which leads to additional reductions in energy costs. The remaining two building types see percentage reductions in energy costs that are marginally smaller than the reductions in energy use because adoption of the LEC design decreases natural gas consumption by a greater percentage than electricity consumption.

18.1.3 Energy-related Carbon Emissions

Table 18-4 shows significant variation in the average percentage change in energy-related carbon emissions for the *ASHRAE 90.1-2007* design across building types, ranging from 6.9 % to -4.9 % with an average of -1.0 %. The LEC design leads to significant changes in average carbon emissions, ranging from -14.3 % to -36.1 % depending on the building type with an average of -22.5 % across all building types. As would be expected, a more energy efficient building design results in greater reductions in carbon emissions.

However, the carbon emissions reductions (increases) are smaller (larger) than the energy use reductions (increases) for 10 of the 11 building types for the *ASHRAE 90.1-2007* design. Similar to the reductions in energy costs, this result is due to the fuel source of the reductions in energy use. For the eight building types that realize smaller reductions in carbon emissions than energy use, the percentage reduction in natural gas consumption is greater than the reduction in electricity. For the two building types that realize a greater percentage increase in carbon emissions than energy use, natural gas consumption is decreased while electricity consumption is increased. Similarly, the LEC design realizes a greater percentage reduction in natural gas consumption than electricity consumption for 2 of 11 building types. The remaining building type for the *ASHRAE 90.1-2007* design and 9 building types for the LEC design realize greater percentage reductions in electricity consumption than natural gas consumption.

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

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

18.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 18-5. Based on the life-cycle costs over a 10-year study period, the *ASHRAE 90.1-2007* design realizes the lowest life-cycle costs for 3 building types while the LEC design has the lowest life-cycle costs for 6 building types. The current state energy code, *ASHRAE 90.1-2004*, results in lower life-cycle costs for the hotel and 16-story office building.

For 9 building types, *ASHRAE 90.1-2007* leads to small percentage reductions in life-cycle costs (-0.9 % or less). The high-rise buildings are the only buildings that realize increases in life-cycle costs. Given that 9 building types realize a percentage decrease in life-cycle costs, it is likely that *ASHRAE 90.1-2007* will decrease total life-cycle costs.

The LEC design results in reductions in life-cycle costs for 9 building types for a 10-year study period. The percentage change in life-cycle costs ranges from -7.7 % to 0.8 %.

Based on the overall average percentage change of -1.4 % in life-cycle costs, the LEC design is likely to be cost-effective 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, Tennessee

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

18.1.5 City Comparisons

Simulations are run for 5 cities located in Tennessee: Memphis in Zone 3A and Bristol, Chattanooga, Knoxville, and Nashville in Zone 4A. The results vary across cities within the state for several reasons. First, the state is covered by two climate zones. The *ASHRAE 90.1* building design requirements vary across climate zone, and will impact the relative energy efficiency of the building. Second, cities within the same climate zone still have some variation in the local climate, which can lead to variation in energy consumption. Third, construction material and labor costs vary by locality.

As can be seen in Table 18-6, the average reduction in energy use for all building types from adopting newer energy standard editions varies little both across and within climate zones. For the *ASHRAE 90.1-2007* design, the percentage change in average energy use ranges from -1.4 % to -2.8 % with an average of -2.3 %. For the LEC design, the percentage change in average energy use ranges from -17.8 % to -19.4 % with an average of -18.8 %. Across both building design alternatives, the warmer climate zone (Zone 3A) realizes slightly lower reductions in energy use than the colder climate zone (Zone 4A).

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

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

The variations in energy costs across cities are a result of two factors, the reductions in energy use and the fuel source of the reduction. Table 18-7 shows that the average reduction in energy costs for all building types varies minimally across and within climate zones. For the *ASHRAE 90.1-2007* design, the percentage change in average energy costs ranges from -0.7 % to -2.6 % with an average of -1.2 %. The average percentage change in energy costs are greater in Zone 3A (-2.6 %) than Zone 4A (-0.8 %). For the LEC design, the percentage change in average energy costs ranges from -21.3 % to -22.1 % with an average of -21.9 %. Zone 3A realizes slightly greater changes in energy use (-22.1 %) than Zone 4A (-21.9 %).

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

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

Table 18-8 reports energy-related carbon emissions by city for the state. For all cities, the more energy efficient designs result in greater reduction in carbon emissions. The city in Zone 3A realizes a slightly greater average percentage change in carbon emissions than the cities in Zone 4A for *ASHRAE 90.1-2007*, -2.9 % versus -1.0 %. The average emissions reduction does not significantly vary across cities for the LEC design, ranging from 22.4 % to 23.3 %.

Table 18-8 Average Percentage Change in Carbon Emissions by City, Tennessee

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

The data reported in Table 18-9 show that the *ASHRAE 90.1-2007* design decreases life-cycle costs across all cities, with changes in life-cycle costs ranging minimally from -0.2 % to -0.4 %. The LEC design realizes the greatest reduction in life-cycle costs across all cities in the state. There is no significant difference between the average percentage changes in life-cycle costs across climate zones.

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

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

18.2 Total Savings

How much can Tennessee save, in terms of energy use, energy costs, and carbon emissions, from adopting a more stringent state energy code for commercial buildings? What are the life-cycle costs associated with the new energy code adoption? To answer these questions, it is 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.[39] The reduction per m^2 (ft^2) is multiplied by the

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

estimated 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 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.[40]

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

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

The annual reduction in energy use shown in Table 18-11 ranges widely across building designs, but the *ASHRAE 90.1-2007* and LEC designs both decrease total statewide energy use across the state. The adoption of the *ASHRAE 90.1-2007* design results in reductions of 10.1 GWh (34.4 GBtu) annually. *ASHRAE 90.1-2007* increases total energy use for the two high-rise buildings and decreases total energy use for the other 7 building types.

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

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

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

Note: Dormitories are excluded because no 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 47.2 GWh (161.1 GBtu) of total statewide energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 58.4 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results can be extrapolated to estimate the statewide savings to be 80.8 GWh (275.8 GBtu) per year. These savings imply over 807.8 GWh (2758.3 GBtu) in energy savings over the 10-year study period.

The relative reduction in energy use across building types is consistent across building designs. The greatest total reductions are realized by retail stores and high schools because they represent 37.5 % and 18.9 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 9.7 % or less. The amount of new construction overwhelms the relative percentage changes in energy use. The building types that lead to the greatest estimated reductions in energy use for the LEC design -- retail stores and high schools -- only rank 4th and 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, Tennessee

Building Type	Standard Edition			
	2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²
APART04	-$2.88	-$0.27	-$17.37	-$1.61
APART06	-$2.47	-$0.23	-$19.35	-$1.80
DORMI04	-$1.83	-$0.17	-$13.12	-$1.22
DORMI06	-$2.17	-$0.20	-$20.21	-$1.88
HOTEL15	$5.11	$0.47	-$10.34	-$0.96
HIGHS02	-$2.46	-$0.23	-$19.86	-$1.84
OFFIC03	-$1.95	-$0.18	-$19.65	-$1.83
OFFIC08	-$1.37	-$0.13	-$17.07	-$1.59
OFFIC16	$6.06	$0.56	-$13.46	-$1.25
RETAIL1	-$4.16	-$0.39	-$17.60	-$1.63
RSTRNT1	-$3.07	-$0.29	-$38.03	-$3.53

Table 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. Overall, reductions in energy costs are greater for the more energy efficient building designs: $3.8 million and $34.3 million for adopting *ASHRAE 90.1-2007* and LEC, respectively. The increase in energy use for the high-rise buildings leads to an increase in energy costs for those buildings for *ASHRAE 90.1-2007*. All building types realize energy cost savings for the LEC design. The energy cost savings are highly correlated with the energy use savings. Assuming that the buildings considered in this study, which represent 58.4 % of all new commercial floor space in the state, are generally representative of the entire new commercial building stock in the state, the results for *ASHRAE 90.1-2007* and LEC can be extrapolated to estimate the total statewide energy cost savings of $6.5 million and $58.7 million over the 10-year study period, respectively.

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

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

Note: Dormitories are excluded because no 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, Tennessee

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	-29.4	-6.0	-186.9	-38.3
APART06	-25.5	-5.2	-209.5	-42.9
DORMI04	-18.2	-3.7	-140.1	-28.7
DORMI06	-22.9	-4.7	-219.5	-45.0
HOTEL15	54.2	11.1	-112.6	-23.1
HIGHS02	-23.8	-4.9	-216.7	-44.4
OFFIC03	-18.3	-3.7	-209.2	-42.9
OFFIC08	-12.1	-2.5	-181.3	-37.1
OFFIC16	64.8	13.3	-146.5	-30.0
RETAIL1	-39.9	-8.2	-184.6	-37.8
RSTRNT1	-29.5	-6.0	-405.3	-83.0

Table 18-15 applies the Table 18-14 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

35 084 metric tons over a 10-year study period. The adoption of the LEC design decreases carbon emissions by 366 027 metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC designs can be extrapolated to estimate statewide reduction in carbon emissions of 60 076 metric tons and 626 759 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, Tennessee – Metric Tons

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

Note: Dormitories are excluded because no 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, Tennessee

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

Table 18-17 applies the Table 18-16 results to one year's worth of new building construction in the state to estimate the change in statewide life-cycle costs from adoption of more energy-efficient codes. *ASHRAE 90.1-2007* results in total reductions in life-cycle costs of $4.4 million over the 10-year study period relative to *ASHRAE 90.1-2004* for the building types considered in this study. The LEC design leads to a decrease in total statewide life-cycle costs of $16.4 million, while reducing life-cycle costs for 7 of 9 building types. The *ASHRAE 90.1-2007* and the LEC designs lead to an increase in life-cycle costs for hotels and 16-story office buildings. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2007* and LEC designs can be extrapolated to estimate the total reductions in life-cycle costs of $7.5 million and $28.1 million over the 10-year study period, respectively.

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

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

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

18.3 State Summary

Tennessee is one of two states in the South 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. 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 172.6 GWh (589.5 GBtu), energy cost savings of $6.5 million, carbon emissions reductions of 66 072 metric tons, and life-cycle cost savings of $7.5 million. The life-cycle cost savings are greater than the energy cost savings. The relaxation of the U-factor 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 impactswith savings of 807.8 GWh (2758.3 GBtu), energy cost savings of $58.7 million, and carbon emissions reductions of 689 317 metric tons while decreasing life-cycle costs by $28.1 million for one year's worth of commercial building construction.

19 Texas

Texas has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, is located in the West South Central Census Division, and spans three climate zones (Zone 2, Zone 3, and Zone 4). Table 19-1 provides an overview of Texas'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 80 kWh/m^2 to 95 kWh/m^2 (25 $kBtu/ft^2$ to 30 $kBtu/ft^2$) annually. The high school uses the greatest amount of energy at 122 kWh/m^2 to 142 kWh/m^2 (39 $kBtu/ft^2$ to 45 $kBtu/ft^2$) annually.

Table 19-1 Average Annual Energy Use by Building Type and Standard Edition, Texas

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	124	39	106	34
APART06	125	40	105	33
DORMI04	95	30	80	25
DORMI06	134	43	112	36
HOTEL15	118	37	100	32
HIGHS02	142	45	122	39
OFFIC03	106	34	83	26
OFFIC08	104	33	83	26
OFFIC16	131	41	109	35
RETAIL1	107	34	91	29
RSTRNT1	153	48	107	34

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

19.1 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 Texas.

19.1.1 Statewide Building Comparison

Table 19-2 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 -14.7 % to -29.8 % depending on the building type with an overall average of -17.8 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 19-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Texas

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-15.0	-18.6	-18.6	0.0
APART06	-16.3	-20.6	-20.6	-0.2
DORMI04	-15.5	-18.6	-18.7	-0.9
DORMI06	-16.3	-20.9	-20.9	-0.6
HOTEL15	-14.9	-19.6	-19.6	0.0
HIGHS02	-14.7	-21.0	-21.1	-1.7
OFFIC03	-21.7	-23.1	-23.1	-1.9
OFFIC08	-19.9	-20.5	-20.5	-2.6
OFFIC16	-16.8	-19.1	-19.1	-0.1
RETAIL1	-15.3	-16.5	-16.5	0.0
RSTRNT1	-29.8	-33.2	-33.2	-5.9
Average	**-17.8**	**-21.0**	**-21.1**	**-1.3**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.5 % to -33.2 % depending on the building type with an average of -21.0 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. In fact, 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 20.4 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 42.9 % greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 2 through Zone 4, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.5 % to -33.2 % with an average of -21.1 %. 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 -5.9 % to 0.0 % for a 10-year study period. Eight of the 11 building types realize reductions in life-cycle costs. Based on the overall average percentage change of -1.3 % in life-cycle costs, the LEC design may be cost-effective for the state to adopt as its state energy code.

19.1.2 City Comparisons

Simulations are run for nineteen cities located in Texas: Austin, Brownsville, Corpus Christi, Houston, Lufkin, Port Arthur, San Antonio, Victoria, and Waco in Zone 2A, Del Rio in Zone 2B, Fort Worth and Wichita Falls in Zone 3A, Abilene, El Paso, Lubbock, Midland, and San Angelo in Zone 3B, and Amarillo in Zone 4B. The results vary across cities within the state for several reasons. First, the state is covered by three climate zones and six climate subzones (five of which are represented by the cities selected for this study). 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 19-3 shows the percentage change in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for the LEC design relative to *ASHRAE 90.1-2007* for each city in the state. The average percentage changes in energy use for all building types from adopting the LEC design varies across cities, ranging from -16.6 % to -19.5 % with an overall average of -17.8 %. The minimal variation occurs within each climate zone while there is no distinct variation across climate zones.

