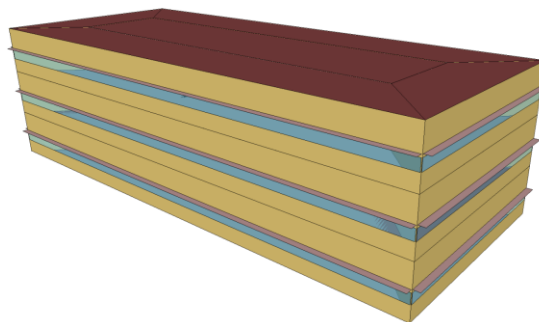
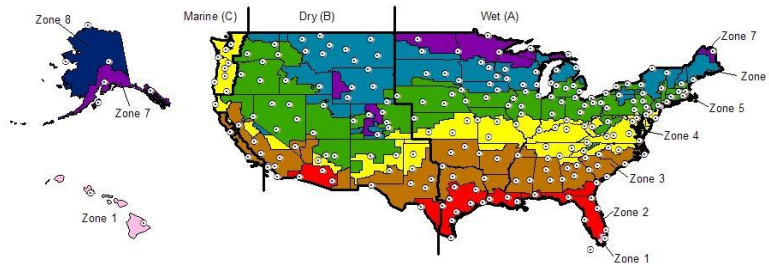


NIST Special Publication 1161

# Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: National Summary

Joshua Kneifel

<http://dx.doi.org/10.6028/NIST.SP.1161>



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



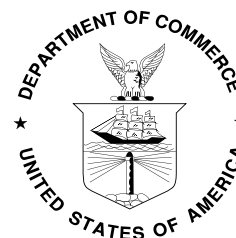
**NIST Special Publication 1161**

# **Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: National Summary**

Joshua Kneifel  
*Applied Economics Office  
Engineering Laboratory*

<http://dx.doi.org/10.6028/NIST.SP.1161>

May 2013



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

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

Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

**National Institute of Standards and Technology Special Publication 1161**  
**Natl. Inst. Stand. Technol. Spec. Publ. 1161, 134 pages (May 2013)**  
<http://dx.doi.org/10.6028/NIST.SP.1161>  
**CODEN: NSPUE2**

## **Abstract**

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

The results of this report are based on analysis of the Building Industry Reporting and Design for Sustainability (BIRDS) database, which includes 12 540 whole building energy simulations covering 11 building types in 228 cities across all U.S. states for 9 study period lengths. The performance of buildings designed to meet current state energy codes is compared to their performance when meeting new editions of *ASHRAE 90.1-2007* design requirements 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 based on *ASHRAE 189.1-2009*, which increases energy efficiency beyond the *ASHRAE 90.1-2007* design. The estimated savings for each of the building types are aggregated using state-level new commercial building construction data to calculate the magnitude of the incremental savings that a state may realize if it were to adopt a more energy efficient standard as its state energy code. These state-level estimates are further aggregated to the national level to estimate the potential total impact from nationwide adoption of more stringent energy codes.

## **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 use, 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.

## **Disclaimers**

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





## **Acknowledgements**

The author wishes to thank all those who contributed ideas and suggestions for this report. They include Dr. David Butry, Ms. Barbara Lippiatt, and Dr. Robert Chapman of EL's Applied Economics Office, Dr. William Healy of EL's Energy and Environment Division, and Dr. Nicos S. Martys of EL's Materials and Structural Systems Division. A special thanks to Mr. Nicholas Long and the EnergyPlus Team for generating the initial energy simulations for this project. Thanks to Mr. Brian Presser for adapting the energy simulations to meet the study requirements and generating the final simulations used in the database. Thanks to Mr. Nathaniel Soares for developing the initial version of the BIRDS database, and to Ms. Priya Lavappa for enhancing the database for the current analysis.

## **Author Information**

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



# Table of Contents

|                                                                      |             |
|----------------------------------------------------------------------|-------------|
| <b>Abstract.....</b>                                                 | <b>v</b>    |
| <b>Preface.....</b>                                                  | <b>vii</b>  |
| <b>Acknowledgements .....</b>                                        | <b>ix</b>   |
| <b>Author Information .....</b>                                      | <b>ix</b>   |
| <b>List of Figures.....</b>                                          | <b>xiii</b> |
| <b>List of Tables .....</b>                                          | <b>xv</b>   |
| <b>List of Acronyms .....</b>                                        | <b>xix</b>  |
| <b>Executive Summary .....</b>                                       | <b>xxi</b>  |
| <b>1 Introduction.....</b>                                           | <b>1</b>    |
| 1.1 Background .....                                                 | 1           |
| 1.2 Literature Review .....                                          | 1           |
| 1.3 Purpose .....                                                    | 3           |
| 1.4 Approach .....                                                   | 3           |
| <b>2 Study Design .....</b>                                          | <b>5</b>    |
| 2.1 Building Types .....                                             | 5           |
| 2.2 Building Designs .....                                           | 6           |
| 2.3 Study Period Lengths .....                                       | 9           |
| <b>3 Cost Data.....</b>                                              | <b>11</b>   |
| 3.1 First Costs.....                                                 | 11          |
| 3.2 Future Costs.....                                                | 14          |
| <b>4 Building Stock Data .....</b>                                   | <b>17</b>   |
| 4.1 Databases.....                                                   | 17          |
| 4.2 Weighting Factors .....                                          | 17          |
| <b>5 Analysis Approach .....</b>                                     | <b>19</b>   |
| 5.1 Energy Use .....                                                 | 19          |
| 5.2 Life-Cycle Costing .....                                         | 19          |
| 5.3 Carbon Assessment .....                                          | 20          |
| 5.4 Analysis Metrics.....                                            | 21          |
| 5.5 Regression Analysis .....                                        | 23          |
| <b>6 Nationwide Impacts of Adopting Low Energy Case Design .....</b> | <b>25</b>   |
| 6.1 Percentage Changes.....                                          | 25          |
| 6.1.1 Results by Study Period Length.....                            | 25          |
| 6.1.2 Results by Building Type.....                                  | 28          |
| 6.1.3 Results by Climate Zone .....                                  | 29          |
| 6.1.4 Results by State Energy Code.....                              | 33          |
| 6.1.4.1 Energy Use, Energy Cost, and Carbon Emissions Savings.....   | 35          |
| 6.1.4.2 Life-Cycle Cost Savings.....                                 | 40          |
| 6.2 Total Changes.....                                               | 41          |
| 6.2.1 State-Level Total Savings .....                                | 41          |
| 6.2.2 Regional and National Total Savings .....                      | 43          |
| 6.3 Changes per Unit of Floor Area and Energy Use Savings.....       | 44          |
| 6.3.1 State Level Changes.....                                       | 44          |

|          |                                                                                                            |            |
|----------|------------------------------------------------------------------------------------------------------------|------------|
| 6.3.1.1  | Energy Use Savings per Unit of Floor Area.....                                                             | 44         |
| 6.3.1.2  | Life-Cycle Cost Savings per Unit of Floor Area.....                                                        | 45         |
| 6.3.1.3  | Energy Cost Savings per Unit of Energy Use Savings .....                                                   | 46         |
| 6.3.1.4  | Carbon Emissions Savings per Unit of Energy Use Savings ....                                               | 48         |
| 6.3.2    | Regional and National Level Changes.....                                                                   | 50         |
| 6.4      | Within-State Impacts of Adopting Low Energy Case Design .....                                              | 53         |
| 6.4.1    | Energy Use Savings across Cities.....                                                                      | 53         |
| 6.4.2    | Life-Cycle Cost Savings across Cities.....                                                                 | 57         |
| <b>7</b> | <b>Nationwide Impacts of Adopting ASHRAE 90.1-2007.....</b>                                                | <b>63</b>  |
| 7.1      | Percentage Changes.....                                                                                    | 63         |
| 7.1.1    | Results by Study Period Length.....                                                                        | 63         |
| 7.1.2    | Results by Building Type.....                                                                              | 66         |
| 7.1.3    | Results by Climate Zone.....                                                                               | 67         |
| 7.1.4    | Results by State Energy Code.....                                                                          | 70         |
| 7.2      | Total Changes.....                                                                                         | 74         |
| 7.2.1    | State-Level Total Savings .....                                                                            | 74         |
| 7.2.2    | Regional and National Total Savings .....                                                                  | 77         |
| 7.3      | Changes per Unit of Floor Area and Energy Use Savings.....                                                 | 78         |
| 7.3.1    | State Level Changes.....                                                                                   | 78         |
| 7.3.1.1  | Energy Use Savings per Unit of Floor Area.....                                                             | 78         |
| 7.3.1.2  | Life-Cycle Cost Savings per Unit of Floor Area.....                                                        | 79         |
| 7.3.1.3  | Energy Cost Savings per Unit of Energy Use Savings .....                                                   | 79         |
| 7.3.1.4  | Carbon Emissions Savings per Unit of Energy Use Savings ....                                               | 82         |
| 7.3.2    | Regional and National Level Changes.....                                                                   | 84         |
| <b>8</b> | <b>Incremental Impacts from Adopting More Stringent Standard Editions .....</b>                            | <b>87</b>  |
| 8.1      | Energy Use Savings .....                                                                                   | 87         |
| 8.2      | Life-Cycle Cost Savings.....                                                                               | 89         |
| <b>9</b> | <b>Discussion.....</b>                                                                                     | <b>93</b>  |
| 9.1      | Key Findings .....                                                                                         | 93         |
| 9.1.1    | Percentage Changes .....                                                                                   | 93         |
| 9.1.2    | Total Changes .....                                                                                        | 95         |
| 9.1.3    | Change per Unit of Floor Area .....                                                                        | 96         |
| 9.1.4    | Incremental Changes from Adopting More Stringent Standard Editions.                                        | 97         |
| 9.2      | Limitations and Future Research.....                                                                       | 97         |
|          | <b>References.....</b>                                                                                     | <b>101</b> |
| <b>A</b> | <b>Building Type, New Construction, and Emissions Rates .....</b>                                          | <b>105</b> |
| <b>B</b> | <b>Percentage Changes by Building Type for the Nationwide Adoption of the LEC Design .....</b>             | <b>111</b> |
| <b>C</b> | <b>Total Changes from Nationwide Adoption of the LEC Design .....</b>                                      | <b>121</b> |
| <b>D</b> | <b>Percentage Changes by Building Type for the Nationwide Adoption of the ASHRAE 90.1-2007 Design.....</b> | <b>127</b> |
| <b>E</b> | <b>Total Changes from Nationwide Adoption of the ASHRAE 90.1-2007 Design</b>                               | <b>131</b> |