Table 19-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Texas

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Austin	2A	-17.2	-20.3	20.6	-1.0
Brownsville	2A	-19.2	-20.1	20.4	-1.5
Corpus Christi	2A	-19.5	-20.7	21.0	-1.2
Houston	2A	-17.5	-20.3	20.6	-1.1
Lufkin	2A	-17.3	-20.7	21.1	-1.4
Port Arthur	2A	-17.9	-20.4	20.8	-1.1
San Antonio	2A	-18.0	-21.0	21.4	-1.1
Victoria	2A	-18.9	-20.7	21.0	-1.3
Waco	2A	-16.6	-20.4	20.8	-1.0
Del Rio	2B	-17.6	-20.0	20.3	-1.6
Fort Worth	3A	-18.1	-21.2	21.5	-1.2
Wichita Falls	3A	-16.6	-20.7	21.0	-1.2
Abilene	3B	-18.1	-21.8	22.1	-1.3
El Paso	3B	-19.4	-22.9	23.2	-1.4
Lubbock	3B	-16.6	-21.5	21.9	-1.3
Midland	3B	-18.0	-22.0	22.4	-1.4
San Angelo	3B	-17.8	-21.7	22.0	-1.4
Amarillo	4B	-16.8	-22.5	22.8	-1.1
Average		**-17.8**	**-21.0**	**21.4**	**-1.3**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -20.1 % to -22.9 % for 10 years of operation. For all cities, reductions in energy costs are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Repeating the pattern, the average percentage change in carbon emissions for all building types also varies minimally across cities, ranging from -20.3 % to -23.2 %. Cities located in colder climate zones tend to realize slightly greater percentage reductions in energy costs and carbon emissions. The change in life-cycle costs for all building types range from –1.0 % to -1.6 %. There is no trend across climate zones in percentage changes in life-cycle costs.

19.2 Total Savings

How much can Texas 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.

19.2.1 Energy Use

Table 19-4 reports the average per unit change in annual energy use by building type and building design in the state.[41] 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 19-5 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.[42]

Table 19-4 Average Per Unit Change in Annual Energy Use, Texas

Building Type	Standard Edition	
	LEC	
	kWh/m²	kBtu/ft²
APART04	-18.6	-5.9
APART06	-20.3	-6.4
DORMI04	-14.7	-4.7
DORMI06	-21.9	-6.9
HOTEL15	-17.4	-5.5
HIGHS02	-23.1	-7.3
OFFIC03	-20.5	-6.5
OFFIC08	-20.7	-6.6
OFFIC16	-21.9	-7.0
RETAIL1	-16.3	-5.2
RSTRNT1	-45.5	-14.4

The adoption of the LEC design as the state's energy code for commercial buildings would save energy for all building types and 173.0 GWh (590.7 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 61.1 % 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 statewide savings to be 283.2 GWh (966.8 GBtu) per year. These savings imply 2.8 TWh (9.7 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 high schools and retail stores because they represent 28.8 % and 29.7 %, respectively, of the combined new construction in the state for the building types in this study while all other building

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

types represent 8.1 % 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 -- high schools and retail stores -- only rank 11th and 8th in percentage reduction, respectively, among the 11 building types, as reported in Table 19-2.

Table 19-5 Statewide Change in Annual Energy Use for One Year of Construction, Texas

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	499	5369	-9 280 450	-31 687 447
APART06	55.1 %	611	6576	-12 401 563	-42 344 267
HOTEL15	100.0 %	714	7687	-12 459 650	-42 542 602
HIGHS02	100.0 %	2539	27 326	-51 932 945	-177 321 406
OFFIC03	37.4 %	623	6710	-14 376 078	-49 086 112
OFFIC08	40.4 %	672	7236	-13 906 567	-47 483 001
OFFIC16	22.2 %	370	3982	-8 116 630	-27 713 666
RETAIL1	100.0 %	2624	28 248	-42 806 401	-146 159 461
RSTRNT1	100.0 %	170	1828	-7 732 107	-26 400 737
Total		**8822**	**94 962**	**-173 012 391**	**-590 738 700**

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

19.2.2 Energy Costs

Table 19-6 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 19-6 Average Per Unit Change in Energy Costs, 10-Year, Texas

Building Type	Standard Edition LEC	
	$/m²	$/ft²
APART04	-$15.32	-$1.42
APART06	-$17.06	-$1.58
DORMI04	-$11.97	-$1.11
DORMI06	-$18.52	-$1.72
HOTEL15	-$14.76	-$1.37
HIGHS02	-$18.03	-$1.68
OFFIC03	-$18.53	-$1.72
OFFIC08	-$15.92	-$1.48
OFFIC16	-$17.70	-$1.64
RETAIL1	-$12.61	-$1.17
RSTRNT1	-$35.39	-$3.29

Table 19-7 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 $143.3 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 61.1 % 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 $234.5 million over the 10-year study period.

Table 19-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Texas

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition LEC
APART04	44.9 %	499	5369	-$7 639 249
APART06	55.1 %	611	6576	-$10 419 606
HOTEL15	100.0 %	714	7687	-$10 538 466
HIGHS02	100.0 %	2539	27 326	-$47 049 343
OFFIC03	37.4 %	623	6710	-$11 242 491
OFFIC08	40.4 %	672	7236	-$10 703 434
OFFIC16	22.2 %	370	3982	-$6 548 979
RETAIL1	100.0 %	2624	28 248	-$33 098 893
RSTRNT1	100.0 %	170	1828	-$6 011 319
Total		**8822**	**94 962**	**-$143 251 781**

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

19.2.3 Energy-related Carbon Emissions

Table 19-8 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 19-8 Average Per Unit Change in Carbon Emissions, 10-Year, Texas

Building Type	Standard Edition	
	LEC	
	kg/m²	lb/ft²
APART04	-171.8	-35.2
APART06	-191.4	-39.2
DORMI04	-134.3	-27.5
DORMI06	-207.9	-42.6
HOTEL15	-165.6	-33.9
HIGHS02	-208.1	-42.6
OFFIC03	-202.2	-41.4
OFFIC08	-178.5	-36.6
OFFIC16	-198.6	-40.7
RETAIL1	-141.4	-29.0
RSTRNT1	-396.8	-81.3

Table 19-9 applies the Table 19-8 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 1.6 million metric tons over the 10-year study period for one year's worth of new commercial construction for these building types. Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the LEC design can be extrapolated to estimate statewide reductions in carbon emissions of 2.6 million metric tons over the 10-year study period.

Table 19-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Texas – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	499	5369	-85 703
APART06	55.1 %	611	6576	-116 917
HOTEL15	100.0 %	714	7687	-118 258
HIGHS02	100.0 %	2539	27 326	-528 288
OFFIC03	37.4 %	623	6710	-126 064
OFFIC08	40.4 %	672	7236	-120 000
OFFIC16	22.2 %	370	3982	-73 457
RETAIL1	100.0 %	2624	28 248	-371 102
RSTRNT1	100.0 %	170	1828	-67 402
Total		**8822**	**94 962**	**-1 607 192**

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

19.2.4 Life-Cycle Costs

Table 19-10 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 19-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Texas

Building Type	Standard Edition LEC $/$m^2$	Standard Edition LEC $/$ft^2$
APART04	$0.09	$0.01
APART06	-$1.50	-$0.14
DORMI04	-$7.55	-$0.70
DORMI06	-$4.98	-$0.46
HOTEL15	$0.46	$0.04
HIGHS02	-$12.18	-$1.13
OFFIC03	-$14.09	-$1.31
OFFIC08	-$19.60	-$1.82
OFFIC16	-$0.41	-$0.04
RETAIL1	$0.25	$0.02
RSTRNT1	-$72.31	-$6.72

Table 19-11 applies the Table 19-10 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 types, with 6 of 9 building types realizing reductions in life-cycle costs. Overall, the LEC design results in a decrease of $65.2 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. High schools, 8-story office buildings, and restaurants realize the greatest statewide decreases in life-cycle costs ($30.9 million, $13.2 million, and $12.3 million, respectively) while retail stores and hotels realize the greatest increases in life-cycle costs ($646 364 and $327 534, 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 $106.8 million over the 10-year study period.

Table 19-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Texas

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	499	5369	$42 775
APART06	55.1 %	611	6576	-$916 202
HOTEL15	100.0 %	714	7687	$327 534
HIGHS02	100.0 %	2539	27 326	-$30 931 583
OFFIC03	37.4 %	623	6710	-$8 784 412
OFFIC08	40.4 %	672	7236	-$13 174 568
OFFIC16	22.2 %	370	3982	-$151 888
RETAIL1	100.0 %	2624	28 248	$646 364
RSTRNT1	100.0 %	170	1828	-$12 283 188
Total		**8822**	**94 962**	**-$65 225 168**

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

19.3 State Summary

Texas 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 2.8 TWh (9.7 TBtu), energy cost savings of $234.5 million, and carbon emissions reductions of 2.6 million metric tons while decreasing life-cycle costs by $106.8 million for one year's worth of commercial building construction.

20 Virginia

Virginia has adopted *ASHRAE 90.1-2007* as its state energy code for commercial buildings, and is located in the South Atlantic Census Division and Climate Zone 4A. Table 20-1 provides an overview of Virginia'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 162 kWh/m^2 to 179 kWh/m^2 (52 $kBtu/ft^2$ to 57 $kBtu/ft^2$) annually.

Table 20-1 Average Annual Energy Use by Building Type and Standard Edition, Virginia

Building Type	Standard Edition			
	2007		LEC	
	kWh/m^2	$kBtu/ft^2$	kWh/m^2	$kBtu/ft^2$
APART04	135	43	118	37
APART06	135	43	116	37
DORMI04	98	31	84	27
DORMI06	149	47	128	41
HOTEL15	137	44	117	37
HIGHS02	179	57	162	52
OFFIC03	102	32	79	25
OFFIC08	98	31	78	25
OFFIC16	141	45	115	37
RETAIL1	106	34	89	28
RSTRNT1	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 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.

20.1 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 Virginia.

20.1.1 Statewide Building Comparison

Table 20-2 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 -9.2 % to -30.3 % depending on the building type with an overall average of -17.0 %. High schools realize the lowest reduction in energy use while restaurants realize the greatest reduction in energy use.

Table 20-2 Average Percentage Change from Adoption of Newer Standard Editions, 10-Year, Virginia

Building Type	LEC			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-12.6	-17.0	-18.1	0.5
APART06	-14.4	-20.0	-21.3	0.3
DORMI04	-14.3	-17.9	-18.7	-0.7
DORMI06	-14.2	-19.6	-20.8	0.0
HOTEL15	-14.9	-18.8	-19.8	0.4
HIGHS02	-9.2	-16.4	-18.3	-0.6
OFFIC03	-22.1	-24.1	-24.5	-2.2
OFFIC08	-20.8	-21.7	-21.9	-2.2
OFFIC16	-18.0	-20.6	-21.1	0.4
RETAIL1	-16.1	-18.2	-18.7	0.5
RSTRNT1	-30.3	-34.0	-34.8	-5.4
Average	**-17.0**	**-20.8**	**-21.6**	**-0.8**

There is a significant variation in the average percentage change in energy costs for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -16.4 % to -34.0 % depending on the building type with an average of -20.8 % for 10 years of building operation. The energy costs are reduced by a greater percentage than energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. For 10 of the 11 building types, the energy efficiency measures increase natural gas consumption while decreasing electricity consumption. The shift is most prevalent for the high school, where the increase in natural gas consumption offsets 37.0 % of the reduction in electricity consumption, and results in a percentage reduction in energy costs that is 78.3 % greater than the percentage reduction in energy use. The LEC design incorporates daylighting and overhangs into the building design for cities in Zone 4, which decreases the building's internal and external heat gains, respectively. The shift in energy use from electricity to natural gas consumption to meet the greater heating loads decreases energy costs because natural gas is cheaper on a per unit of energy basis relative to electricity.

There is significant variation in the average change in energy-related carbon emissions across building types for the LEC design relative to *ASHRAE 90.1-2007*, ranging from -18.1 % to -34.8 % with an average of -21.6 %. For the LEC design, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use for all 11 building types because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. The greater relative reduction in electricity leads to a greater reduction in carbon emissions because natural gas has a lower average carbon emissions rate than electricity. As mentioned above, the energy efficiency measures decrease electricity consumption while increasing natural gas consumption for 10 of the 11 building types. The combination of the reduction in total energy use and the shift in energy use from electricity consumption to natural gas consumption leads to even greater reductions in carbon emissions.

The percentage change in life-cycle costs varies across building types, ranging from -5.4 % to 0.5 % 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 -0.8 % in life-cycle costs, the LEC design may be cost-effective if the state adopted it as its state energy code for commercial buildings.

20.1.2 City Comparisons

Simulations are run for four cities located in Virginia, all of which are located in Zone 4A: Lynchburg, Norfolk, Richmond, and Roanoke. While the four 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 20-3 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 -16.5 % to -17.6 %. Any variation in local climate appears to have minimal effects on energy consumption.

Table 20-3 Average Percentage Change from Adoption of Newer Standard Editions by City, 10-Year, Virginia

Cities	Zone	LEC			
		Energy Use	Energy Cost	Carbon	LCC
Lynchburg	4A	-16.5	-20.7	-21.9	-0.9
Norfolk	4A	-17.6	-20.8	-21.9	-0.7
Richmond	4A	-16.8	-20.5	-21.6	-0.6
Roanoke	4A	-17.0	-20.9	-22.1	-1.1
Average		**-17.0**	**-20.8**	**-21.9**	**-0.8**

The average percentage change in energy costs for all building types also varies minimally across cities, ranging from -20.5 % to -20.9 % for 10 years of operation. Repeating the pattern, the average percentage change in carbon emissions across cities ranges only from -21.6 % to -22.1 %. For all cities, reductions in energy costs and carbon emissions are greater than reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. The percentage change in life-cycle costs for all building types ranges from -1.1 % to -0.6 %, driven by variation in local construction costs across the state.

20.2 Total Savings

How much can Virginia 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.