## List of Figures

|             |                                                                                                                                                  |    |
|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 2-1  | State Commercial Energy Codes .....                                                                                                              | 8  |
| Figure 2-2  | Cities and ASHRAE Climate Zones .....                                                                                                            | 9  |
| Figure 6-1  | Nationwide Average Percentage Change in Life-cycle Costs from Nationwide Adoption of the LEC Design by Building Type and Study Period Length ... | 28 |
| Figure 6-2  | States with Energy Standard Editions 2001 or Older or No energy code .....                                                                       | 34 |
| Figure 6-3  | Average Energy Use, Energy Cost, and Carbon Emissions Savings by State, 3-Story Office Building, 10-Year .....                                   | 36 |
| Figure 6-4  | Total Energy Use – High School – Tennessee .....                                                                                                 | 38 |
| Figure 6-5  | Change in Energy Use – High School – Tennessee .....                                                                                             | 39 |
| Figure 6-6  | Percentage Change in Energy Use – High School – Tennessee .....                                                                                  | 39 |
| Figure 6-7  | Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year .....                                                                 | 40 |
| Figure 6-8  | Average Annual New Floor Area by State .....                                                                                                     | 41 |
| Figure 6-9  | Total Energy Use, Energy Costs, and Carbon Emissions Savings by State, 10-Year .....                                                             | 42 |
| Figure 6-10 | Total Life-Cycle Cost Savings by State, 10-Year .....                                                                                            | 43 |
| Figure 6-11 | Energy Use Savings per Unit of Floor Area by State, 10-Year .....                                                                                | 45 |
| Figure 6-12 | Life-Cycle Cost Savings per Unit of Floor Area by State, 10-Yr .....                                                                             | 46 |
| Figure 6-13 | Energy Cost Savings per Unit of Energy Use Savings and Average Electricity Price by State .....                                                  | 47 |
| Figure 6-14 | Weighted Average Offset by State .....                                                                                                           | 48 |
| Figure 6-15 | Average State Energy Cost Savings per Unit of Energy Use Savings by Weighted Average Offset and Energy Price Differential .....                  | 48 |
| Figure 6-16 | Energy-related Carbon Emissions Savings per Unit of Energy Use Savings and Average Electricity Emissions Rate by State .....                     | 49 |
| Figure 6-17 | Average State Carbon Emissions Savings per Unit of Floor Area by Weighted Average Offset and Energy Emissions Rate Differential .....            | 50 |
| Figure 6-18 | Average Percentage Change in Energy Use by City - Texas .....                                                                                    | 53 |
| Figure 7-1  | States with Energy Code based on <i>ASHRAE 90.1-2001</i> or No Energy Code                                                                       | 71 |
| Figure 7-2  | States with Energy Code based on <i>ASHRAE 90.1-2007</i> (Shown in Gray) ...                                                                     | 71 |
| Figure 7-3  | Average Energy Use Savings by State, 3-Story Office Building, 10-Year ...                                                                        | 73 |
| Figure 7-4  | Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year .....                                                                 | 74 |
| Figure 7-5  | Average Annual New Floor Area by State .....                                                                                                     | 75 |
| Figure 7-6  | Total Energy Use, Energy Cost, and Carbon Emissions Savings by State, 10-Year .....                                                              | 76 |
| Figure 7-7  | Total Life-Cycle Cost Savings by State, 10-Year .....                                                                                            | 77 |
| Figure 7-8  | Energy Use Savings per Unit of Floor Area by State, 10-Year .....                                                                                | 79 |
| Figure 7-9  | Life-Cycle Cost Savings per Unit of Floor Area by State, 10-Yr .....                                                                             | 79 |
| Figure 7-10 | Energy Cost Savings per Unit of Energy Use Savings and Average Electricity Price by State .....                                                  | 80 |
| Figure 7-11 | Weighted Average Offset by State .....                                                                                                           | 81 |
| Figure 7-12 | Average State Energy Cost Savings per Unit of Energy Use Savings by Weighted Average Offset and Energy Price Differential .....                  | 82 |

|                                                                                                                                                      |    |
|------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 7-13 Energy-related Carbon Emissions Savings per Unit of Energy Use Savings<br>and Average Electricity Emissions Rate by State.....           | 83 |
| Figure 7-14 Average State Carbon Emissions Savings per Unit of Energy Use by<br>Weighted Average Offset and Energy Emissions Rate Differential ..... | 84 |
| Figure 8-1 Incremental Energy Use Savings by State and Standard Edition .....                                                                        | 89 |
| Figure 8-2 Incremental Life-cycle Cost Savings by State and Building Design .....                                                                    | 92 |

## List of Tables

|                                                                                                                                                    |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Table 2-1 Building Characteristics .....                                                                                                           | 5  |
| Table 2-2 Energy Code by State and City Exception .....                                                                                            | 7  |
| Table 3-1 Energy Efficiency Component Requirements for Alternative Building Designs .....                                                          | 12 |
| Table 3-2 Energy Efficiency Component Requirements for the <i>ASHRAE 90.1-2007</i> ,<br><i>ASHRAE 90.1-2010</i> , and LEC Designs .....            | 13 |
| Table 3-3 HVAC Energy Efficiency Requirements for Alternative Building Designs...                                                                  | 13 |
| Table 4-1 New Commercial Building Construction (U.S., 2003 through 2007).....                                                                      | 18 |
| Table 5-1 Greenhouse Gas Global Warming Potentials.....                                                                                            | 21 |
| Table 6-1 Nationwide Average Percentage Change in Energy Use from Adoption of the<br>LEC Design by Building Type .....                             | 25 |
| Table 6-2 Nationwide Average Percentage Change in Energy Costs from Adoption of<br>the LEC Design by Building Type and Study Period Length .....   | 26 |
| Table 6-3 Nationwide Average Percentage Change in Carbon Emissions from Adoption<br>of the LEC Design by Building Type .....                       | 27 |
| Table 6-4 National Average Percentage Change in Life-Cycle Costs from Adoption of<br>the LEC Design by Building Type and Study Period Length ..... | 27 |
| Table 6-5 Nationwide Average Percentage Change for Adoption of the LEC Design by<br>Building Type, 10-Year .....                                   | 29 |
| Table 6-6 Average Percentage Change in Energy Use for LEC by Climate Zone and<br>State Energy Code .....                                           | 30 |
| Table 6-7 Average Percentage Change in Energy Costs for LEC by Climate Zone and<br>State Energy Code, 10-Year .....                                | 31 |
| Table 6-8 Average Change in Energy-related Carbon Emissions for LEC by Climate<br>Zone and State Energy Code .....                                 | 32 |
| Table 6-9 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and<br>Study Period.....                                           | 33 |
| Table 6-10 Average Percentage Change by State, 3-Story Office Building, 10-Year ....                                                               | 35 |
| Table 6-11 Fuel Source Reduction Example .....                                                                                                     | 37 |
| Table 6-12 Emissions and Energy Costs Associated with Fuel Source Reductions .....                                                                 | 37 |
| Table 6-13 Total Reductions by Census Region from Adoption of the LEC Design, 10-<br>Year.....                                                     | 44 |
| Table 6-14 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC<br>Design by Census Region, 10-Year.....                            | 51 |
| Table 6-15 Energy Cost Reduction per kWh of Energy Use Reduction for Adoption of<br>the LEC Design by Census Region, 10-Year .....                 | 51 |
| Table 6-16 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the<br>LEC Design by Census Region, 10-Year .....                      | 52 |
| Table 6-17 Life-Cycle Cost Reductions per Unit of New Floor Area for Adoption of the<br>LEC Design by Census Region, 10-Year .....                 | 52 |
| Table 6-18 Variation in Energy Use, Heating Degree Days, and Cooling Degree Days for<br>Cities located in Climate Zone 3B in Texas .....           | 54 |
| Table 6-19 Regression Analysis – Percentage Change in Energy Use from Adopting the<br>LEC Design by City.....                                      | 56 |
| Table 6-20 Regression Analysis, Within State Variation in Life-Cycle Costs.....                                                                    | 58 |

|            |                                                                                                                                         |     |
|------------|-----------------------------------------------------------------------------------------------------------------------------------------|-----|
| Table 6-21 | Regression Analysis – Percentage Change in Life-cycle Costs from Adopting the LEC Design by City.....                                   | 60  |
| Table 7-1  | Nationwide Average Percentage Change in Energy Use from Adoption of ASHRAE 90.1-2007 by Building Type .....                             | 64  |
| Table 7-2  | Nationwide Average Percentage Change in Energy Costs from Adoption of ASHRAE 90.1-2007 by Building Type and Study Period Length .....   | 64  |
| Table 7-3  | Nationwide Average Percentage Change in Carbon Emissions from Adoption of ASHRAE 90.1-2007 by Building Type.....                        | 65  |
| Table 7-4  | National Average Percentage Change in Life-Cycle Costs from Adoption of ASHRAE 90.1-2007 by Building Type and Study Period Length ..... | 65  |
| Table 7-5  | Nationwide Percentage Change for ASHRAE 90.1-2007 by Building Type, 10-Year .....                                                       | 66  |
| Table 7-6  | Average Percentage Change in Energy Use for ASHRAE 90.1-2007 by Climate Zone .....                                                      | 67  |
| Table 7-7  | Average Percentage Change in Energy Costs for ASHRAE 90.1-2007 by Climate Zone, 10-Year .....                                           | 68  |
| Table 7-8  | Average Change in Energy-related Carbon Emissions for ASHRAE 90.1-2007 by Climate Zone .....                                            | 70  |
| Table 7-9  | Average Percentage Change by State, 3-Story Office Building, 10-Year .....                                                              | 72  |
| Table 7-10 | Total Reductions by Census Region from Adoption of the ASHRAE 90.1-2007 Design, 10-Year.....                                            | 78  |
| Table 7-11 | Energy Use Reduction per Unit of Floor Area for Adoption of the ASHRAE 90.1-2007 Design by Census Region, 10-Year .....                 | 84  |
| Table 7-12 | Energy Cost Reduction per kWh of Energy Use Reduction for Adoption of the ASHRAE 90.1-2007 Design by Census Region, 10-Year.....        | 85  |
| Table 7-13 | Carbon Reduction per GWh of Energy Use Reduction for Adoption of the ASHRAE 90.1-2007 Design by Census Region, 10-Year.....             | 85  |
| Table 7-14 | Life-Cycle Cost Reductions per Unit of New Floor Area for Adoption of the ASHRAE 90.1-2007 Design by Census Region, 10-Year.....        | 86  |
| Table 8-1  | Incremental Change in Energy Use by State and Building Design, 10-Year..                                                                | 87  |
| Table 8-2  | Change in Energy Use per Unit of Floor Area by State and Building Design, 10-Year .....                                                 | 88  |
| Table 8-3  | Incremental Change in Life-Cycle Cost Reductions by State and Building Design, 10-Year .....                                            | 90  |
| Table 8-4  | Incremental Change in Life-Cycle Cost Reductions per Unit of New Floor Area by State and Building Design, 10-Year .....                 | 91  |
| Table A-1  | CBECS Categories and Subcategories .....                                                                                                | 105 |
| Table A-2  | New Commercial Building Construction Volume for 2003 through 2007 by State and Building Type (S-I).....                                 | 107 |
| Table A-3  | New Commercial Building Construction Volume for 2003 through 2007 by State and Building Type (I-P).....                                 | 108 |
| Table A-4  | New Commercial Building Construction Share by State and Building Type .....                                                             | 109 |
| Table A-5  | CO <sub>2</sub> , CH <sub>4</sub> , and N <sub>2</sub> O Emissions Rates Electricity Generation by State.....                           | 110 |
| Table B-1  | 4-Story Apartment Building Summary Table for LEC and 10-Year Study Period.....                                                          | 111 |



|            |                                                                                                               |     |
|------------|---------------------------------------------------------------------------------------------------------------|-----|
| Table B-2  | 6-Story Apartment Building Summary Table for LEC and 10-Year Study Period.....                                | 112 |
| Table B-3  | 4-Story Dormitory Summary Table for LEC and 10-Year Study Period .....                                        | 113 |
| Table B-4  | 6-Story Dormitory Summary Table for LEC and 10-Year Study Period .....                                        | 114 |
| Table B-5  | 15-Story Hotel Building Summary Table for LEC and 10-Year Study Period .....                                  | 115 |
| Table B-6  | 2-Story High School Summary Table for LEC and 10-Year Study Period                                            | 116 |
| Table B-7  | 8-Story Office Building Summary Table for LEC and 10-Year Study Period .....                                  | 117 |
| Table B-8  | 16-Story Office Building Summary Table for LEC and 10-Year Study Period .....                                 | 118 |
| Table B-9  | 1-Story Retail Store Summary Table for LEC and 10-Year Study Period.                                          | 119 |
| Table B-10 | 1-Story Restaurant Summary Table for LEC and 10-Year Study Period.                                            | 120 |
| Table C-1  | Total Reductions by State for Adoption of the LEC Design, 10-Year .....                                       | 121 |
| Table C-2  | Energy Use Reduction per Unit of Floor Area from Adoption of the LEC Design, 10-Year .....                    | 122 |
| Table C-3  | Life-Cycle Cost Reductions per Unit of New Floor Area from Adoption of the LEC Design, 10-Year .....          | 123 |
| Table C-4  | Energy Cost Reduction per kWh of Energy Use Reduction from Adoption of the LEC Design, 10-Year .....          | 124 |
| Table C-5  | Carbon Reduction per GWh of Energy Use Reduction from Adoption of the LEC Design, 10-Year .....               | 125 |
| Table D-1  | 4-Story Apartment Building Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period .....           | 127 |
| Table D-2  | 6-Story Apartment Building Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period .....           | 127 |
| Table D-3  | 4-Story Dormitory Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period.....                     | 128 |
| Table D-4  | 6-Story Dormitory Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period.....                     | 128 |
| Table D-5  | 15-Story Hotel Building Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period .....              | 128 |
| Table D-6  | 2-Story High School Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period.....                   | 129 |
| Table D-7  | 8-Story Office Building Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period .....              | 129 |
| Table D-8  | 16-Story Office Building Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period .....             | 129 |
| Table D-9  | 1-Story Retail Store Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period.....                  | 130 |
| Table D-10 | 1-Story Restaurant Summary Table for <i>ASHRAE 90.1-2007</i> and 10-Year Study Period.....                    | 130 |
| Table E-1  | Total Reductions by State for Adoption of the <i>ASHRAE 90.1-2007</i> Design, 10-Year.....                    | 131 |
| Table E-2  | Energy Use Reduction per Unit of Floor Area from Adoption of the <i>ASHRAE 90.1-2007</i> Design, 10-Year..... | 132 |

|           |                                                                                                                             |     |
|-----------|-----------------------------------------------------------------------------------------------------------------------------|-----|
| Table E-3 | Life-Cycle Cost Reductions per Unit of New Floor Area from Adoption of the<br><i>ASHRAE 90.1-2007</i> Design, 10-Year ..... | 133 |
| Table E-4 | Energy Cost Reduction per kWh of Energy Use Reduction from Adoption of<br>the <i>ASHRAE 90.1-2007</i> Design, 10-Year ..... | 133 |
| Table E-5 | Carbon Reduction per GWh of Energy Use Reduction from Adoption of the<br><i>ASHRAE 90.1-2007</i> Design, 10-Year .....      | 134 |

## List of Acronyms

| <b>Acronym</b>    | <b>Definition</b>                                                         |
|-------------------|---------------------------------------------------------------------------|
| 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 <sub>4</sub>   | Methane                                                                   |
| CO <sub>2</sub>   | Carbon Dioxide                                                            |
| CO <sub>2</sub> e | 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 Laboratory                                                    |
| 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 <sub>2</sub> O  | Nitrous Oxide                                                             |
| NERC              | North American Electric Reliability Corporation                           |
| NIST              | National Institute of Standards and Technology                            |
| PNNL              | Pacific Northwest National Laboratory                                     |
| ROI               | Return On Investment                                                      |
| S-I               | System International (Metric Units)                                       |
| SEER              | Seasonal Energy Efficiency Ratio                                          |
| SHGC              | Solar Heat Gain Coefficient                                               |

| <b>Acronym</b> | <b>Definition</b>                                        |
|----------------|----------------------------------------------------------|
| SPV            | Single Present Value                                     |
| 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 all fifty states in the U.S. 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 use and energy-related carbon emissions. Each state energy code is also compared to a “Low Energy Case” (LEC) building design based on *ASHRAE 189.1-2009 (Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings)*, which increases energy efficiency beyond the *ASHRAE 90.1-2007* design.

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

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

overwhelm the stricter requirements for other energy efficiency measures analyzed in this study.

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

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

Over all building types, states located in the warmest climates realize the greatest reductions in energy use from adopting the “Low Energy Case” (LEC) design because several of the energy efficiency improvements (e.g., overhangs and daylighting controls) are more beneficial for warmer climates. However, states in colder climates see greater percentage reductions in energy costs and carbon emissions per percentage reduction in energy use because the energy efficiency measures tend to shift some energy use from electricity to natural gas consumption. Electricity is more expensive per unit of energy and typically has greater carbon dioxide equivalent (CO<sub>2</sub>e) emissions per unit of energy relative to natural gas. Therefore the shift of energy consumption from electricity to natural gas can lead to greater reductions in energy costs and energy-related carbon emissions than reductions in total energy use. In an extreme case, cities located in Zone 8 realize a reduction in energy costs and carbon emissions while realizing an increase in total energy use.

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

greatest for cities in Zone 2 followed by Zone 7 and smallest for cities in Zone 1 and Zone 3.

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

The length of the study period impacts life-cycle cost-effectiveness to some degree. Assuming nationwide adoption of the LEC design, a 10-year study period realizes average life-cycle cost decreases of 1.1 % for all building types and locations. The percentage decrease in life-cycle costs is 1.4 % for a 20-year, 1.8 % for a 30-year, and 1.9 % for a 40-year study period. As the study period length increases from 5 years to 40 years, life-cycle cost-effectiveness tends to increase for more energy efficient commercial building designs.

By combining the amount of new floor area in a state with its average impacts, it is possible to estimate the magnitude of the impacts that nationwide adoption of a given building design would have at the state and national levels. States with the most newly constructed commercial building floor area tend to realize the greatest total energy use, energy cost, energy-related carbon emissions, and life-cycle cost reductions from adopting the *ASHRAE 90.1-2007* and LEC design even if those states do not realize the greatest percentage reductions. California, Florida, and Texas realize the greatest reductions in energy use (>1900 GWh) from adopting the LEC design. In comparison, states with the smallest amount of new floor area (Alaska, Delaware, Montana, Rhode Island, Vermont, and Wyoming) realize savings of less than 100 GWh from adopting the LEC design. For the 19 states that have not yet adopted the *ASHRAE 90.1-2007* design, Arizona realizes the greatest reductions in energy use (946 GWh) from doing so, while states with the smallest amount of new floor area (Alaska, Hawaii, Maine, North Dakota, South Dakota, and Wyoming) realize savings of less than 106 GWh. Similar trends occur for total energy cost reductions and energy-related carbon emissions savings.