20.2.1 Energy Use

Table 20-4 reports the average per unit change in annual energy use by building type and building design in the state.[43] 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 20-5 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.[44]

Table 20-4 Average Per Unit Change in Annual Energy Use, Virginia

Building Type	Standard Edition LEC	
	kWh/m^2	$kBtu/ft^2$
APART04	-17.0	-5.4
APART06	-19.4	-6.2
DORMI04	-14.0	-4.4
DORMI06	-21.2	-6.7
HOTEL15	-20.4	-6.5
HIGHS02	-22.5	-7.1
OFFIC03	-16.4	-5.2
OFFIC08	-20.5	-6.5
OFFIC16	-25.3	-8.0
RETAIL1	-17.1	-5.4
RSTRNT1	-45.9	-14.5

[43] 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.
[44] 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 54.8 GWh (187.1 GBtu) of total energy use annually for one year's worth of new construction for these building types. Assuming that the buildings considered in this study, which represent 62.9 % 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 87.1 GWh (297.5 GBtu) per year. These savings imply 871.3 GWh (2975.0 GBtu) in energy use savings over the 10-year study period.

The change in energy use varies across building types. The building types that have the greatest percentage reductions are not always the same buildings that lead to the greatest total reductions for the state. Instead the building types that represent a greater amount of new floor area realize the largest changes in energy use. The greatest total reductions are realized by retail stores and high schools because they represent 21.3 % and 16.8 %, respectively, of the combined new construction in the state for the building types in this study while all other building types represent 13.6 % 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 20-2.

Table 20-5 Statewide Change in Annual Energy Use for One Year of Construction, Virginia

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC kWh	Standard Edition LEC kBtu
APART04	44.9 %	315	3388	-5 348 319	-18 261 461
APART06	55.1 %	386	4150	-7 489 535	-25 572 492
HOTEL15	100.0 %	272	2929	-5 554 997	-18 967 147
HIGHS02	100.0 %	477	5138	-7 810 316	-26 667 776
OFFIC03	37.4 %	276	2976	-6 226 565	-21 260 171
OFFIC08	40.4 %	298	3209	-6 100 040	-20 828 159
OFFIC16	22.2 %	164	1765	-4 145 554	-14 154 706
RETAIL1	100.0 %	603	6488	-10 298 916	-35 164 927
RSTRNT1	100.0 %	40	430	-1 831 391	-6 253 157
Total		**2831**	**30 473**	**-54 805 632**	**-187 129 994**

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

20.2.2 Energy Costs

Table 20-6 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 20-6 Average Per Unit Change in Energy Costs, 10-Year, Virginia

Building Type	Standard Edition LEC	
	$/m^2	$/ft^2
APART04	-$11.77	-$1.09
APART06	-$13.91	-$1.29
DORMI04	-$9.26	-$0.86
DORMI06	-$15.02	-$1.39
HOTEL15	-$13.39	-$1.24
HIGHS02	-$14.81	-$1.38
OFFIC03	-$13.93	-$1.29
OFFIC08	-$13.26	-$1.23
OFFIC16	-$16.89	-$1.57
RETAIL1	-$11.16	-$1.04
RSTRNT1	-$29.24	-$2.72

Table 20-7 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 $38.1 million for 10 years of building operation. Assuming that the buildings considered in this study, which represent 62.9 % 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 $60.5 million over the 10-year study period.

Table 20-7 Statewide Change in Energy Costs for One Year of Construction, 10-Year, Virginia

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	315	3388	-$3 705 986
APART06	55.1 %	386	4150	-$5 361 561
HOTEL15	100.0 %	272	2929	-$3 643 721
HIGHS02	100.0 %	477	5138	-$6 649 179
OFFIC03	37.4 %	276	2976	-$4 093 791
OFFIC08	40.4 %	298	3209	-$3 953 594
OFFIC16	22.2 %	164	1765	-$2 769 954
RETAIL1	100.0 %	603	6488	-$6 725 227
RSTRNT1	100.0 %	40	430	-$1 167 500
Total		**2831**	**30 473**	**-$38 070 512**

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

20.2.3 Energy-related Carbon Emissions

Table 20-8 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 20-8 Average Per Unit Change in Carbon Emissions, 10-Year, Virginia

Building Type	Standard Edition LEC kg/m^2	Standard Edition LEC lb/ft^2
APART04	-135.1	-27.7
APART06	-160.4	-32.9
DORMI04	-105.4	-21.6
DORMI06	-173.0	-35.4
HOTEL15	-152.2	-31.2
HIGHS02	-164.8	-33.8
OFFIC03	-168.5	-34.5
OFFIC08	-150.5	-30.8
OFFIC16	-192.6	-39.5
RETAIL1	-126.8	-26.0
RSTRNT1	-330.8	-67.7

Table 20-9 applies the Table 20-8 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 437 139 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 694 975 metric tons over the 10-year study period.

Table 20-9 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, Virginia – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition
				LEC
APART04	44.9 %	315	3388	-42 536
APART06	55.1 %	386	4150	-61 864
HOTEL15	100.0 %	272	2929	-41 432
HIGHS02	100.0 %	477	5138	-78 664
OFFIC03	37.4 %	276	2976	-46 568
OFFIC08	40.4 %	298	3209	-44 860
OFFIC16	22.2 %	164	1765	-31 598
RETAIL1	100.0 %	603	6488	-76 410
RSTRNT1	100.0 %	40	430	-13 208
Total		**2831**	**30 473**	**-437 139**

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

20.2.4 Life-Cycle Costs

Table 20-10 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 20-10 Average Per Unit Change in Life-Cycle Costs, 10-Year, Virginia

Building Type	Standard Edition LEC $/m^2$	Standard Edition LEC $/ft^2$
APART04	$4.74	$0.44
APART06	$2.99	$0.28
DORMI04	-$6.28	-$0.58
DORMI06	-$0.11	-$0.01
HOTEL15	$3.71	$0.34
HIGHS02	-$4.65	-$0.43
OFFIC03	-$16.56	-$1.54
OFFIC08	-$17.55	-$1.63
OFFIC16	$2.83	$0.26
RETAIL1	$2.98	$0.28
RSTRNT1	-$68.04	-$6.32

Table 20-11 applies the Table 20-10 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 $8.8 million in statewide life-cycle costs relative to *ASHRAE 90.1-2007*. Eight-story office buildings ($5.2 million) and 3-story office buildings ($4.6 million) realize the greatest reductions in life-cycle costs. 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 $14.0 million over the 10-year study period.

Table 20-11 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, Virginia

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition LEC
APART04	44.9 %	315	3388	$1 491 533
APART06	55.1 %	386	4150	$1 154 253
HOTEL15	100.0 %	272	2929	$1 008 641
HIGHS02	100.0 %	477	5138	-$2 217 770
OFFIC03	37.4 %	276	2976	-$4 576 972
OFFIC08	40.4 %	298	3209	-$5 231 828
OFFIC16	22.2 %	164	1765	$464 086
RETAIL1	100.0 %	603	6488	$1 794 940
RSTRNT1	100.0 %	40	430	-$2 716 793
Total		**2831**	**30 473**	**-$8 829 909**

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

20.3 State Summary

Virginia 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 871.3 GWh (2975.0 GBtu), energy cost savings of $60.5 million, and carbon emissions reductions of 694 975 metric tons while decreasing life-cycle costs of $14.0 million for one year's worth of commercial building construction.

21 West Virginia

West Virginia is one of two states in the South Census Region that have adopted *ASHRAE 90.1-2001* as their state energy code for commercial buildings, is located in the South Atlantic Census Division, and spans two climate zones (Zone 4A and Zone 5A). Table 21-1 provides an overview of West Virginia's simulated energy use keyed to building type 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 113 kWh/m^2 (25 kBtu/ft^2 to 36 kBtu/ft^2) annually. The high school uses the greatest amount of energy at 192 kWh/m^2 to 221 kWh/m^2 (61 kBtu/ft^2 to 70 kBtu/ft^2) annually.

Table 21-1 Average Annual Energy Use by Building Type and Standard Edition, West Virginia

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	173	55	150	48	145	46	129	41
APART06	170	54	148	47	144	46	126	40
DORMI04	129	41	114	36	108	34	95	30
DORMI06	184	58	161	51	159	50	139	44
HOTEL15	160	51	142	45	149	47	130	41
HIGHS02	221	70	213	68	206	65	192	61
OFFIC03	120	38	111	35	104	33	84	27
OFFIC08	113	36	102	32	98	31	79	25
OFFIC16	147	47	138	44	146	46	123	39
RETAIL1	139	44	125	40	112	36	97	31
RSTRNT1	188	60	170	54	156	49	114	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.

21.1 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 West Virginia.

21.1.1 Energy Use

Table 21-2 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 -3.4 % to -13.0 % depending on the building type, with an overall average of -9.9 %. The average percentage change in energy use from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -0.8 % to -19.5 %, with an overall average of -12.6 %.

Table 21-2 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions, West Virginia

Building Type	Standard Edition		
	2004	2007	LEC
APART04	-12.9	-15.9	-25.3
APART06	-13.0	-15.4	-26.2
DORMI04	-12.3	-16.2	-26.7
DORMI06	-12.5	-13.8	-24.4
HOTEL15	-11.4	-6.7	-18.9
HIGHS02	-3.4	-6.7	-13.3
OFFIC03	-7.9	-13.5	-30.4
OFFIC08	-9.8	-13.3	-30.1
OFFIC16	-6.1	-0.8	-16.9
RETAIL1	-10.0	-19.5	-30.7
RSTRNT1	-9.5	-17.2	-39.3
Average	**-9.9**	**-12.6**	**-25.7**

For the high-rise buildings (15-story hotel and 16-story office building), *ASHRAE 90.1-2004* is actually more energy efficient than *ASHRAE 90.1-2007* because the maximum window SHGC requirement in Zone 4 and 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 percentage change in energy use relative to *ASHRAE 90.1-2001*, with a range of -13.3 % to -39.3 % and an overall average of -25.7 %. Similar to the *ASHRAE 90.1-2007* design, the smallest reduction in energy use for the LEC design occurs 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 West Virginia climate requires significant heating during the coldest months.

21.1.2 Energy Costs

Table 21-3 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 -4.9 % to -16.5 % depending on the building type, with an overall average of -12.2 %. The average change in energy costs from constructing buildings using *ASHRAE 90.1-2007* requirements ranges from -1.5 % to -19.4 %, with an overall average of -14.2 %. 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. For three building types, adopting *ASHRAE 90.1-2007* leads to a slightly smaller percentage reduction in energy costs than the reduction in energy use because the percentage reduction in natural gas consumption is greater than the reduction in electricity consumption.

Table 21-3 Average Percentage Change in Energy Costs, 10-Year, West Virginia

Building Type	Standard Edition		
	2004	2007	LEC
APART04	-16.4	-19.0	-29.8
APART06	-16.5	-18.6	-31.2
DORMI04	-16.2	-19.4	-31.0
DORMI06	-16.1	-17.2	-29.6
HOTEL15	-14.6	-9.7	-23.4
HIGHS02	-4.9	-7.9	-17.1
OFFIC03	-8.8	-13.1	-31.4
OFFIC08	-10.4	-12.8	-30.4
OFFIC16	-7.1	-1.5	-19.1
RETAIL1	-11.7	-19.4	-31.6
RSTRNT1	-11.5	-17.8	-41.8
Average	**-12.2**	**-14.2**	**-28.8**

The LEC design realizes the greatest percentage changes in energy costs, with the average reduction by building type ranging from -17.1 % to -41.8 % and an overall average of -28.8 %. For all building designs, the average reductions in energy costs are greater than the reductions in energy use because the percentage reduction in electricity consumption is greater than the reduction in natural gas consumption. Adopting the *ASHRAE 90.1-2004*, *-2007*, and LEC designs increase natural gas consumption while decreasing electricity consumption for 11, 7, and 7 building types, respectively. 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.

21.1.3 Energy-related Carbon Emissions

Table 21-4 shows significant changes in average energy-related carbon emissions for *ASHRAE 90.1-2004* for all building types, ranging from -8.5 % to -23.5 % with an average of -16.6 %. The average change in carbon emissions from constructing buildings using *ASHRAE 90.1-2007* requirements is -17.2 % overall with the average change in carbon emissions varying across building types from -2.7 % to -25.3 %. The LEC design leads to the greatest average percentage changes in carbon emissions, ranging from -23.0 % to -45.3 % depending on the building type with an overall average of -34.6 % across all building types.

Table 21-4 Average Percentage Change in Energy-related Carbon Emissions, 10-Year, West Virginia

Building Type	Standard Edition		
	2004	**2007**	**LEC**
APART04	-23.5	-25.3	-38.9
APART06	-23.4	-24.8	-41.0
DORMI04	-23.5	-25.1	-38.8
DORMI06	-22.8	-23.5	-39.1
HOTEL15	-21.0	-15.8	-32.3
HIGHS02	-8.5	-10.7	-26.4
OFFIC03	-10.2	-12.1	-32.4
OFFIC08	-10.9	-11.8	-30.3
OFFIC16	-8.9	-2.7	-23.0
RETAIL1	-14.7	-19.0	-32.9
RSTRNT1	-14.9	-18.3	-45.3
Average	**-16.6**	**-17.2**	**-34.6**

As would be expected, a more energy efficient building design results in greater reductions in carbon emissions. For the *ASHRAE 90.1-2004* and LEC designs, the percentage reduction in carbon emissions is greater than the percentage reduction in energy use because the adopted energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. Since electricity production in West Virginia generates greater emissions per unit of energy consumed than natural gas, the greater relative reduction in electricity consumption leads to greater percentage reductions in carbon emissions relative to the reductions in energy use. The adoption of the *ASHRAE 90.1-2007* design leads to a percentage reduction in carbon emissions that is smaller than the reduction in energy use for three building types because the percentage reduction in natural gas consumption is greater than the reduction in electricity consumption.