The nationwide adoption of more efficient energy codes decreases total life-cycle costs. Adopting the LEC design decreases total life-cycle costs for 48 of 50 states for a 10-year study period, with Florida (\$151.3 million), California (\$124.9 million), and Texas (\$106.8 million) realizing the greatest life-cycle cost savings. The two states that realize an increase in life-cycle costs are Oregon (\$0.4 million) and Washington (\$11.5 million). For a 10-year study period, adopting the *ASHRAE 90.1-2007* design reduces total life-cycle costs for 17 of 19 states, including 8 of 10 that have adopted *ASHRAE*

*90.1-2001* or have not yet adopted a state energy code for commercial buildings. The greatest life-cycle cost savings are realized by Colorado (\$53.9 million), Arizona (\$30.8 million), and Alabama (\$25.7 million). The two states that realize an increase in total life-cycle costs are Kansas (\$2.9 million) and Oklahoma (\$5.7 million).

The state-level impacts are aggregated to determine the total impact of nationwide adoption of both the *ASHRAE 90.1-2007* and LEC designs. Nationwide adoption of the LEC design leads to reductions totaling 34.4 TWh in energy consumption, \$2.8 billion in energy costs, 26.3 million metric tons in energy-related carbon emissions, and \$1.0 billion in life-cycle costs for a 10-year study period. Nationwide adoption of the *ASHRAE 90.1-2007* design leads to reductions totaling 4.9 TWh in energy consumption, \$312 million in energy costs, 3.8 million metric tons in energy-related carbon emissions, and \$173 million in life-cycle costs for a 10-year study period. An increase in the study period length increases the total savings for all four impacts because as the length of the study period increases, energy cost savings become a greater fraction of total life-cycle cost savings.

In general, the states that realize the greatest total reductions in energy use also realize the greatest reductions in energy costs and energy-related carbon emissions. However, states with higher average electricity prices and electricity emissions rates, and states that realize a greater shift of fuel consumption from electricity to natural gas, realize greater reductions in energy costs and carbon emissions holding energy use savings constant.

The changes per unit of floor area vary across Census regions, with the same trends holding for adoption of both the *ASHRAE 90.1-2007* and LEC designs. The Northeast realizes the greatest energy cost savings per unit energy use savings due to its higher average higher electricity price. The Midwest realizes the greatest carbon emissions savings per unit of energy use savings because its average electricity emissions rate is much higher than that of the other Census regions. The West realizes the greatest life-cycle cost savings per unit of floor area, which is a result of a number of factors, including the baseline energy codes for the cities located in the Census region, the regional average electricity price, average energy use savings, and local construction costs.

The incremental impacts in a state from adopting each newer edition of *ASHRAE 90.1* lead to some interesting conclusions. For the nine states that have no state energy code, adoption of *ASHRAE 90.1-2001* would lead to minimal energy use reductions (16 kWh/m<sup>2</sup>) while significantly increasing total life-cycle costs (\$15.39/m<sup>2</sup>).<sup>1</sup> The reason for this result is that the primary changes in the standard from *ASHRAE 90.1-1999* to

---

<sup>1</sup> Excludes Arizona because three of the six cities in the BIRDS database have adopted *ASHRAE 90.1-2004* as their local energy code.



*ASHRAE 90.1-2001* target the required efficiencies of HVAC equipment. The additional first costs of increasing the efficiency of HVAC equipment appear to be greater than the energy cost savings realized over the 10-year study period.

The adoption of *ASHRAE 90.1-2004* leads to significant incremental average reductions in energy use ( $112 \text{ kWh/m}^2$ ) while significantly decreasing total life-cycle costs ( $\$15.52/\text{m}^2$ ) relative to adopting *ASHRAE 90.1-2001*, and entirely offsets the incremental increase in life-cycle costs from adopting *ASHRAE 90.1-2001* for five of the nine states with no state energy code. One state, Alaska, realizes an increase in energy use relative to *ASHRAE 90.1-2001*, which is a result of building requirements being relaxed for some cities due to the climate zone consolidation from *ASHRAE 90.1-2001* to *ASHRAE 90.1-2004*.

The adoption of *ASHRAE 90.1-2007* leads to significantly smaller average incremental reductions in energy use ( $71 \text{ kWh/m}^2$ ) and life-cycle costs ( $\$3.04/\text{m}^2$ ) relative to adopting *ASHRAE 90.1-2004*. Two of the nineteen states (Arkansas and Oklahoma) realize an increase in life-cycle costs relative to *ASHRAE 90.1-2004*.

The adoption of the LEC design leads to the greatest incremental impacts on total energy use ( $202 \text{ kWh/m}^2$ ), and similar incremental impacts on life-cycle costs ( $\$4.24/\text{m}^2$ ) as *ASHRAE 90.1-2007* for the nineteen states that have not yet adopted *ASHRAE 90.1-2007*. Only one of the nineteen states (West Virginia) realizes an increase in life-cycle costs relative to *ASHRAE 90.1-2007*.

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. The environmental assessment in the BIRDS database is currently being expanded beyond energy-related carbon emissions to cover building materials and a full range of cradle-to-grave life-cycle environmental impacts. 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 comprehensive sustainability assessment and more detailed reporting and release of the BIRDS software scheduled for September 2013.



# 1 Introduction

## 1.1 Background

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.

## 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 based on *ASHRAE 189.1-2009*, which 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.

Kneifel (2013b), Kneifel (2013c), Kneifel (2013d), and Kneifel (2013e) implement the analysis approach developed in Kneifel (2013a) for an individual state and analyze each state in the Northeast, Midwest, South, and West Census Regions, respectively. The results for each state, both on a percentage and aggregate basis, are compared across the Census Region to determine the driving factors for variation across states in the relative impacts of adopting more stringent state energy codes. The results are aggregated to the Census Region level to estimate the total region-wide impacts.

### 1.3 Purpose

The purpose of this study is to analyze the results from the BIRDS database reported in Kneifel (2013a, 2013b, 2013c, 2013d, 2013e), and summarize the results into the key nationwide trends and important interpretations for energy efficiency in new commercial buildings. The performance of buildings designed to meet current state energy codes is compared to their performance when meeting newer editions of *ASHRAE 90.1* requirements 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 based on *ASHRAE 189.1-2009*, which 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 incremental savings that the nation may realize if its states were to adopt more energy efficient standard editions.

### 1.4 Approach

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

Results are analyzed both in percentage and total value terms. The percentage savings results allow for direct comparisons across energy standard editions, building types, study period lengths, climate zones, and cities both within each state and across the nation. Results are aggregated to the state and national levels 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 more stringent energy codes, 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 energy-related carbon emissions for 5 energy efficiency designs for 11 building types, 228 cities across all fifty states, and 9 study period lengths.<sup>2</sup>

### 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.<sup>3</sup> The prototype buildings range in size from 465 m<sup>2</sup> (5000 ft<sup>2</sup>) to 41 806 m<sup>2</sup> (450 000 ft<sup>2</sup>). 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<br>m (ft) | Wall  | Roof† | Pct. Glazing | Building Size<br>m <sup>2</sup> (ft <sup>2</sup> ) | 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

<sup>2</sup> See Kneifel (2011b) for additional details on the whole building energy simulations used in the BIRDS database.

<sup>3</sup> Estimate is based on the Commercial Building Energy Consumption Survey (CBECS) database.

## 2.2 Building Designs

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

Table 2-2 shows that commercial building energy codes as of December 2011 vary by state.<sup>4</sup> In a few instances, local jurisdictions have adopted energy standard editions that are more stringent than the state energy codes.<sup>5</sup> These cities are also included in Table 2-2.

---

<sup>4</sup> 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.

<sup>5</sup> Local and jurisdictional requirements are obtained from the Database of State Incentives for Renewables and Efficiency (DSIRE). State energy code requirements targeting only public buildings and green standards are ignored in this study.



**Table 2-2 Energy Code by State and City Exception**

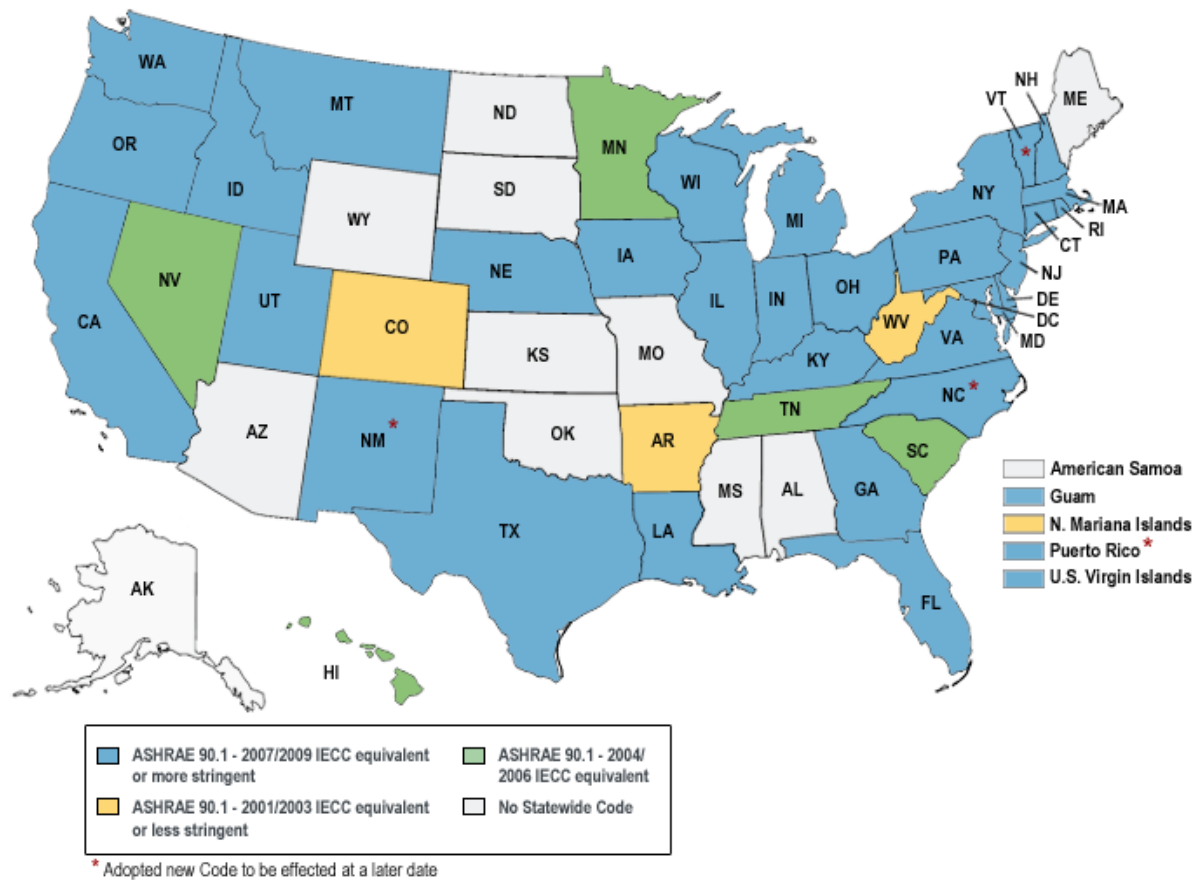
| Location       | Energy Code | Location | Energy Code | Location | Energy Code |
|----------------|-------------|----------|-------------|----------|-------------|
| AK             | None        | IN       | 2007        | NV       | 2004        |
| AL             | None        | KS       | None   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

Note: Some city ordinances require energy codes that exceed state energy codes.