21.1.4 Life-Cycle Costs

The most cost-effective building design for each building type is bolded in Table 21-5. The *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs realize the lowest life-cycle costs for two, four, 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 reductions in life-cycle costs for 10 of 11 building types. The change in life-cycle costs for the LEC design ranges from -6.4 % to 0.9 %. Based on the overall average change of -2.2 % 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 21-5 Average Percentage Change in Life-Cycle Costs, 10-Year, West Virginia

Building Type	Standard Edition		
	2004	2007	LEC
APART04	-1.4	**-1.7**	-0.8
APART06	-1.4	**-1.6**	-0.8
DORMI04	-2.2	-2.2	**-3.3**
DORMI06	-1.8	**-1.9**	-1.4
HOTEL15	**-1.9**	-1.4	-0.6
HIGHS02	-0.6	-1.0	**-1.3**
OFFIC03	-1.6	-2.1	**-4.3**
OFFIC08	-2.3	-2.8	**-4.8**
OFFIC16	**-0.7**	-0.2	0.9
RETAIL1	-1.9	**-2.6**	-1.8
RSTRNT1	-1.9	-3.5	**-6.4**
Average	**-1.6**	**-1.9**	**-2.2**

21.1.5 City Comparisons

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

As can be seen in Table 21-6, the average percentage reduction in energy use for all building types from adopting newer energy standard editions is greater for the cities located in Zone 4 than in Zone 5. For the LEC design, cities in Zone 4 realize an average change in energy use of -27.1 % compared to -22.8 % for Zone 5. There is minimal variation between cities within Zone 4.

Table 21-6 Average Percentage Change in Energy Use from Adoption of Newer Standard Editions by City, West Virginia

Cities	Zone	Standard Edition		
		2004	**2007**	**LEC**
Charleston	4A	-11.5	-13.9	-27.5
Huntington	4A	-10.1	-12.8	-26.7
Elkins	5A	-8.0	-11.2	-22.8
Average		**-9.9**	**-12.6**	**-25.7**

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 21-7 shows that average reduction in energy costs for all building types is greater for cities located in Zone 4 than for the city in Zone 5. The reductions in energy costs are greater than the reductions in energy use because the energy efficiency measures decrease electricity consumption by a greater percentage than natural gas consumption. Similar to energy use, there is minimal variation between cities within Zone 4.

Table 21-7 Average Percentage Change in Energy Costs by City, 10-Year, West Virginia

Cities	Zone	Standard Edition		
		2004	**2007**	**LEC**
Charleston	4A	-13.5	-15.2	-30.3
Huntington	4A	-12.4	-14.3	-29.6
Elkins	5A	-10.7	-13.1	-26.5
Average		**-12.2**	**-14.2**	**-28.8**

Table 21-8 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 4 realize slightly lower average emission reductions than the cities in Zone 5 for all building designs. The LEC design realizes the greatest percentage reductions in carbon emissions, with the average percentage reduction ranging from -33.9 % to -35.4 % depending on the location.

Table 21-8 Average Percentage Change in Carbon Emissions by City, 10-Year, West Virginia

Cities	Zone	Standard Edition		
		2004	2007	LEC
Charleston	4A	-16.5	-17.4	-35.4
Huntington	4A	-15.8	-16.7	-34.6
Elkins	5A	-15.6	-16.8	-33.9
Average		**-16.0**	**-17.0**	**-34.6**

The data reported in Table 21-9 show that, over a 10-year period, the LEC design results in the lowest average life-cycle costs for all cities in both Zone 4 and Zone 5. All building designs realize reductions in life-cycle costs for all cities in both climate zones. Reductions in life-cycle costs are similar across all cities in the state, with Charleston realizing slightly greater percentage reductions for all building designs.

Table 21-9 Average Percentage Change in Life-Cycle Costs by City, 10-Year, West Virginia

Cities	Zone	Standard Edition		
		2004	2007	LEC
Charleston	4A	-1.8	-2.1	**-2.4**
Huntington	4A	-1.7	-1.8	**-2.2**
Elkins	5A	-1.4	-1.8	**-2.0**
Average		**-1.6**	**-1.9**	**-2.2**

21.2 Total Savings

How much can West Virginia 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.

21.2.1 Energy Use

Table 21-10 reports the average per unit change in annual energy use by building type and building design in the state.[45] 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 21-11 reports the estimated average annual floor area of new construction and the total annual

[45] 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.

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.[46]

Table 21-10 Average Per Unit Change in Annual Energy Use, West Virginia

Building Type	Standard Edition					
	2004		2007		LEC	
	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²	kWh/m²	kBtu/ft²
APART04	-22.2	-7.0	-27.3	-8.7	-43.5	-13.8
APART06	-22.1	-7.0	-26.2	-8.3	-44.6	-14.1
DORMI04	-15.8	-5.0	-20.8	-6.6	-34.5	-10.9
DORMI06	-23.0	-7.3	-25.4	-8.0	-45.0	-14.3
HOTEL15	-18.1	-5.7	-10.6	-3.4	-30.1	-9.6
HIGHS02	-9.5	-3.0	-16.2	-5.1	-36.5	-11.6
OFFIC03	-7.3	-2.3	-14.7	-4.7	-29.0	-9.2
OFFIC08	-11.1	-3.5	-15.0	-4.8	-34.0	-10.8
OFFIC16	-9.0	-2.8	-1.2	-0.4	-24.8	-7.9
RETAIL1	-13.9	-4.4	-27.1	-8.6	-42.6	-13.5
RSTRNT1	-17.7	-5.6	-32.3	-10.2	-73.8	-23.4

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 3.9 GWh (13.4 GBtu) while adopting *ASHRAE 90.1-2007* saves 6.4 GWh (22.0 GBtu) annually. The adoption of the LEC design as the state's energy code would save energy for all building types and 11.8 GWh (40.4 GBtu) of total energy use annually for one year's worth of new construction for these building types.

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

Table 21-11 Statewide Change in Annual Energy Use for One Year of Construction, West Virginia

Building Type	Subcat. Weight.	m^2 (1000s)	ft^2 (1000s)	Standard Edition					
				2004		2007		LEC	
				kWh	kBtu	kWh	kBtu	kWh	kBtu
APART04	44.9 %	6	63	-129 146	-440 959	-159 121	-543 309	-253 198	-864 525
APART06	55.1 %	7	77	-157 233	-536 862	-186 920	-638 224	-317 977	-1 085 710
HOTEL15	100.0 %	30	318	-534 134	-1 823 765	-313 258	-1 069 597	-890 958	-3 042 113
HIGHS02	100.0 %	97	1043	-711 898	-2 430 724	-1 426 267	-4 869 889	-2 808 660	-9 589 972
OFFIC03	37.4 %	14	156	-137 066	-468 003	-234 320	-800 069	-528 712	-1 805 249
OFFIC08	40.4 %	16	168	-173 511	-592 440	-234 100	-799 319	-531 019	-1 813 126
OFFIC16	22.2 %	9	92	-76 905	-262 587	-10 154	-34 670	-213 209	-727 988
RETAIL1	100.0 %	134	1438	-1 855 765	-6 336 378	-3 615 214	-12 343 897	-5 696 712	-19 451 023
RSTRNT1	100.0 %	8	84	-138 775	-473 836	-252 758	-863 024	-577 427	-1 971 586
Total		**319**	**3439**	**-3 914 432**	**-13 365 555**	**-6 432 113**	**-21 961 998**	**-11 817 871**	**-40 351 293**

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

Assuming that the buildings considered in this study, which represent 66.7 % 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 use savings to be 17.7 GWh (60.5 GBtu) annually. These savings imply 177.2 GWh (605.0 GBtu) in energy savings over the 10-year study period. In comparison, *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* would save 5.9 GWh and 9.6 GWh annually, or 58.7 GWh and 96.4 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. 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 11th in percentage reduction, respectively, among the 11 building types, as reported in Table 21-2.

21.2.2 Energy Costs

Table 21-12 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 21-12 Average Per Unit Change in Energy Costs, 10-Year, West Virginia

Building Type	Standard Edition					
	2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	-$13.77	-$1.28	-$15.95	-$1.48	-$25.00	-$2.32
APART06	-$13.70	-$1.27	-$15.45	-$1.44	-$25.94	-$2.41
DORMI04	-$10.28	-$0.96	-$12.29	-$1.14	-$19.70	-$1.83
DORMI06	-$14.47	-$1.34	-$15.44	-$1.43	-$26.59	-$2.47
HOTEL15	-$11.32	-$1.05	-$7.52	-$0.70	-$18.15	-$1.69
HIGHS02	-$5.37	-$0.50	-$7.99	-$0.74	-$19.19	-$1.78
OFFIC03	-$4.89	-$0.45	-$7.94	-$0.74	-$17.21	-$1.60
OFFIC08	-$6.08	-$0.56	-$7.54	-$0.70	-$17.89	-$1.66
OFFIC16	-$5.27	-$0.49	-$1.09	-$0.10	-$14.19	-$1.32
RETAIL1	-$8.09	-$0.75	-$13.44	-$1.25	-$21.90	-$2.03
RSTRNT1	-$10.73	-$1.00	-$16.63	-$1.55	-$39.15	-$3.64

Table 21-13 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: $2.4 million, $3.4 million, and $6.4 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 total statewide energy cost savings of $3.6 million, $5.0 million, and $9.7 million over the 10-year study period, respectively.

Table 21-13 Statewide Change in Energy Costs for One Year of Construction, 10-Year, West Virginia

Building Type	Subcategory Weighting	m² (1000s)	ft² (1000s)	Standard Edition		
				2004	2007	LEC
APART04	44.9 %	6	63	-$80 167	-$92 816	-$145 535
APART06	55.1 %	7	77	-$97 712	-$110 144	-$184 947
HOTEL15	100.0 %	30	318	-$334 770	-$222 395	-$536 802
HIGHS02	100.0 %	97	1043	-$474 223	-$769 782	-$1 667 488
OFFIC03	37.4 %	14	156	-$77 718	-$115 669	-$277 776
OFFIC08	40.4 %	16	168	-$94 913	-$117 729	-$279 147
OFFIC16	22.2 %	9	92	-$45 286	-$9 393	-$121 882
RETAIL1	100.0 %	134	1438	-$1 081 113	-$1 796 377	-$2 925 965
RSTRNT1	100.0 %	8	84	-$83 967	-$130 122	-$306 235
Total		**319**	**3439**	**-$2 369 868**	**-$3 364 429**	**-$6 445 777**

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

21.2.3 Energy-related Carbon Emissions

Table 21-14 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 21-14 Average Per Unit Change in Carbon Emissions, 10-Year, West Virginia

Building Type	Standard Edition					
	2004		2007		LEC	
	kg/m²	lb/ft²	kg/m²	lb/ft²	kg/m²	lb/ft²
APART04	-271.4	-55.6	-291.9	-59.8	-449.0	-92.0
APART06	-270.4	-55.4	-286.4	-58.7	-473.1	-96.9
DORMI04	-213.0	-43.6	-227.9	-46.7	-351.5	-72.0
DORMI06	-289.0	-59.2	-297.8	-61.0	-495.3	-101.4
HOTEL15	-225.4	-46.2	-168.8	-34.6	-345.6	-70.8
HIGHS02	-103.7	-21.2	-130.5	-26.7	-322.0	-66.0
OFFIC03	-94.7	-19.4	-112.5	-23.1	-302.1	-61.9
OFFIC08	-101.9	-20.9	-110.0	-22.5	-281.8	-57.7
OFFIC16	-97.7	-20.0	-29.4	-6.0	-253.1	-51.8
RETAIL1	-147.9	-30.3	-191.7	-39.3	-331.8	-68.0
RSTRNT1	-205.5	-42.1	-253.0	-51.8	-625.7	-128.2

Table 21-15 applies the Table 21-14 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 45 392 metric tons while adopting *ASHRAE 90.1-2007* saves 52 578 metric tons over a 10-year study period. The adoption of the LEC design as the state's energy code decreases carbon emissions by 107 582 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 68 054 metric tons, 78 828 metric tons, and 161 292 metric tons over the 10-year study period, respectively.

Table 21-15 Statewide Change in Total Carbon Emissions for One Year of Construction, 10-Year, West Virginia – Metric Tons

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition		
				2004	2007	LEC
APART04	44.9 %	6	63	-1580	-1699	-2614
APART06	55.1 %	7	77	-1928	-2042	-3373
HOTEL15	100.0 %	30	318	-6667	-4993	-10 224
HIGHS02	100.0 %	97	1043	-10 051	-12 646	-31 201
OFFIC03	37.4 %	14	156	-1371	-1629	-4373
OFFIC08	40.4 %	16	168	-1591	-1717	-4398
OFFIC16	22.2 %	9	92	-839	-253	-2173
RETAIL1	100.0 %	134	1438	-19 758	-25 620	-44 331
RSTRNT1	100.0 %	8	84	-1607	-1979	-4895
Total		**319**	**3439**	**-45 392**	**-52 578**	**-107 582**

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

21.2.4 Life-Cycle Costs

Table 21-16 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 21-16 Average Per Unit Change in Life-Cycle Costs, 10-Year, West Virginia

Building Type	Standard Edition					
	2004		2007		LEC	
	$/m²	$/ft²	$/m²	$/ft²	$/m²	$/ft²
APART04	-$14.11	-$1.31	-$17.13	-$1.59	-$8.06	-$0.75
APART06	-$14.10	-$1.31	-$16.46	-$1.53	-$8.21	-$0.76
DORMI04	-$21.92	-$2.04	-$21.86	-$2.03	-$32.93	-$3.06
DORMI06	-$18.78	-$1.75	-$19.97	-$1.86	-$14.57	-$1.35
HOTEL15	-$18.49	-$1.72	-$14.38	-$1.34	-$6.12	-$0.57
HIGHS02	-$4.93	-$0.46	-$8.33	-$0.77	-$10.76	-$1.00
OFFIC03	-$13.22	-$1.23	-$17.26	-$1.60	-$35.68	-$3.31
OFFIC08	-$20.14	-$1.87	-$24.73	-$2.30	-$42.06	-$3.91
OFFIC16	-$5.53	-$0.51	-$1.74	-$0.16	$6.85	$0.64
RETAIL1	-$13.07	-$1.21	-$17.97	-$1.67	-$12.05	-$1.12
RSTRNT1	-$27.63	-$2.57	-$49.85	-$4.63	-$91.44	-$8.49

Table 21-17 applies the Table 21-16 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 an increase in life-cycle costs for the LEC design and the smallest total reductions for the other two designs. *ASHRAE 90.1-2007* results in greater total reductions in life-cycle costs than the *ASHRAE 90.1-2004* and LEC designs for the building types considered in this study ($4.9 million versus $3.7 million and $4.8 million, respectively). Assuming that the buildings considered in this study are generally representative of the entire new commercial building stock in the state, the results for the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs can be extrapolated to estimate statewide changes in life-cycle costs of $5.6 million, $7.3 million, and $7.2 million over the 10-year study period, respectively.