Note: State codes as of December 1, 2011.

Note: *ASHRAE 90.1-2007* is the building design that best matches Title 24 requirements.

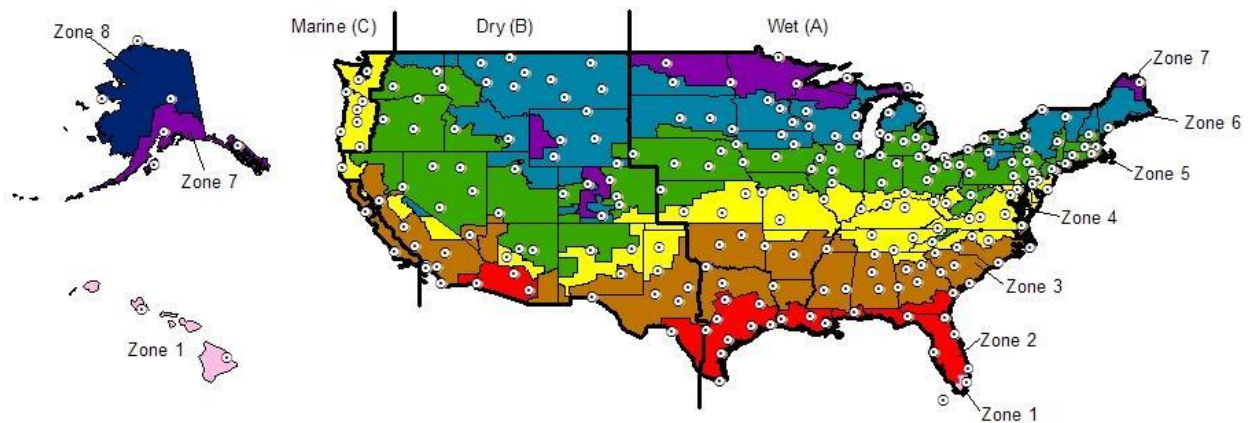
State energy codes vary from *ASHRAE 90.1-1999* to *ASHRAE 90.1-2007* with some regional trends shown in Figure 2-1. The states in the central U.S. tend to wait longer to adopt newer *ASHRAE 90.1 Standard* editions. However, there are many cases in which energy codes of neighboring states vary drastically. For example, Missouri has no state energy code while of the 8 surrounding states, 2 have no state energy code, 1 has adopted *ASHRAE 90.1-2001*, 1 has adopted *ASHRAE 90.1-2004*, and 4 have adopted *ASHRAE 90.1-2007*.



**Figure 2-1 State Commercial Energy Codes<sup>6</sup>**

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

<sup>6</sup> Figure was obtained from the DOE Building Technologies Program in December 2011.



**Figure 2-2 Cities and ASHRAE Climate Zones**

### **2.3 Study Period Lengths**

Nine study period lengths are chosen for this analysis: 1 year, 5 years, 10 years, 15 years, 20 years, 25 years, 30 years, 35 years, and 40 years. The wide 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).<sup>7</sup> 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 of each component within each separate building type. 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.

---

<sup>7</sup> 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 <sup>2</sup> ·K/W<br>(ft <sup>2</sup> ·°F·h/Btu)     | 1.7 to 4.4<br>(10.0 to 25.0)   | 1.7 to 4.4<br>(10.0 to 25.0)   | 2.6 to 3.5<br>(15.0 to 20.0)   | 2.6 to 3.5<br>(15.0 to 20.0)   | 4.4 to 6.2<br>(25.0 to 35.0)   |
| Wall Insulation  | R-Value       | m <sup>2</sup> ·K/W<br>(ft <sup>2</sup> ·°F·h/Btu)     | 0.0 to 3.8<br>(0.0 to 21.6)    | 0.0 to 3.8<br>(0.0 to 21.6)    | 0.0 to 2.7<br>(0.0 to 15.2)    | 0.0 to 2.7<br>(0.0 to 15.2)    | 0.7 to 5.5<br>(3.8 to 31.3)    |
| Windows          | U-Factor      | W/(m <sup>2</sup> ·K)<br>(Btu/(h·ft <sup>2</sup> ·°F)) | 1.42 to 7.21<br>(0.25 to 1.27) | 1.42 to 7.21<br>(0.25 to 1.27) | 1.99 to 6.47<br>(0.35 to 1.14) | 2.50 to 6.47<br>(0.44 to 1.14) | 1.97 to 6.42<br>(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 <sup>2</sup> (W/ft <sup>2</sup> )                  | 14.0 to 20.5<br>(1.3 to 1.9)   | 14.0 to 20.5<br>(1.3 to 1.9)   | 10.8 to 16.1<br>(1.0 to 1.5)   | 10.8 to 16.1<br>(1.0 to 1.5)   | 8.6 to 16.1<br>(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, and are based on *ASHRAE 189.1-2009*.

NR = No Requirement for one or more climate zones. By definition, the value of SHGC cannot exceed 1.0.

The LEC design increases the thermal efficiency of insulation and windows beyond *ASHRAE 90.1-2007*, further reduces the lighting power density, and adds daylighting and window overhangs. The lighting density of the lighting system is decreased by first increasing the efficiency of the lighting system and then decreasing the number of fixtures in the lighting system.<sup>8</sup> 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.<sup>9</sup>

Since the design of the BIRDS database, *ASHRAE 90.1-2010* has been finalized and published. Table 3-2 gives a perspective of how the *ASHRAE 90.1-2007* and LEC designs compare to *ASHRAE 90.1-2010*. In general, the requirements for *ASHRAE 90.1-2010* are stricter than *ASHRAE 90.1-2007* and less strict than the LEC design. The key exception is the lighting power density requirements for mid-rise and high-rise residential buildings, and wall insulation requirements for steel-framed mid-rise and high-rise residential buildings, where the requirements for *ASHRAE 90.1-2010* are more stringent than for the LEC design.

<sup>8</sup> 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).

<sup>9</sup> Overhang cost source is Winiarski et al. (2003)

**Table 3-2 Energy Efficiency Component Requirements for the ASHRAE 90.1-2007, ASHRAE 90.1-2010, and LEC Designs**

| Design Component | Parameter     | Units                                                  | ASHRAE 90.1-2007               | ASHRAE 90.1-2010              | Low Energy Case*               |
|------------------|---------------|--------------------------------------------------------|--------------------------------|-------------------------------|--------------------------------|
| Roof Insulation  | R-Value       | m <sup>2</sup> ·K/W<br>(ft <sup>2</sup> ·°F·h/Btu)     | 2.6 to 3.5<br>(15.0 to 20.0)   | 2.6 to 3.5<br>(15.0 to 20.0)  | 4.4 to 6.2<br>(25.0 to 35.0)   |
| Wall Insulation  | R-Value       | m <sup>2</sup> ·K/W<br>(ft <sup>2</sup> ·°F·h/Btu)     | 0.0 to 2.7<br>(0.0 to 15.2)    | 0.0 to 2.7<br>(0.0 to 25.0)   | 0.7 to 5.5<br>(3.8 to 31.3)    |
| Windows          | U-Factor      | W/(m <sup>2</sup> ·K)<br>(Btu/(h·ft <sup>2</sup> ·°F)) | 2.50 to 6.47<br>(0.44 to 1.14) | 1.99 to 6.47<br>(0.35 to 1.2) | 1.97 to 6.42<br>(0.35 to 1.13) |
|                  | SHGC          | Fraction                                               | 0.25 to NR                     | 0.25 to NR†                   | 0.25 to 0.47                   |
| Lighting         | Power Density | W/m <sup>2</sup> (W/ft <sup>2</sup> )                  | 10.8 to 16.1<br>(1.0 to 1.5)   | 6.5 to 15.1<br>(0.6 to 1.4)   | 8.6 to 16.1<br>(0.8 to 1.5)    |
| Overhangs        |               |                                                        | None                           | None                          | Zones 1 to 5                   |
| Daylighting      |               |                                                        | None                           | Zones 1 to 8                  | Zones 1 to 8                   |

\* Low Energy Case design requirements are taken from the EnergyPlus simulations, and are based on ASHRAE 189.1-2009.  
NR = No Requirement for one or more climate zones. By definition, the value of SHGC cannot exceed 1.0.

Table 3-3 summarizes the HVAC efficiency requirements for each building design option across the different types of HVAC equipment.<sup>10</sup> Note that the LEC design assumes the same efficiency as ASHRAE 90.1-2007. This study assumes that cooling equipment is run on electricity while heating equipment is run on natural gas. The most significant increases in HVAC efficiency requirements occur between ASHRAE 90.1-1999 and ASHRAE 90.1-2001 except for rooftop packaged units, which have consistently increasing requirements across multiple ASHRAE 90.1 Standard editions.

**Table 3-3 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 <sub>t</sub> | 75% to 80%       | 75% to 80%       | 75% to 80%       | 75% to 80%       | 75% to 80%      |
|           | Furnace                           | E <sub>t</sub> | 80%              | 75% to 80%       | 75% to 80%       | 75% to 80%       | 75% to 80%      |

Assume that 80 %E<sub>c</sub> = 75% E<sub>t</sub> and AFUE = E<sub>t</sub>, where E<sub>c</sub> = combustion efficiency; E<sub>t</sub> = thermal efficiency; AFUE = Annual Fuel Utilization Efficiency  
EER = Energy Efficiency Ratio  
COP = Coefficient of Performance  
Note: Efficiency requirement ranges are based on the system sizes calculated in the whole building energy simulations.

<sup>10</sup> This study does not account for new HVAC efficiency requirements set by federal regulations.

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

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

### **3.2 Future Costs**

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

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

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

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

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

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

Annual energy costs are estimated by multiplying annual electricity and natural gas use predicted by the whole building energy simulation by the average state retail commercial electricity and natural gas prices, respectively. Average state commercial electricity and natural gas prices for 2009 are collected from the Energy Information Administration (EIA) Electric Power Annual State Data Tables and Natural Gas Navigator, respectively. The electricity and natural gas prices are assumed to change over time according to EIA forecasts from 2009 to 2039. These forecasts are embodied in the Federal Energy

Management Program (FEMP) Uniform Present Value Discount Factors for energy price estimates (UPV\*) reported in Rushing and Lippiatt (2009).<sup>11</sup> 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.

---

<sup>11</sup> The escalation rates for years 31 to 40 are assumed to be the same as for year 30.

## **4 Building Stock Data**

Aggregating the savings for newly constructed commercial buildings to the state and national levels 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 the 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<sup>2</sup> (8.2 billion ft<sup>2</sup>) of new construction, for 2003 through 2007. The data are more detailed than the CBECS data, and includes year of construction and location.

### **4.2 Weighting Factors**

Jarnagin and Bandyopadhyay (2010) maps the more detailed McGraw-Hill dataset to the CBECS categories and subcategories shown in Table 4-1. The prototype commercial buildings analyzed in this study, shown in bold, represent 46.4 % of nationwide new commercial building stock square footage for 2003 through 2007. The McGraw-Hill dataset is aggregated at the CBECS category-level. For this study, a prototype building is assumed to represent its entire CBECS category, which implies the prototypes together represent 56.8 % of the new commercial building stock.

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

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

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

## 5 Analysis Approach

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

### 5.1 Energy Use

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

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

### 5.2 Life-Cycle Costing

Life-cycle costing (LCC) takes into account all relevant costs throughout the chosen study period, including construction costs, maintenance, repair, and replacement costs, energy costs, and residual values. A cost's present value (PV) is calculated by discounting its nominal value into today's dollars based on the year the cost occurs and the assumed discount rate. LCC of buildings typically compares the costs for a baseline building design to the costs for alternative, more energy-efficient building designs to determine if future operational savings justify higher initial investments.<sup>12</sup> 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.

---

<sup>12</sup> 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<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O) 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.<sup>13</sup> 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 (eGRID, 2007), which is a collection of data from the EIA, the Federal Energy Regulatory Commission (FERC), and the Environmental Protection Agency (EPA).<sup>14</sup> Table A-5 in the 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.<sup>15</sup>

These greenhouse gas emissions are converted into a common unit of measure called carbon dioxide equivalents (CO<sub>2</sub>e) using equivalency factors reported in Table 5-1, which represent the global warming potential (GWP) of one unit of greenhouse gas relative to that of the same amount of carbon dioxide. For example, one unit of methane has 25 times the GWP as the same amount of carbon dioxide, and nitrous oxide has 298 times the GWP as carbon dioxide. The aggregated CO<sub>2</sub>e is calculated by taking the amount of

---

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

<sup>14</sup> Emissions rates are held constant over all study periods.

<sup>15</sup> While carbon assessment of building construction, maintenance, repair, and replacement is currently excluded from the analysis, it is currently under development and will be included in future versions of this work.

each flow multiplied by its CO<sub>2</sub>e factor, and summing the resulting CO<sub>2</sub> equivalencies. The results are analyzed in metric tons of CO<sub>2</sub>e 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 <sub>2</sub> e) |
|----------------------------------------------------|-------------------------|
| Carbon Dioxide (CO <sub>2</sub> )                  | 1                       |
| Methane (CH <sub>4</sub> )                         | 25                      |
| Nitrous Oxide (N <sub>2</sub> O)                   | 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

Three metrics are used to analyze the results: simple percentage changes, aggregate changes, and changes per unit of floor area. 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 the average change in total values for the state or nation because that would in effect give greater weight to buildings or locations with greater total changes. The simple average approach used in this study weights each location-building type equally.

The estimated change in total energy use, energy costs, energy-related carbon emissions, and life-cycle costs for each of the building types is combined with new commercial building construction data to calculate the magnitude of the available total savings a state

may realize if it were to adopt a more energy efficient standard as its state energy code using the following equation.

$$(1) I_j = \frac{\sum_{i=1}^{11} CFA_{ji} * R_{ji}}{\sum_{i=1}^{11} F_{ji}}$$

Where  $I_j$  = total change for state  $j$   
 $CFA_i$  = average annual newly constructed floor area for building type  $i$  for state  $j$   
 $R_i$  = average change per unit of floor area for building type  $i$  for state  $j$   
 $F_i$  = fraction of average annual new floor area represented by building type  $i$  for state  $j$

For each building type  $i$ , the average change per unit of floor area for all cities in a state ( $R_i$ ) is multiplied by the average annual floor area of new construction for 2003 to 2007 for building type  $i$  in that state ( $CFA_i$ ) to estimate the total savings for that building type for that state. The impacts are summed across all eleven building prototypes. These impacts are then divided by the amount of average annual new commercial floor area represented by the eleven building prototypes ( $F$ ), which scale the results to the statewide impacts of all new commercial construction ( $I_j$ ). Using this approach to estimate the total impacts for a state requires the assumption that the savings realized by the BIRDS building prototypes are representative of new commercial building construction as a whole.

The national-level impacts ( $I_T$ ) are estimated using Equation 2, where the impacts for state  $j$  estimated using Equation 1 ( $I_j$ ) are summed across all fifty states.

$$(2) I_T = \sum_{j=1}^{50} (I_j)$$

Where  $I_T$  = nationwide total impacts  
 $I_j$  = total impacts in state  $j$

The third metric, change per unit of floor area, allows for comparisons across states to determine which states realize the greatest impacts per unit of construction. Equation 3 shows this calculation, where the total statewide impacts estimated in Equation 1 ( $I_j$ ) are divided by the total average annual new floor area for all building types in a state ( $TCFA_j$ ), creating a metaphorical “bang-for-your-buck” comparison across states.

$$(3) AVGI_j = \frac{I_j}{TCFA_j}$$

Where  $AVGI_j$  = average impact per unit of new floor area in state  $j$   
 $I_j$  = total impacts in state  $j$   
 $TCFA_j$  = total average annual new floor area for all building types in state  $j$



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

## **5.5 Regression Analysis**

Determining the influence of some factors considered in this study requires a more statistically rigorous approach: regression analysis. Regression analysis is used to estimate the correlation between characteristics of a location and the impact the location realizes from adopting a more stringent energy code. This study applies an Ordinary Least Squares (OLS) model with dummy variables, also referred to as a Least Squares Dummy Variable (LSDV) Model, for the regression analysis.



## 6 Nationwide Impacts of Adopting Low Energy Case Design

This section analyzes benefits from nationwide adoption of the LEC design relative to the current collection of state energy codes. Benefits are evaluated across several dimensions: time, building type, geography (climate zone and state), and energy code. There are three metrics implemented to analyze the results: percentage changes, total changes, and changes per unit of floor area. Regression analysis is used to statistically estimate the drivers of variation in impacts across cities within the same state.

### 6.1 Percentage Changes

Average percentage change impacts from adopting the LEC design are estimated for energy use, energy costs, carbon emissions, and life-cycle costs. Impacts are evaluated across four dimensions: study period length, building type, climate zone, and state energy code.

#### 6.1.1 Results by Study Period Length

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.

The average reduction in energy use from adoption of the LEC design is constant over all study period lengths because energy efficiency is assumed to be constant over time. Table 6-1 shows that the national average reduction in energy use across all cities in the study ranges from -10.6 % to -30.7 %, depending on the building type, with an overall national average of -17.8 %.

**Table 6-1 Nationwide Average Percentage Change in Energy Use from Adoption of the LEC Design by Building Type**

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

As shown in Table 6-2, reductions in energy costs vary slightly, in percentage terms, over increasing study period lengths. The national average reduction in energy costs across all location-building type combinations changes from -22.8 % for a 1-year study period to -22.3 % for a 40-year study period. The minor variation is a result of the escalation rates used to adjust future energy prices, which vary by Census Region. The national average reduction ranges from -17.4 % to -35.6 %, depending on the building type and study period.