Table 21-17 Statewide Change in Life-Cycle Costs for One Year of Construction, 10-Year, West Virginia

Building Type	Subcategory Weighting	m^2 (1000s)	ft^2 (1000s)	Standard Edition		
				2004	2007	LEC
APART04	44.9 %	6	63	-$82 161	-$99 684	-$46 945
APART06	55.1 %	7	77	-$100 525	-$117 334	-$58 561
HOTEL15	100.0 %	30	318	-$546 827	-$425 343	-$181 162
HIGHS02	100.0 %	97	1043	-$478 187	-$807 446	-$1 042 613
OFFIC03	37.4 %	14	156	-$191 378	-$249 808	-$516 341
OFFIC08	40.4 %	16	168	-$314 316	-$385 951	-$656 457
OFFIC16	22.2 %	9	92	-$47 471	-$14 944	$58 832
RETAIL1	100.0 %	134	1438	-$1 746 322	-$2 401 432	-$1 610 309
RSTRNT1	100.0 %	8	84	-$216 100	-$389 915	-$715 267
Total		**319**	**3439**	**-$3 723 287**	**-$4 891 859**	**-$4 768 825**
Note: Dormitories are excluded because no such floor area category is reported in the construction						

21.3 State Summary

West Virginia is one of the two states in the South Census Region that have adopted *ASHRAE 90.1-2001* as their state energy code for commercial buildings. 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, 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 for commercial buildings would lead to energy use savings of 96.4 GWh (329.3 GBtu), energy cost savings of $5.0 million, 78 828 metric tons of carbon emissions reductions, and life-cycle costs savings of $7.2 million for one year's worth of commercial building construction. Adopting the LEC design would lead to even greater impactswith savings of 177.2 GWh (605.0 GBtu), $9.7 million in energy costs, and 161 292 metric tons of carbon emissions. However, it leads to slightly lower life-cycle cost savings of $7.2 million.

22 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 South 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 South Census Region that have adopted the more energy efficient *ASHRAE 90.1-2004* or *ASHRAE 90.1-2007*.

22.1 Total Savings Comparison

By comparing the aggregate results from the detailed state-by-state analysis, some interesting trends emerge. Table 22-1 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 South 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 energy source fuel mix.

Table 22-1 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)
AL	1999	2254 (24 266)	1050.6	84.9	908.8	37.0
AR	2001	1186 (12 762)	426.1	28.6	372.7	20.4
DE	2007	344 (3700)	60.1	6.5	45.1	4.5
FL	2007	16 542 (178 061)	3790.5	333.0	3230.2	151.3
GA	2007	7240 (77 934)	1348.0	102.5	1250.2	28.5
KY	2007	1956 (21 050)	378.0	24.6	341.2	9.8
LA	2007	1700 (18 294)	324.6	20.8	269.7	3.2
MD	2007	3385 (36 433)	622.2	62.4	448.9	28.8
MS	1999	1251 (13 465)	689.6	46.3	465.2	14.8
NC	2007	4437 (47 758)	827.9	56.2	585.0	20.3
OK	1999	1590 (17 115)	598.1	35.4	678.9	0.7
SC	2004	2718 (29 257)	594.5	43.8	412.4	12.2
TN	2004	3272 (35 219)	807.8	58.7	626.8	28.1
TX	2007	14 446 (155 495)	2831.6	234.5	2630.4	106.8
VA	2007	4499 (48 426)	871.3	60.5	695.0	14.0
WV	2001	479 (5159)	177.2	9.7	161.3	7.1
Total		**67 299 (724 394)**	**16 426.9**	**1208.4**	**12 890.0**	**487.5**

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

Consider the reductions in energy use for two states with similar amounts of new floor area, Maryland and Tennessee. Tennessee realizes a greater amount of total reductions in energy use (807.8 GWh) than Maryland (622.2 GWh). Even though Maryland has slightly more new floor area of construction than Tennessee, Tennessee realizes greater total reductions because Tennessee has adopted *ASHRAE 90.1-2004* while Maryland has adopted *ASHRAE 90.1-2007*.

Table 22-2 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 is driven by the state's adopted energy code for commercial buildings. The greatest reduction from adoption of the LEC design is realized by the three states that have no state energy code, ranging from 376 kWh/m^2 (119 kBtu/ft^2) to 551 kWh/m^2 (175 kBtu/ft^2), followed by the states that have adopted *ASHRAE 90.1-2001* and realizes reductions of 359 kWh/m^2 (114 kBtu/ft^2) to 370 kWh/m^2 (117 kBtu/ft^2). The states that have adopted *ASHRAE 90.1-2004* and *-2007* realize reductions ranging from 175 kWh/m^2 (56 kBtu/ft^2) to 247 kWh/m^2 (78 kBtu/ft^2).

Table 22-2 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC Design by State, 10-Year

State	Code	U.S. Floor Area Ranking	Average Annual New Floor Area 1000 m^2 (1000 ft^2)	Energy Use Reduction		
				GWh	kWh/m^2	kBtu/ft^2
MS	1999	33	1251 (13465)	689.6	551	175
AL	1999	25	2254 (24266)	1050.6	466	148
OK	1999	30	1590 (17115)	598.1	376	119
WV	2001	42	479 (5159)	177.2	370	117
AR	2001	34	1186 (12762)	426.1	359	114
TN	2004	18	3272 (35219)	807.8	247	78
FL	2007	1	16542 (178061)	3790.5	229	73
SC	2004	20	2718 (29257)	594.5	219	69
KY	2007	26	1956 (21050)	378	193	61
LA	2007	29	1700 (18294)	324.6	191	61
TX	2007	3	14446 (155495)	2831.6	196	62
VA	2007	10	4499 (48426)	871.3	194	62
GA	2007	4	7240 (77934)	1348	186	59
MD	2007	16	3385 (36433)	622.2	184	58
NC	2007	11	4437 (47758)	827.9	187	59
DE	2007	43	344 (3700)	60.1	175	56

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 22-3 shows each state's reduction in energy costs per unit of reduction in energy use, natural gas rate, electricity rate, and the fraction of reductions in energy use coming from electricity.[47] States with the highest electricity rates tend to realize the greatest reductions in energy costs per unit of reduction in energy use. Relative to electricity prices, natural gas prices are fairly constant across states ($0.03/kWh to $0.05/kWh) and are always cheaper per unit of energy.

There is some fluctuation in the results due to the fuel source of the reductions in energy use. For example, Georgia has a lower electricity rate than Tennessee and Mississippi. However, Georgia realizes a greater average energy cost savings per unit of energy use

[47] 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.

savings ($0.08) than Tennessee or Mississippi ($0.07 each) because Georgia realizes a shift in fuel consumption from electricity to natural gas, leading to additional savings. Meanwhile, Tennessee and Mississippi realize a reduction in both electricity and natural gas consumption, which lowers the average reduction in energy costs.

Table 22-3 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)
DE	2007	17.4	12.0	4.6	0.11
MD	2007	13.3	12.0	3.2	0.10
FL	2007	4.0	10.8	3.2	0.09
AL	1999	1.8	10.1	4.4	0.08
TX	2007	9.2	9.7	2.4	0.08
GA	2007	10.4	8.9	3.4	0.08
TN	2004	-9.4	9.6	3.1	0.07
MS	1999	-20.7	9.5	2.8	0.07
SC	2004	9.1	8.7	3.3	0.07
VA	2007	12.4	8.1	3.0	0.07
NC	2007	11.3	8.0	3.4	0.07
KY	2007	11.1	7.6	3.2	0.07
AR	2001	17.2	7.6	3.1	0.07
LA	2007	7.7	7.7	3.1	0.06
OK	1999	17.2	6.8	3.1	0.06
WV	2001	3.9	6.8	4.2	0.05

Note: The fraction of reductions in energy use is usually greater than 100 % because natural gas use increases, reducing total energy use

Table 22-4 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 sixteen 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, Kentucky realizes greater reductions in carbon emissions per unit of energy than Tennessee even though its electricity emissions rate is the same. Kentucky realizes a shift in fuel consumption from electricity to natural gas, leading to savings in addition to those from the reduction in total energy use alone. Meanwhile, Tennessee realizes a reduction in both electricity and natural gas consumption, which lowers the average reduction in carbon emissions.

Table 22-4 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the LEC Design by State, 10-Year

State	Code	Offset (%)	CO_2 Emissions Rate for Electricity (t/GWh)	CO_2e Emissions Rate for Natural Gas (t/GWh)	CO_2e Reduction (t/GWh)
OK	1999	17.2	970	241	1135
TX	2007	9.2	858	241	929
GA	2007	10.4	847	241	927
WV	2001	3.9	875	241	910
KY	2007	11.1	819	241	903
AR	2001	17.2	756	241	875
AL	1999	1.8	847	241	865
FL	2007	4.0	826	241	852
LA	2007	7.7	780	241	831
VA	2007	12.4	723	241	798
TN	2004	-9.4	819	241	776
DE	2007	17.4	652	241	750
MD	2007	13.3	652	241	721
NC	2007	11.3	647	241	707
SC	2004	9.1	647	241	694
MS	1999	-20.7	759	241	675

The relative change in life-cycle costs per unit of new floor area is shown in Table 22-5. There is no correlation between the energy cost savings (Table 22-3) and the life-cycle cost-effectiveness of adopting the LEC design because in order to obtain energy cost savings, additional construction costs are usually required. All Southern states realize an average decrease in life-cycle costs from adoption of the LEC design, with savings ranging from \$0.44/m^2 (\$0.04/ft^2) to \$17.20/m^2 (\$1.60/ft^2). There is no correlation between the state energy code and the total statewide reduction in life-cycle costs per unit of floor area.

Table 22-5 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	Energy Savings (kWh/m^2)	LCC Reduction		
				$million	$\$/m^2$	$\$/ft^2$
AR	2001	34	359	20.4	17.20	1.60
AL	1999	25	466	37.0	16.42	1.52
WV	2001	42	370	7.1	14.82	1.38
DE	2007	43	175	4.5	13.08	1.22
MS	1999	33	551	14.8	11.83	1.10
FL	2007	1	229	151.3	9.15	0.85
TN	2004	18	247	28.1	8.59	0.80
MD	2007	16	184	28.8	8.51	0.79
TX	2007	3	196	106.8	7.39	0.69
KY	2007	26	193	9.8	5.01	0.47
NC	2007	11	187	20.3	4.58	0.43
SC	2004	20	219	12.2	4.49	0.42
GA	2007	4	186	28.5	3.94	0.37
VA	2007	10	194	14.0	3.11	0.29
LA	2007	29	191	3.2	1.88	0.17
OK	1999	30	376	0.7	0.44	0.04

22.2 Percentage Change Comparison

State comparisons are made based on the simple average changes for the cities analyzed in each state by building type.[48] 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 Appendix B.

22.2.1 3-Story Office Building

Table 22-6 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 1.9 %.

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

Table 22-6 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
AL	-36.3	-36.6	-36.8	-0.7
AR	-30.4	-33.0	-33.9	-3.8
DE	-20.0	-22.7	-23.2	-3.4
FL	-24.0	-24.3	-24.3	-2.3
GA	-21.6	-22.9	-23.3	-1.2
KY	-19.8	-22.4	-23.5	-2.4
LA	-21.9	-22.7	-23.0	-0.3
MD	-20.0	-23.4	-23.1	-3.0
MS	-41.9	-39.1	-39.0	0.4
NC	-21.9	-23.3	-23.7	-2.1
OK	-30.8	-33.7	-35.7	2.0
SC	-23.8	-24.9	-25.0	-2.0
TN	-25.3	-25.8	-25.9	-2.6
TX	-21.7	-23.1	-23.1	-1.9
VA	-22.1	-24.1	-24.5	-2.2
WV	-30.4	-31.4	-32.4	-4.3
Avg.	**-24.5**	**-25.6**	**-25.9**	**-1.9**

These detailed results can be readily analyzed in mappings of the South Census Region. Figure 22-1, Figure 22-2, Figure 22-3, and Figure 22-4, 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 22-1 shows that the states that have not yet adopted *ASHRAE 90.1-2007* realize the greatest reductions in energy use. Alabama, Arkansas, Mississippi, Oklahoma, and West Virginia realize energy use savings greater than 30 % by adopting the LEC design over their current code. Tennessee, which has adopted *ASHRAE 90.1-2004*, realizes reductions of 25 % to 30 %. None of the nine Southern states that have adopted *ASHRAE 90.1-2007* or the other state that has adopted *ASHRAE 90.1-2004* (South Carolina) realizes energy use savings of greater than 25 %.

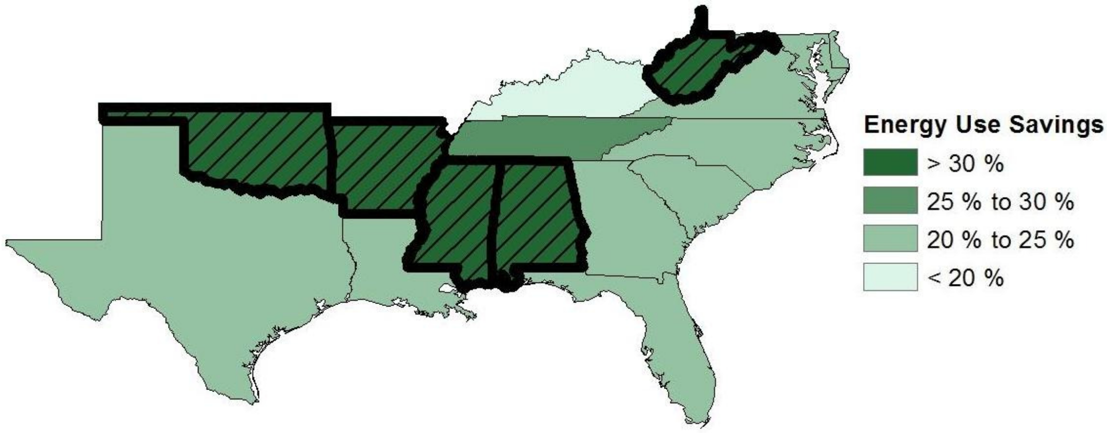

Figure 22-1 Average Energy Use Savings by State, 3-Story Office Building, 10-Year

Figure 22-2 shows the average energy cost savings over 10 years by state from adopting the LEC design. Every state reduces energy costs by at least 20 %. All three states that have no state energy code and both states that have adopted *ASHRAE 90.1-2001* realize energy cost savings of greater than 30 %. None of the nine states that have adopted *ASHRAE 90.1-2007* have energy cost savings greater than 25 %.

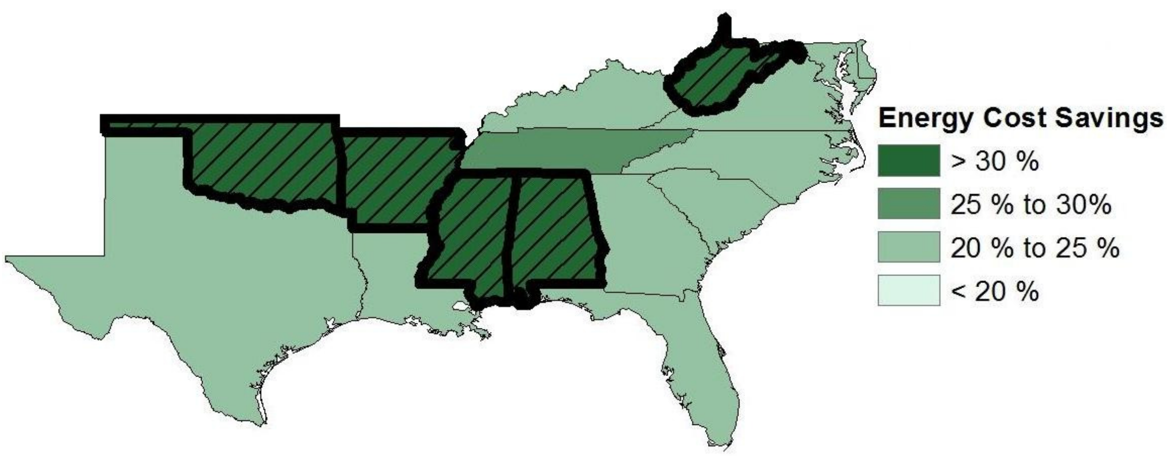

Figure 22-2 Average Energy Cost Savings by State, 3-Story Office Building, 10-Year

Figure 22-3 shows the average reductions in energy-related carbon emissions by state from adopting the LEC design. Similar to energy cost savings, the five states that have no state energy code or have adopted *ASHRAE 90.1-2001* realize reductions in carbon emissions of greater than 30 %. The nine states that have adopted *ASHRAE 90.1-2007* realize reductions between 20 % and 25 %.

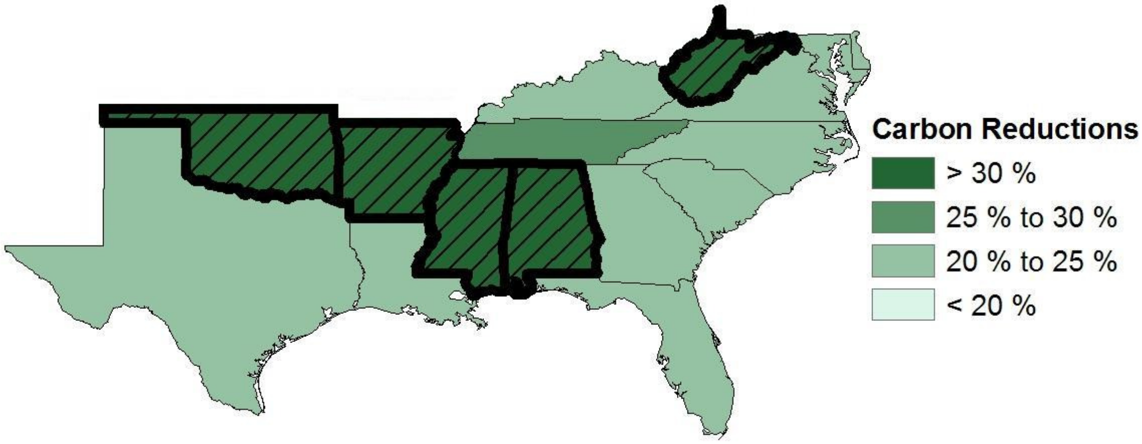

Figure 22-3 Average Energy-related Carbon Emissions Reduction by State, 3-Story Office Building, 10-Year

Figure 22-4 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 while the third (Alabama) realizes a small reduction in life-cycle costs (0.7 %). Of the states that have adopted *ASHRAE 90.1-2004* and *-2007*, three states realize reductions in life-cycle costs of less than 2 % while the other eight states realize reductions in life-cycle costs between 2 % and 4 %. The states that have adopted *ASHRAE 90.1-2001* realize the greatest reductions life-cycle costs.

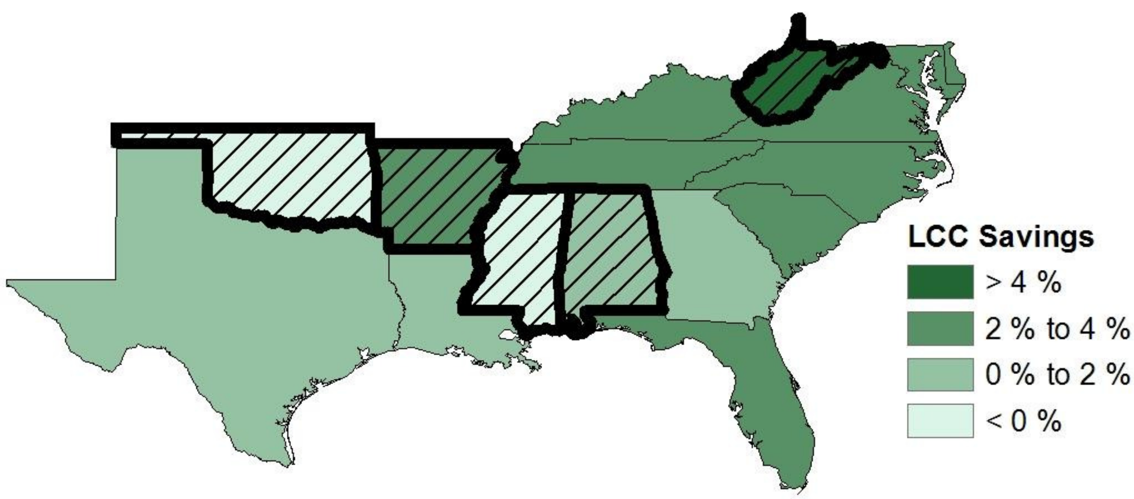

Figure 22-4 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year

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 states with no state energy code are either life-cycle cost-ineffective or marginally cost-effective. The other thirteen states 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.

22.2.2 Region-wide Results by Study Period Length

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

Average reductions in energy use from adoption of the LEC design are constant over all study period lengths because energy efficiency is assumed to be constant over time. The regional reduction in average energy use across all 71 cities in the study ranges from 14.7 % to 32.3 %, depending on the building type, with an overall regional average of 20.1 %. Table 22-7 shows these results.

Table 22-7 South Region Average Percentage Change in Energy Use by Building Type

Building Type	Percentage Change
APART04	-17.7
APART06	-18.8
DORMI04	-18.6
DORMI06	-19.1
HOTEL15	-16.2
HIGHS02	-14.7
OFFIC03	-24.5
OFFIC08	-22.3
OFFIC16	-17.1
RETAIL1	-19.7
RSTRNT1	-32.3
Average	**-20.1**

As shown in Table 22-8, 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 23.4 % for a 1-year study period to 23.0 % 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 19.2 % to 35.4 %, depending on the building type, over all study periods.

Table 22-8 South 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	-21.8	-21.6	-21.6	-21.5	-21.5	-21.4	-21.4	-21.3	-21.3
APART06	-23.7	-23.5	-23.5	-23.4	-23.3	-23.3	-23.2	-23.2	-23.1
DORMI04	-22.3	-22.1	-22.1	-22.0	-22.0	-21.9	-21.9	-21.8	-21.8
DORMI06	-24.1	-23.9	-23.8	-23.8	-23.7	-23.7	-23.6	-23.6	-23.5
HOTEL15	-20.9	-20.7	-20.7	-20.6	-20.5	-20.5	-20.4	-20.4	-20.4
HIGHS02	-20.8	-20.6	-20.5	-20.4	-20.3	-20.3	-20.2	-20.1	-20.1
OFFIC03	-25.7	-25.6	-25.6	-25.6	-25.6	-25.6	-25.6	-25.6	-25.6
OFFIC08	-22.9	-22.8	-22.8	-22.8	-22.8	-22.8	-22.8	-22.8	-22.8
OFFIC16	-19.5	-19.4	-19.3	-19.3	-19.3	-19.3	-19.2	-19.2	-19.2
RETAIL1	-20.7	-20.7	-20.6	-20.6	-20.6	-20.6	-20.6	-20.6	-20.6
RSTRNT1	-35.4	-35.3	-35.3	-35.2	-35.2	-35.2	-35.1	-35.1	-35.1
Average	**-23.4**	**-23.3**	**-23.3**	**-23.2**	**-23.2**	**-23.1**	**-23.1**	**-23.1**	**-23.0**

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 24.2 %. The regional average reduction in carbon emissions ranges from 20.0 % to 36.0 % depending on the building type, as shown in Table 22-9.

Table 22-9 South Region Average Percentage Change in Carbon Emissions by Building Type

Building Type	Percentage Change
APART04	-22.9
APART06	-24.9
DORMI04	-23.2
DORMI06	-25.3
HOTEL15	-22.1
HIGHS02	-22.2
OFFIC03	-25.9
OFFIC08	-23.0
OFFIC16	-20.0
RETAIL1	-20.9
RSTRNT1	-36.0
Average	**-24.2**

Table 22-10 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 22-10 South 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	0.6	0.1	-0.3	-0.8	-0.7	-1.0	-1.2	-1.3	-1.2
APART06	-0.1	-0.2	-0.4	-0.9	-0.9	-1.1	-1.3	-1.5	-1.4
DORMI04	-5.2	-1.7	-1.4	-1.8	-1.7	-1.9	-2.0	-2.1	-2.0
DORMI06	0.3	-0.6	-0.9	-1.4	-1.5	-1.7	-1.9	-2.1	-2.0
HOTEL15	1.5	0.3	-0.1	-0.8	-1.0	-1.3	-1.5	-1.7	-1.7
HIGHS02	-1.0	-1.4	-1.6	-2.1	-2.1	-2.4	-2.6	-2.7	-2.7
OFFIC03	-7.1	-2.2	-1.9	-2.2	-2.0	-2.3	-2.5	-2.6	-2.5
OFFIC08	-4.1	-2.4	-2.3	-2.7	-2.6	-2.9	-3.1	-3.2	-3.1
OFFIC16	2.2	0.8	0.2	-0.6	-0.7	-1.0	-1.3	-1.5	-1.5
RETAIL1	-5.6	-0.1	-0.1	-0.7	-0.6	-0.8	-1.0	-1.2	-1.1
RSTRNT1	-13.3	-6.8	-5.6	-6.5	-6.6	-7.1	-7.5	-7.4	-7.3
Average	**-2.9**	**-1.3**	**-1.3**	**-1.9**	**-1.9**	**-2.1**	**-2.4**	**-2.5**	**-2.4**

Figure 22-5 shows that four building types – the 4-story apartment building, 6-story dormitory, hotel, and 16-story office building -- are not cost-effective for a 1-year study period, with an average increase in life-cycle costs ranging from 0.3 % to 2.2 %. By a 10-year study period, three of the four building types become cost-effective and by a 15-year study period, all four are cost-effective.