**Table 6-2 Nationwide Average Percentage Change in Energy Costs from Adoption of the LEC Design by Building Type and Study Period Length**

| Building Type  | Study Period Length |              |              |              |              |              |              |              |              |
|----------------|---------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                | 1                   | 5            | 10           | 15           | 20           | 25           | 30           | 35           | 40           |
| APART04        | -21.5               | -21.3        | -21.2        | -21.1        | -21.0        | -21.0        | -20.9        | -20.8        | -20.7        |
| APART06        | -23.2               | -23.0        | -22.9        | -22.8        | -22.7        | -22.6        | -22.5        | -22.4        | -22.4        |
| DORMI04        | -22.4               | -22.3        | -22.2        | -22.1        | -22.1        | -22.0        | -21.9        | -21.9        | -21.8        |
| DORMI06        | -22.7               | -22.5        | -22.4        | -22.3        | -22.2        | -22.1        | -22.0        | -22.0        | -21.9        |
| HOTEL15        | -19.8               | -19.6        | -19.6        | -19.5        | -19.4        | -19.3        | -19.3        | -19.2        | -19.2        |
| HIGHS02        | -18.3               | -18.1        | -18.0        | -17.9        | -17.8        | -17.7        | -17.6        | -17.5        | -17.4        |
| OFFIC03        | -25.3               | -25.2        | -25.2        | -25.2        | -25.2        | -25.2        | -25.1        | -25.1        | -25.1        |
| OFFIC08        | -22.8               | -22.8        | -22.8        | -22.8        | -22.8        | -22.8        | -22.7        | -22.7        | -22.7        |
| OFFIC16        | -18.4               | -18.4        | -18.3        | -18.3        | -18.3        | -18.2        | -18.2        | -18.2        | -18.1        |
| RETAIL1        | -20.9               | -20.9        | -20.9        | -20.9        | -20.8        | -20.8        | -20.8        | -20.8        | -20.8        |
| RSTRNT1        | -35.6               | -35.5        | -35.4        | -35.3        | -35.3        | -35.2        | -35.2        | -35.1        | -35.1        |
| <b>Average</b> | <b>-22.8</b>        | <b>-22.7</b> | <b>-22.6</b> | <b>-22.6</b> | <b>-22.5</b> | <b>-22.5</b> | <b>-22.4</b> | <b>-22.3</b> | <b>-22.3</b> |

Since the national average reduction in energy use across all location-building type combinations is constant over all study periods, the average energy-related carbon emissions are also assumed constant at -22.9 %.<sup>16</sup> The national average reduction in carbon emissions ranges from -18.5 % to -35.6 % depending on the building type, as shown in Table 6-3.

<sup>16</sup> Electricity fuel mixes are assumed to be fixed over all study periods.

**Table 6-3 Nationwide Average Percentage Change in Carbon Emissions from Adoption of the LEC Design by Building Type**

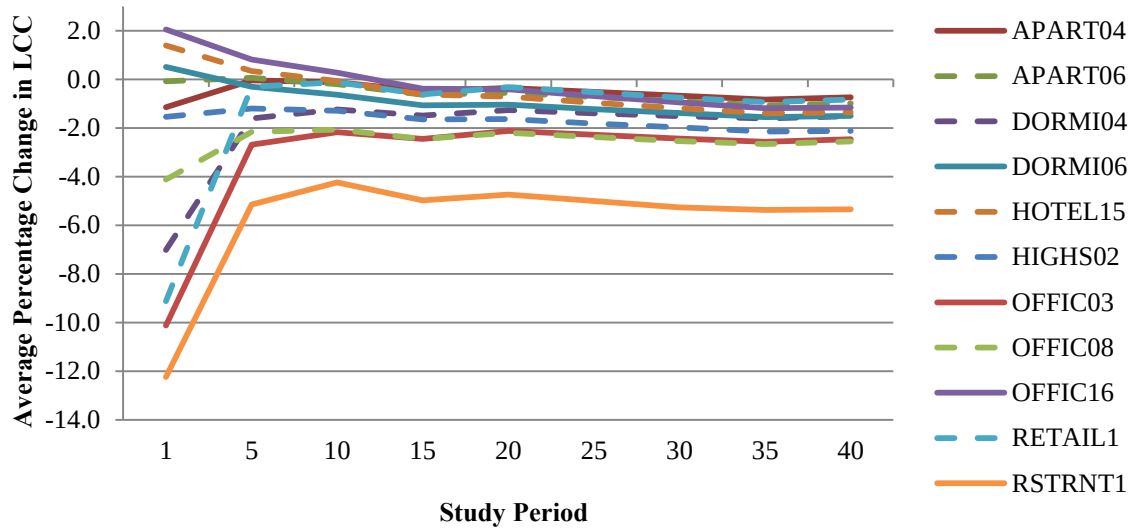
| Building Type  | Percentage Change |
|----------------|-------------------|
| APART04        | -21.6             |
| APART06        | -23.3             |
| DORMI04        | -22.6             |
| DORMI06        | -22.8             |
| HOTEL15        | -20.0             |
| HIGHS02        | -18.5   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

Table 6-4 shows that the nationwide average percentage change in life-cycle costs varies significantly over increasing study period lengths, with the average change across all location-building type combinations ranging from -3.8 % to -1.1 %.

**Table 6-4 National Average Percentage Change in Life-Cycle Costs from Adoption of the LEC Design by Building Type and Study Period Length**

| Building Type  | Study Period Length |             |             |             |             |             |             |             |             |
|----------------|---------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                | 1                   | 5           | 10          | 15          | 20          | 25          | 30          | 35          | 40          |
| APART04        | -1.1                | 0.0         | -0.1        | -0.5        | -0.4        | -0.5        | -0.7        | -0.8        | -0.7        |
| APART06        | -0.1                | 0.1         | -0.2        | -0.6        | -0.6        | -0.7        | -0.9        | -1.1        | -1.0        |
| DORMI04        | -7.0                | -1.6        | -1.2        | -1.5        | -1.3        | -1.4        | -1.5        | -1.6        | -1.5        |
| DORMI06        | 0.5                 | -0.3        | -0.6        | -1.1        | -1.0        | -1.2        | -1.4        | -1.6        | -1.5        |
| HOTEL15        | 1.4                 | 0.3         | -0.1        | -0.6        | -0.7        | -1.0        | -1.2        | -1.4        | -1.4        |
| HIGHS02        | -1.5                | -1.2        | -1.3        | -1.6        | -1.6        | -1.8        | -2.0        | -2.2        | -2.1        |
| OFFIC03        | -10.1               | -2.7        | -2.2        | -2.4        | -2.1        | -2.3        | -2.4        | -2.6        | -2.5        |
| OFFIC08        | -4.1                | -2.2        | -2.1        | -2.5        | -2.2        | -2.4        | -2.5        | -2.7        | -2.6        |
| OFFIC16        | 2.1                 | 0.8         | 0.3         | -0.4        | -0.4        | -0.7        | -1.0        | -1.2        | -1.2        |
| RETAIL1        | -9.1                | -0.3        | -0.1        | -0.6        | -0.3        | -0.5        | -0.8        | -0.9        | -0.8        |
| RSTRNT1        | -12.2               | -5.2        | -4.2        | -5.0        | -4.7        | -5.0        | -5.3        | -5.4        | -5.4        |
| <b>Average</b> | <b>-3.8</b>         | <b>-1.1</b> | <b>-1.1</b> | <b>-1.5</b> | <b>-1.4</b> | <b>-1.6</b> | <b>-1.8</b> | <b>-1.9</b> | <b>-1.9</b> |

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



**Figure 6-1 Nationwide Average Percentage Change in Life-cycle Costs from Nationwide Adoption of the LEC Design by Building Type and Study Period Length**

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

### 6.1.2 Results by Building Type

Table 6-5 shows the simple average changes by building type, in percentage terms, from adopting the LEC design for a 10-year study period. The restaurant realizes the greatest reductions while the high school realizes the smallest reductions in energy use, energy costs, and energy-related carbon emissions.

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

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

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

**Table 6-5 Nationwide Average Percentage Change for Adoption of the LEC Design by Building Type, 10-Year**

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

### 6.1.3 Results by Climate Zone

Table 6-6 shows the nationwide average change in energy use by *ASHRAE* climate zone for the adoption of the LEC design relative to current state energy codes for all building types. The average reduction in energy use nationwide is 17.8 %. Zone 1 realizes the greatest average reduction in energy use, 22.1 %, while Zone 8 realizes the smallest, 10.2 %. For Zone 1 through Zone 5, the warmer the climate the greater the reduction in energy use, which is a result of the energy efficiency improvement options considered in the LEC design. Warmer climates have an additional option (adding overhangs) that is not beneficial in the colder climates because solar heat gains are beneficial in cold climates and harmful in warm climates.

Zone 7 realizes a greater overall average reduction in energy use (19.8 %) than Zone 6 (16.1 %), Zone 5 (14.9 %), or Zone 4 (18.6 %). To explain this result, the average

percentage change in energy use by climate zone is segmented by a location's current energy code in Table 6-6. Considering only the states that have adopted *ASHRAE 90.1-2007*, the average percentage reduction in energy use consistently decreases from Zone 4 (-15.7 %) to Zone 7 (-11.1 %), where the warmer the climate zone, the greater the reduction in energy use.

**Table 6-6 Average Percentage Change in Energy Use for LEC by Climate Zone and State Energy Code**

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

Table 6-7 shows that the overall average reduction in energy costs over a 10-year study period ranges from 21.0 % to 25.5 % depending on the climate zone. The greatest overall reductions in energy costs are realized by cities located in Zone 7 followed by Zone 3. Similar to energy use, this result can largely be explained by segmenting the average percentage change in energy costs for a climate zone by a location's current energy code. Considering only the locations that have adopted *ASHRAE 90.1-2007*, the average percentage reductions in energy costs trend lower from the warmer to colder climate zones. However, there is some additional variation that results from each location's average cost per unit of energy. For example, cities in Zone 3 realize the greatest



reductions in energy costs, particularly the cities in California located in Subzone 3C, because the state average cost of electricity in California is the 9<sup>th</sup> highest in the United States, and 2<sup>nd</sup> highest behind Hawaii of all states that have cities located in the warmer climate zones (Zone 1 through Zone 4).

**Table 6-7 Average Percentage Change in Energy Costs for LEC by Climate Zone and State Energy Code, 10-Year**

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

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

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

**Table 6-8 Average Change in Energy-related Carbon Emissions for LEC by Climate Zone and State Energy Code**

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

The results reported in Table 6-9 show that changes in life-cycle costs vary across climate zones and study periods. The LEC design is cost-effective for all study periods across all climate zones. The percentage reduction in life-cycle costs becomes smaller from the 1-year to 5-year and 10-year study periods, and then slowly increases from the 10-year to 40-year study period. For study period lengths of 10 years or greater, the warmer the

climate zone, the greater the percentage reduction in life-cycle costs. For example, the average percentage reduction for the 40-year study period ranges from 3.0 % in Zone 1 to 0.6 % for Zone 8.