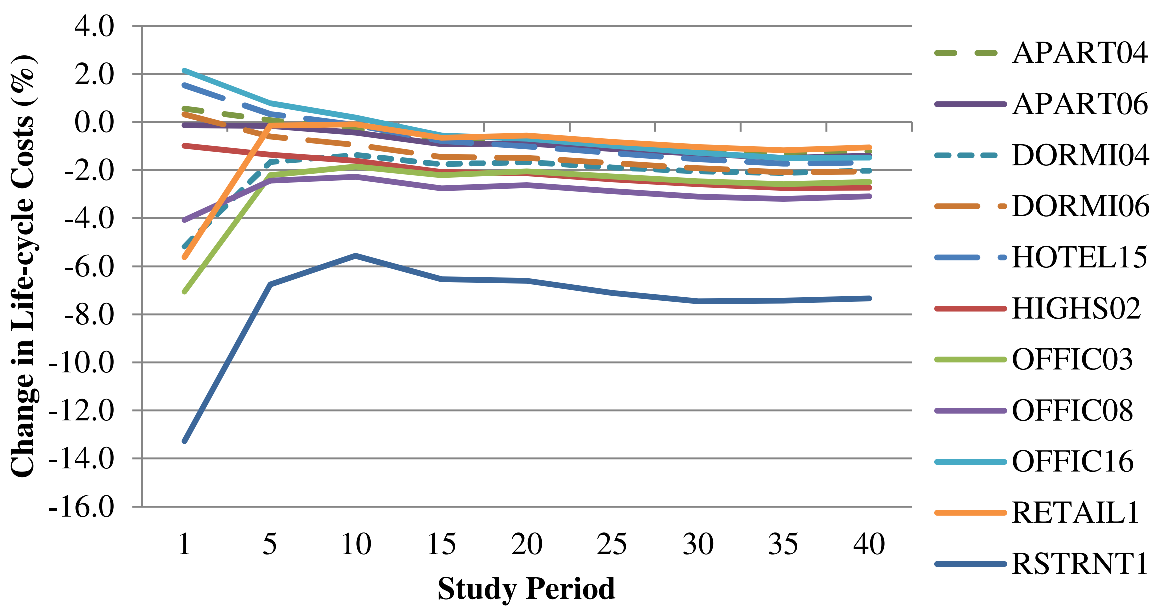

Figure 22-5 Average Change in Life-Cycle Costs by Building Type and Study Period Length

22.2.3 Region-wide Results by Building Type

For a 10-year study period length, Table 22-11 shows the simple average changes across all 71 cities in the South 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, hotel, and 16-story office building 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, 8-story office building, and 3-story office building realize the greatest percentage reduction in life-cycle costs. The 16-story office building realizes the only increase in life-cycle costs.

Table 22-11 South Region Percentage Change for LEC by Building Type, 10-Year

Building Type	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
APART04	-17.7	-21.6	-22.9	-0.3
APART06	-18.8	-23.5	-24.9	-0.4
DORMI04	-18.6	-22.1	-23.2	-1.4
DORMI06	-19.1	-23.8	-25.3	-0.9
HOTEL15	-16.2	-20.7	-22.1	-0.1
HIGHS02	-14.7	-20.5	-22.2	-1.6
OFFIC03	-24.5	-25.6	-25.9	-1.9
OFFIC08	-22.3	-22.8	-23.0	-2.3
OFFIC16	-17.1	-19.3	-20.0	0.2
RETAIL1	-19.7	-20.6	-20.9	-0.1
RSTRNT1	-32.3	-35.3	-36.0	-5.6
Average	**-20.1**	**-23.3**	**-24.2**	**-1.3**

22.2.4 Region-wide Results by Climate Zone

Table 22-12 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 22-12 Average Percentage Change for LEC by Climate Zone

Climate Zone	Energy Use	Energy Cost	Carbon Emissions	LCC
1	-21.2	-21.3	-22.0	-2.0
2	-19.2	-21.4	-21.9	-1.2
3	-21.8	-25.6	-26.9	-1.3
4	-18.1	-21.7	-23.3	-1.3
5	-22.8	-26.5	-33.9	-2.0
Average	**-20.1**	**-23.3**	**-24.5**	**-1.3**

Table 22-13 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 20.1 % with Zone 5 realizing the greatest reduction (22.8 %) and Zone 4 the smallest (18.1 %). Controlling for state energy codes, the warmer the climate the greater the reduction in energy use, which is a result of the energy efficiency improvement options (daylighting and overhangs) considered in the LEC design for cities located in Zone 1 through Zone 5.

Table 22-13 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				-21.2	-21.2
2	-37.4			-18.2	-19.2
3	-32.8	-27.4	-18.5	-17.5	-21.8
4		-27.1	-19.0	-16.4	-18.1
5		-22.8			-22.8
Grand Total	**-33.4**	**-26.5**	**-18.8**	**-17.6**	**-20.1**

Table 22-14 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 23.3 % with Zone 5 realizing the greatest average reduction in energy costs and Zone 1 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 22-14 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				-21.3	-21.3
2	-39.1			-20.4	-21.4
3	-36.8	-33.7	-22.3	-20.8	-25.6
4		-29.9	-21.9	-20.4	-21.7
5		-26.5			-26.5
Grand Total	**-37.1**	**-31.2**	**-22.1**	**-20.5**	**-23.3**

Table 22-15 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 22-15 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				-22.0	-22.0
2	-39.9			-21.0	-21.9
3	-38.8	-36.2	-23.3	-21.6	-26.9
4		-35.0	-23.0	-21.6	-23.3
5		-33.9			-33.9
Grand Total	**-39.0**	**-35.4**	**-23.1**	**-21.4**	**-24.5**

Table 22-16 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. The only exception is states that have adopted *ASHRAE 90.1-2004*.

Table 22-16 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				-2.0	-2.0
2	-2.2			-1.1	-1.2
3	-1.5	-3.4	-1.0	-1.0	-1.3
4		-2.3	-1.5	-1.0	-1.3
5		-2.0			-2.0
Grand Total	**-1.6**	**-2.8**	**-1.2**	**-1.1**	**-1.3**

23 Discussion

This study analyzes the impacts of adopting new, more stringent state energy codes for 71 cities located across the South Census Region. Results are summarized at the regional level as well as the state level for all sixteen Southern states. This section will discuss the key findings, limitations of the research, and recommended directions for future research.

23.1 Key Findings

Three states in the South Census Region have not yet adopted a state energy code for commercial buildings: Alabama, Mississippi, and Oklahoma. For these states, 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. The additional costs from implementing the energy efficiency measures overwhelm the future energy cost savings. *ASHRAE 90.1-2004* and *-2007* lead to greater reductions in energy use, energy costs, and carbon emissions than *ASHRAE 90.1-2001*, and are life-cycle cost-effective to adopt in two of the three states, with only Oklahoma realizing an increase in life-cycle costs.

Arkansas and West Virginia are the states in the South Census Region that have adopted *ASHRAE 90.1-2001* as their state energy code for commercial buildings. Both states would realize reductions in energy use, energy costs, and energy-related carbon emissions while realizing reductions in life-cycle costs from adopting *ASHRAE 90.1-2004* as their state energy code for commercial buildings. 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*.

Tennessee and South Carolina are the states in the South Census Region that have adopted *ASHRAE 90.1-2004* as their state energy code for commercial buildings. Both states would realize reductions in energy use, energy costs, and energy-related carbon emissions while realizing reductions in life-cycle costs from adopting *ASHRAE 90.1-2007*.

The adoption of the LEC design is analyzed for all sixteen 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 South 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 (20.1 %), energy costs (23.3 %), and carbon emissions (24.2 %), on average, while reducing life-cycle costs (1.3 %), on average, for a 10-year study period. Although the LEC design leads to reductions in energy use, energy costs, and carbon emissions for all states, the magnitude of the reductions varies according to each state's adopted energy code. The three states with no energy code realize the greatest percentage savings in energy use, energy costs, and carbon emissions. However, two of the three states realize percentage increases in life-cycle costs and the third state realizes a minimal percentage decrease. Meanwhile, the states that have already adopted *ASHRAE 90.1-2001*, *-2004*, or *-2007* realize percentage reductions in life-cycle costs.

The study period length impacts the resulting reductions in life-cycle costs. As the study period length increases from 5 years to 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 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 realize the smallest reductions while restaurants and 3- and 8-story office buildings realize the greatest reductions. The greatest percentage reductions in life-cycle costs 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 Texas than in Delaware because the amount of newly constructed floor area from 2003 to 2007 was 42 times greater in Texas.

A number of other factors impact total reductions in energy use, energy costs, and carbon emissions: state energy codes, energy rates, and emissions rates. The greatest 10-year reduction in energy use per unit of floor area resulting from adoption of the LEC design is realized by the three states that have no state energy code, ranging from 376 kWh/m^2 (119 $kBtu/ft^2$) to 551 kWh/m^2 (175 $kBtu/ft^2$), followed by the states that have adopted *ASHRAE 90.1-2001*, where the reduction ranges from 359 kWh/m^2 (114 $kBtu/ft^2$) to

370 kWh/m^2 (117 kBtu/ft^2). The states that have adopted *ASHRAE 90.1-2004* or *-2007* realize reductions ranging from 175 kWh/m^2 (56 kBtu/ft^2) to 247 kWh/m^2 (78 kBtu/ft^2). States with the highest electricity rates tend to realize the largest reductions in energy costs per unit of energy consumption reduced. Similarly, states with higher emission rates per unit of electricity generated tend to realize greater reductions in emissions per unit of energy consumption reduced. The greater the 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.

23.2 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 16 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 34 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 statewide averages of constructed floor area to summarize energy use, energy cost, carbon emissions, and life-cycle cost changes. However, the amount of total floor area constructed will vary significantly from city to city. Future research could develop a weighted average of savings in a state based on the fraction of newly constructed floor area by city. Second, the 11 prototypical buildings analyzed in this study are likely not representative of the entire building stock for each building type. For example, all high-rise buildings are not 100 % glazed, as assumed here. For this reason, the results should be considered as general magnitudes instead of hard numbers. Future research should include additional prototypes, such as the DOE Benchmark Buildings (NREL, 2011), in the database. Additionally, since existing buildings account for nearly the entire building stock, prototypes for retrofitting buildings should be incorporated into the BIRDS database as well. Another addition to expand the database is the inclusion of building designs to meet the newest edition of *ASHRAE 90.1* (*-2010*) as well as *ASHRAE*'s green building standard (*ASHRAE 189.1-2011*). The state average energy cost rates and energy-related carbon emissions rates do not control for local variation in energy tariffs or electricity fuel mixes. By using utility-level energy cost and emissions rate data, the accuracy of the estimates in BIRDS could be improved. Additionally, the fuel mix used for electricity generation across the United States will change over time as economic and regulatory conditions change. A range of potential emissions rates could be included to allow for potential changes in emissions rates in the future.

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

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

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

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A Building and Energy Characteristics

Table A-1 CBECS Categories and Subcategories

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

Category	Subcategory
Public Assembly	social or meeting recreation entertainment or culture library funeral home student activities center armory exhibition hall broadcasting studio transportation terminal
Public Order and Safety	police station fire station jail, reformatory, or penitentiary courthouse or probation office
Religious Worship	None
Service	vehicle service or vehicle repair shop vehicle storage/ maintenance (car barn) repair shop dry cleaner or laundromat post office or postal center car wash gas station photo processing shop beauty parlor or barber shop tanning salon copy center or printing shop kennel
Warehouse and Storage	refrigerated warehouse non-refrigerated warehouse distribution or shipping center
Other	airplane hangar crematorium laboratory telephone switching agricultural with some retail space manufacturing or industrial with some retail space data center or server farm
Vacant	None

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

State	Building Construction Floor Area in 1000 m² (1,000 ft²)										
	Apartment	Healthcare	Hotel	Office	Public Assembly	Restaurant	Retail	School	Warehouse	No Prototype	Total
AL	801 (8619)	705 (7587)	853 (9184)	1504 (16 191)	639 (6876)	169 (1821)	2485 (26 748)	1534 (16 514)	842 (9060)	1740 (18 729)	11 272 (121 329)
AR	118 (1272)	465 (5000)	483 (5198)	647 (6962)	335 (3611)	77 (829)	1359 (14 624)	1295 (13 936)	335 (3609)	815 (8768)	5928 (63 810)
DE	70 (755)	155 (1672)	124 (1330)	224 (2410)	119 (1282)	16 (173)	237 (2551)	290 (3126)	160 (1722)	323 (3480)	1719 (18 501)
FL	21 397 (230 315)	3399 (36 591)	2979 (32 071)	9031 (97 212)	3124 (33 622)	678 (7299)	11 904 (128 133)	7760 (83 524)	9692 (104 327)	12 748 (137 213)	82 712 (890 306)
GA	3696 (39 780)	1551 (16 699)	1510 (16 254)	3630 (39 076)	1212 (13 043)	331 (3563)	5893 (63 430)	5580 (60 062)	7449 (80 180)	5350 (57 586)	36 202 (389 672)
KY	268 (2888)	757 (8150)	643 (6922)	1167 (12 558)	760 (8185)	138 (1489)	1667 (17 941)	1270 (13 672)	2001 (21 538)	1106 (11 906)	9778 (105 248)
LA	169 (1823)	650 (7001)	807 (8689)	1175 (12 647)	593 (6386)	135 (1454)	1736 (18 681)	842 (9061)	1011 (10 886)	1379 (14 841)	8498 (91 469)
MD	3341 (35 967)	813 (8750)	826 (8888)	2802 (30 163)	580 (6242)	109 (1173)	1549 (16 672)	1527 (16 432)	1989 (21 414)	3388 (36 463)	16 924 (182 163)
MS	150 (1613)	336 (3618)	479 (5153)	631 (6789)	411 (4423)	55 (587)	1166 (12 551)	743 (7999)	1593 (17 146)	692 (7447)	6255 (67 326)
NC	1607 (17 294)	1362 (14 663)	1178 (12 678)	3368 (36 249)	1119 (12 044)	230 (2481)	4472 (48 139)	3418 (36 794)	1910 (20 559)	3520 (37 891)	22 185 (238 792)
OK	115 (1242)	794 (8547)	512 (5511)	763 (8216)	878 (9450)	141 (1523)	1364 (14 686)	1179 (12 691)	932 (10 032)	1271 (13 680)	7950 (85 577)
SC	1981 (21 321)	746 (8033)	563 (6056)	1539 (16 562)	539 (5801)	168 (1810)	2600 (27 984)	2222 (23 920)	1101 (11 848)	2132 (22 949)	13 590 (146 284)
TN	987 (10 621)	1036 (11 152)	683 (7347)	2296 (24 718)	733 (7891)	199 (2145)	3581 (38 548)	1809 (19 476)	2698 (29 045)	2337 (25 152)	16 360 (176 095)
TX	5548 (59 723)	4508 (48 519)	3571 (38 437)	8328 (89 641)	3325 (35 794)	849 (9142)	13 121 (141 238)	12 693 (136 629)	10 609 (114 193)	9676 (104 156)	72 230 (777 473)
VA	3502 (37 694)	1011 (10 887)	1361 (14 646)	3693 (39 749)	1096 (11 794)	200 (2149)	3014 (32 438)	2387 (25 691)	1826 (19 659)	4406 (47 422)	22 495 (242 129)
WV	65 (697)	215 (2314)	148 (1592)	193 (2081)	117 (1259)	39 (421)	668 (7191)	484 (5215)	179 (1930)	288 (3098)	2397 (25 797)
Total	43 815 (471 624)	18 505 (199 183)	16 718 (179 956)	40 991 (441 224)	15 580 (167 703)	3536 (38 059)	56 815 (611 555)	45 034 (484 742)	44 329 (477 148)	51 169 (550 781)	33 6492 (362 1971)

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
AL	7.1 %	6.3 %	7.6 %	13.3 %	5.7 %	1.5 %	22.0 %	13.6 %	7.5 %	15.4 %	100.0 %	65.2 %
AR	2.0 %	7.8 %	8.1 %	10.9 %	5.7 %	1.3 %	22.9 %	21.8 %	5.7 %	13.7 %	100.0 %	67.1 %
DE	4.1 %	9.0 %	7.2 %	13.0 %	6.9 %	0.9 %	13.8 %	16.9 %	9.3 %	18.8 %	100.0 %	55.9 %
FL	25.9 %	4.1 %	3.6 %	10.9 %	3.8 %	0.8 %	14.4 %	9.4 %	11.7 %	15.4 %	100.0 %	65.0 %
GA	10.2 %	4.3 %	4.2 %	10.0 %	3.3 %	0.9 %	16.3 %	15.4 %	20.6 %	14.8 %	100.0 %	57.0 %
KY	2.7 %	7.7 %	6.6 %	11.9 %	7.8 %	1.4 %	17.0 %	13.0 %	20.5 %	11.3 %	100.0 %	52.7 %
LA	2.0 %	7.7 %	9.5 %	13.8 %	7.0 %	1.6 %	20.4 %	9.9 %	11.9 %	16.2 %	100.0 %	57.2 %
MD	19.7 %	4.8 %	4.9 %	16.6 %	3.4 %	0.6 %	9.2 %	9.0 %	11.8 %	20.0 %	100.0 %	60.0 %
MS	2.4 %	5.4 %	7.7 %	10.1 %	6.6 %	0.9 %	18.6 %	11.9 %	25.5 %	11.1 %	100.0 %	51.5 %
NC	7.2 %	6.1 %	5.3 %	15.2 %	5.0 %	1.0 %	20.2 %	15.4 %	8.6 %	15.9 %	100.0 %	64.3 %
OK	1.5 %	10.0 %	6.4 %	9.6 %	11.0 %	1.8 %	17.2 %	14.8 %	11.7 %	16.0 %	100.0 %	51.3 %
SC	14.6 %	5.5 %	4.1 %	11.3 %	4.0 %	1.2 %	19.1 %	16.4 %	8.1 %	15.7 %	100.0 %	66.8 %
TN	6.0 %	6.3 %	4.2 %	14.0 %	4.5 %	1.2 %	21.9 %	11.1 %	16.5 %	14.3 %	100.0 %	58.4 %
TX	7.7 %	6.2 %	4.9 %	11.5 %	4.6 %	1.2 %	18.2 %	17.6 %	14.7 %	13.4 %	100.0 %	61.1 %
VA	15.6 %	4.5 %	6.0 %	16.4 %	4.9 %	0.9 %	13.4 %	10.6 %	8.1 %	19.6 %	100.0 %	62.9 %
WV	2.7 %	9.0 %	6.2 %	8.1 %	4.9 %	1.6 %	27.9 %	20.2 %	7.5 %	12.0 %	100.0 %	66.7 %

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

State	CO_2 (t/GWh)	CH4 (t/GWh)	N2O (t/GWh)
AL	804.2	42.7	0.5
AR	695.9	58.6	1.7
DE	618.7	33.4	0.4
FL	767.5	57.2	1.5
GA	804.2	42.7	0.5
KY	781.9	36.9	0.2
LA	719.2	59.2	1.6
MD	618.7	33.4	0.4
MS	709.8	48.3	1.0
NC	616.6	30.5	0.2
OK	904.8	63.9	1.4
SC	616.6	30.5	0.2
TN	781.9	36.9	0.2
TX	790.9	65.8	1.8
VA	689.6	33.3	0.2
WV	835.7	38.9	0.2

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
AL	-35.2	-40.3	-42.9	-3.4
AR	-29.0	-36.6	-39.4	-1.8
DE	-10.4	-15.0	-16.0	-0.2
FL	-16.6	-17.7	-17.8	-0.3
GA	-14.3	-17.7	-18.8	0.4
KY	-11.5	-15.6	-17.9	0.7
LA	-15.4	-17.6	-18.3	0.5
MD	-10.9	-17.1	-16.4	0.2
MS	-35.7	-42.4	-42.6	-3.3
NC	-13.5	-17.0	-18.1	0.4
OK	-27.2	-35.1	-40.8	-1.3
SC	-18.0	-22.6	-23.2	-0.1
TN	-16.1	-20.5	-21.3	-0.1
TX	-15.0	-18.6	-18.6	0.0
VA	-12.6	-17.0	-18.1	0.5
WV	-25.3	-29.8	-38.9	-0.8

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
AL	-35.6	-41.2	-44.1	-3.5
AR	-29.8	-37.9	-40.8	-1.9
DE	-11.2	-17.0	-18.2	-0.4
FL	-17.5	-18.9	-19.0	-0.4
GA	-15.5	-19.5	-20.9	0.3
KY	-13.4	-18.6	-21.4	0.5
LA	-16.5	-19.1	-20.0	0.4
MD	-12.1	-19.9	-19.0	0.0
MS	-36.2	-43.3	-43.5	-3.4
NC	-14.8	-19.2	-20.6	0.2
OK	-28.1	-36.5	-42.6	-1.5
SC	-18.9	-24.4	-25.1	-0.2
TN	-17.3	-22.9	-23.9	-0.3
TX	-16.3	-20.6	-20.6	-0.2
VA	-14.4	-20.0	-21.3	0.3
WV	-26.2	-31.2	-41.0	-0.8

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AL	-36.7	-41.7	-44.2	-2.9
AR	-28.8	-37.1	-40.0	-4.9
DE	-12.3	-16.3	-17.2	-0.5
FL	-17.4	-18.4	-18.5	-2.1
GA	-15.1	-18.1	-19.1	-1.2
KY	-12.9	-16.4	-18.3	-1.0
LA	-15.5	-17.8	-18.5	-0.8
MD	-12.5	-17.8	-17.2	-0.2
MS	-39.0	-44.2	-44.4	-1.8
NC	-14.8	-17.7	-18.5	-0.7
OK	-27.6	-36.1	-42.2	0.0
SC	-16.9	-21.7	-22.3	-1.3
TN	-17.3	-20.4	-20.9	-1.1
TX	-15.5	-18.6	-18.7	-0.9
VA	-14.3	-17.9	-18.7	-0.7
WV	-26.7	-31.0	-38.8	-3.3

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AL	-37.9	-43.7	-46.7	-4.9
AR	-30.8	-39.1	-42.1	-2.9
DE	-11.3	-16.9	-18.0	-0.8
FL	-18.4	-20.0	-20.1	-0.9
GA	-15.5	-19.7	-21.2	-0.1
KY	-12.9	-17.9	-20.6	0.2
LA	-16.7	-19.6	-20.6	0.0
MD	-12.0	-19.7	-18.8	-0.4
MS	-38.2	-45.6	-45.9	-4.7
NC	-14.7	-19.1	-20.4	-0.1
OK	-29.9	-38.5	-44.8	-2.6
SC	-20.2	-26.0	-26.8	-0.7
TN	-16.1	-21.9	-22.9	-0.5
TX	-16.3	-20.9	-20.9	-0.6
VA	-14.2	-19.6	-20.8	0.0
WV	-24.4	-29.6	-39.1	-1.4

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
AL	-30.3	-36.2	-39.2	-3.0
AR	-21.5	-32.1	-36.0	-1.6
DE	-13.1	-17.6	-18.5	-0.6
FL	-16.7	-18.8	-19.0	-0.1
GA	-14.5	-18.5	-19.9	0.4
KY	-13.7	-17.6	-19.8	0.6
LA	-14.5	-18.1	-19.3	0.6
MD	-13.4	-19.4	-18.7	-0.1
MS	-34.4	-37.0	-37.1	-2.8
NC	-14.9	-18.4	-19.4	0.3
OK	-19.7	-29.9	-37.5	-1.2
SC	-8.5	-14.6	-15.4	0.9
TN	-9.6	-13.6	-14.3	0.8
TX	-14.9	-19.6	-19.6	0.0
VA	-14.9	-18.8	-19.8	0.4
WV	-18.9	-23.4	-32.3	-0.6

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
AL	-23.6	-29.4	-32.7	-3.3
AR	-16.5	-25.0	-28.5	-1.8
DE	-6.4	-13.3	-14.8	-1.8
FL	-21.2	-23.4	-23.7	-1.9
GA	-12.6	-18.2	-20.3	-1.6
KY	-8.0	-14.1	-17.8	-0.9
LA	-15.4	-19.5	-21.0	-0.8
MD	-7.2	-16.9	-15.6	-1.7
MS	-26.7	-33.1	-33.4	-3.4
NC	-10.5	-16.2	-18.1	-1.1
OK	-15.0	-22.8	-29.7	-1.3
SC	-13.8	-19.8	-20.6	-1.3
TN	-12.9	-19.9	-21.3	-1.7
TX	-14.7	-21.0	-21.1	-1.7
VA	-9.2	-16.4	-18.3	-0.6
WV	-13.3	-17.1	-26.4	-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
AL	-31.7	-32.2	-32.4	-0.7
AR	-30.0	-31.4	-31.9	-5.2
DE	-19.7	-21.1	-21.3	-3.2
FL	-20.1	-20.2	-20.2	-2.6
GA	-19.5	-20.2	-20.4	-1.7
KY	-19.5	-20.8	-21.4	-2.4
LA	-19.9	-20.2	-20.3	-1.8
MD	-19.7	-21.4	-21.2	-2.9
MS	-32.4	-32.0	-31.9	1.1
NC	-20.2	-20.9	-21.1	-1.9
OK	-31.2	-32.9	-34.0	0.9
SC	-21.7	-21.9	-22.0	-2.2
TN	-23.4	-22.7	-22.6	-3.0
TX	-19.9	-20.5	-20.5	-2.6
VA	-20.8	-21.7	-21.9	-2.2
WV	-30.1	-30.4	-30.3	-4.8

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
AL	-23.3	-25.1	-26.0	-1.0
AR	-18.2	-23.8	-25.7	0.0
DE	-16.0	-19.4	-19.9	-1.0
FL	-17.6	-18.5	-18.5	-0.2
GA	-16.5	-18.4	-19.1	0.5
KY	-16.2	-19.3	-20.7	0.7
LA	-16.6	-18.3	-18.8	0.7
MD	-16.0	-20.1	-19.7	-0.3
MS	-27.3	-24.8	-24.7	-0.5
NC	-17.2	-19.1	-19.6	0.4
OK	-17.3	-23.0	-26.9	0.3
SC	-12.1	-15.5	-15.9	1.0
TN	-12.3	-15.0	-15.4	0.8
TX	-16.8	-19.1	-19.1	-0.1
VA	-18.0	-20.6	-21.1	0.4
WV	-16.9	-19.1	-23.0	0.9

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
AL	-35.1	-35.6	-35.9	-0.9
AR	-29.8	-31.8	-32.5	-1.7
DE	-14.2	-16.7	-17.1	-0.8
FL	-17.9	-18.2	-18.2	-0.7
GA	-15.5	-16.5	-16.8	0.5
KY	-14.9	-17.2	-18.3	0.5
LA	-15.0	-15.5	-15.7	0.7
MD	-14.3	-17.3	-17.0	-0.1
MS	-40.6	-38.8	-38.8	-0.3
NC	-15.8	-17.2	-17.6	0.1
OK	-30.5	-32.6	-34.0	1.9
SC	-20.2	-20.5	-20.5	0.2
TN	-23.1	-22.6	-22.5	-0.4
TX	-15.3	-16.5	-16.5	0.0
VA	-16.1	-18.2	-18.7	0.5
WV	-30.7	-31.6	-32.9	-1.8

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

State	Percentage Change			
	Energy Use	Energy Cost	Carbon	LCC
AL	-43.9	-46.5	-47.7	-3.4
AR	-39.8	-44.8	-46.5	-10.3
DE	-27.7	-32.2	-33.0	-8.5
FL	-30.5	-31.5	-31.6	-5.3
GA	-30.0	-32.7	-33.6	-4.9
KY	-27.9	-32.3	-34.3	-5.4
LA	-29.3	-31.3	-31.9	-6.0
MD	-27.7	-33.5	-32.9	-9.0
MS	-46.0	-47.7	-47.7	-1.9
NC	-30.2	-33.0	-33.8	-4.8
OK	-39.7	-45.1	-48.8	-3.1
SC	-32.0	-34.7	-35.1	-4.2
TN	-32.9	-35.6	-36.1	-7.7
TX	-29.8	-33.2	-33.2	-5.9
VA	-30.3	-34.0	-34.8	-5.4
WV	-39.3	-41.8	-45.3	-6.4