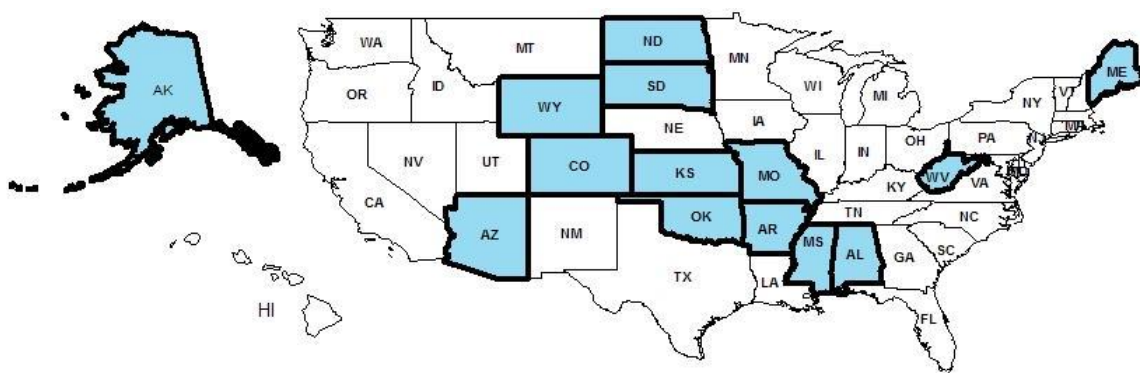
**Table 6-9 Average Percentage Change in Life-Cycle Costs for LEC by Climate Zone and Study Period**

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

#### 6.1.4 Results by State Energy Code

One purpose of this study is to determine which states could benefit the most from adopting a more stringent state energy code for commercial buildings. It would be expected that states with energy codes based on older editions of *ASHRAE 90.1*, or no energy code at all, would realize greater benefits from adopting the LEC design because buildings in those states are expected to be built in a less energy efficient manner. Figure 6-2 shows the 14 states with energy codes based on an older edition of *ASHRAE 90.1* (-2001) or that have no energy code,<sup>17</sup> many of which are located in the central U.S. as well as a few states in the south, West Virginia, Arizona, Maine, and Alaska.

<sup>17</sup> All maps are generated in ArcMap 10.1.



**Figure 6-2 States with Energy Standard Editions 2001 or Older or No energy code**

It is necessary to assume a particular study period length because energy costs fluctuate on an annual basis. A 10-year study period is used as the baseline because it is one of the most realistic investor time horizons out of the 9 study period length options in BIRDS.

State benefit comparisons are made based on the simple average changes for the cities analyzed in each state by building type. One building type is chosen to illustrate the detailed analysis possible with the powerful BIRDS database compiled for this study. Energy use, energy costs, life-cycle costs, and cradle-to-grave energy-related carbon emissions are analyzed for the most common existing building type, small office buildings. Summary results for the other 10 building types are reported in Table B-1 through Table B-10 in Appendix B. The same interpretations hold for the other ten building types. No states have adopted the LEC design so all should realize impacts across the four metrics listed above.

Table 6-10 summarizes the percentage changes in energy use, energy costs, carbon emissions, and life-cycle costs for the 3-story office building. On average, adoption of the LEC design for a 3-story office building decreases energy use, energy costs, and energy-related carbon emissions by more than 20 % each while reducing life-cycle costs. These detailed results can be readily analyzed in mappings of the United States.

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

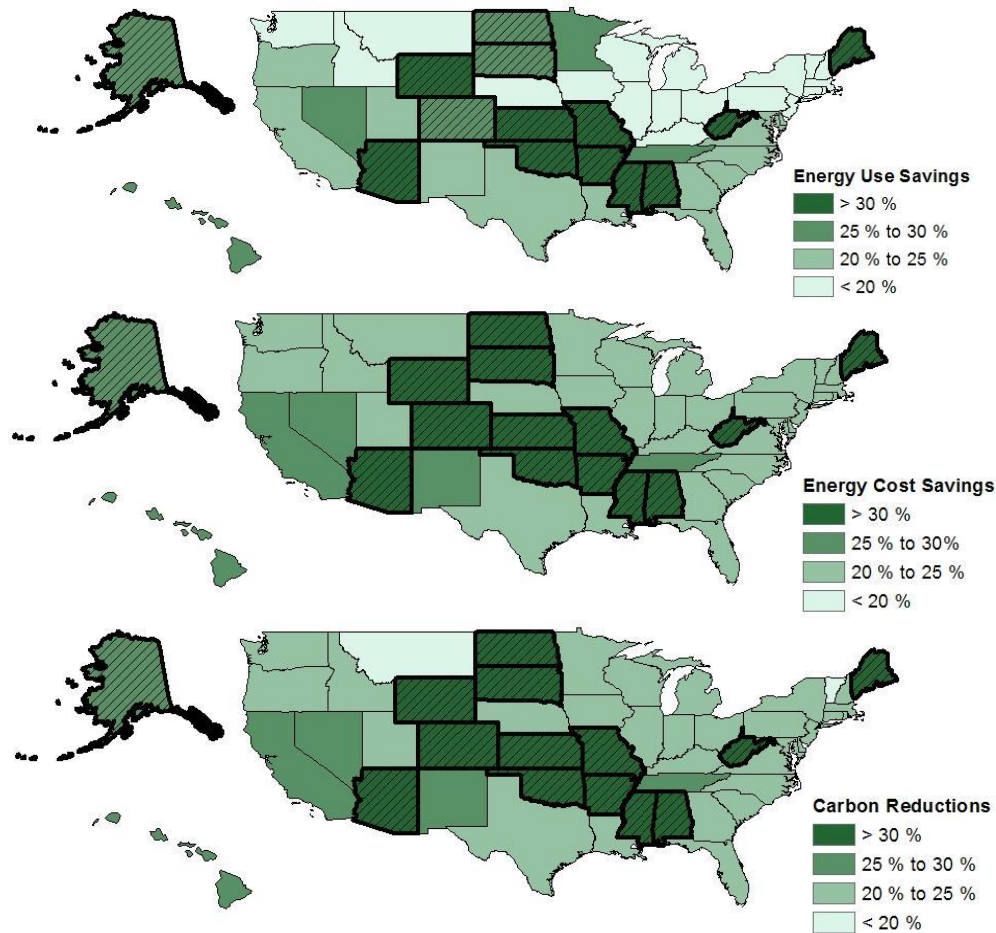
| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |             |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|-------------|
|       | Energy Use    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

#### 6.1.4.1 Energy Use, Energy Cost, and Carbon Emissions Savings

Figure 6-3 overlays Figure 6-2 and displays the average percentage energy savings, energy cost savings, and carbon emissions reduction for a 10-year study period by state. The states with codes based on older editions of *ASHRAE 90.1*, or no energy code at all, are shown with cross hatching and bolded state borders. Figure 6-3 shows that 31 of 50 states realize energy use savings of 20 % or more by adopting the LEC design over their current state energy code. Many of the states that realize the greatest energy use savings are the ones that currently have energy codes based on older editions of *ASHRAE 90.1*, or no energy code at all. Of the 18 states that realize energy use savings of at least 25 %, 14 are states with either no energy code or a code based on *ASHRAE 90.1-1999* or *ASHRAE 90.1-2001*, including all 10 states that realize energy use savings of more than 30 %.

The state average percentage reductions in energy costs and carbon emissions are highly correlated with the percentage reductions in energy use. However, the reductions in energy costs and carbon emissions tend to be greater than the reductions in energy use. Figure 6-3 allows for a comparison of the three impacts. A total of 19 states realize an average reduction in energy use of less than 20 %. Meanwhile, all states realize an

average reduction in energy costs of greater than 20 % and two states realize an average reduction in carbon emissions of less than 20 %.



**Figure 6-3 Average Energy Use, Energy Cost, and Carbon Emissions Savings by State, 3-Story Office Building, 10-Year**

As has been previously discussed, there are two fuel types consumed in each building, natural gas for heating and electricity for all other energy demands (e.g., cooling, plug and process loads, etc.). Electricity and natural gas have different price and emissions rate profiles, with natural gas costing less and being associated with fewer emissions per unit of energy consumed. As a result, the fuel source of reductions in energy use is an important determining factor for the relative savings in energy costs and energy-related carbon emissions per unit of savings in energy use.

Consider the example in Table 6-11, with three alternative building designs that decrease energy use from 100 units to 50 units. Each alternative decreases total energy use by the same amount (50 units or 50 %), but the source of the reduction in energy use varies significantly. Alternative #1 decreases electricity consumption by a greater percentage than natural gas consumption. Alternative #2 decreases electricity and natural gas

consumption by the same percentage. Alternative #3 decreases electricity consumption by a smaller percentage than natural gas consumption.

**Table 6-11 Fuel Source Reduction Example**

| Design |                             | Energy Use |        |     | % Change |              |              |
|--------|-----------------------------|------------|--------|-----|----------|--------------|--------------|
|        |                             | Total      | Elect. | Gas | %Δ Total | %Δ Elect.    | %Δ Gas       |
|        | Baseline                    | 100        | 50     | 50  |          |              |              |
| (1)    | Electricity Reduction Heavy | 50         | 10     | 40  | -50 %    | <b>-80 %</b> | -20 %        |
| (2)    | Equal Reduction             | 50         | 25     | 25  | -50 %    | <b>-50 %</b> | <b>-50 %</b> |
| (3)    | Natural Gas Reduction Heavy | 50         | 40     | 10  | -50 %    | -20 %        | <b>-80 %</b> |

The total emissions and energy costs are estimated for the baseline and each building design alternative in Table 6-12 based on the average state energy prices and emissions rates.<sup>18</sup> The percentage changes in carbon emissions and energy costs are greatest for Alternative #1, with reductions of 65 % and 66 %, respectively. Alternative #2 realizes reductions in emissions and energy costs of 50 %. Alternative #3 realizes the smallest percentage reductions in emissions (35 %) and energy costs (34 %).

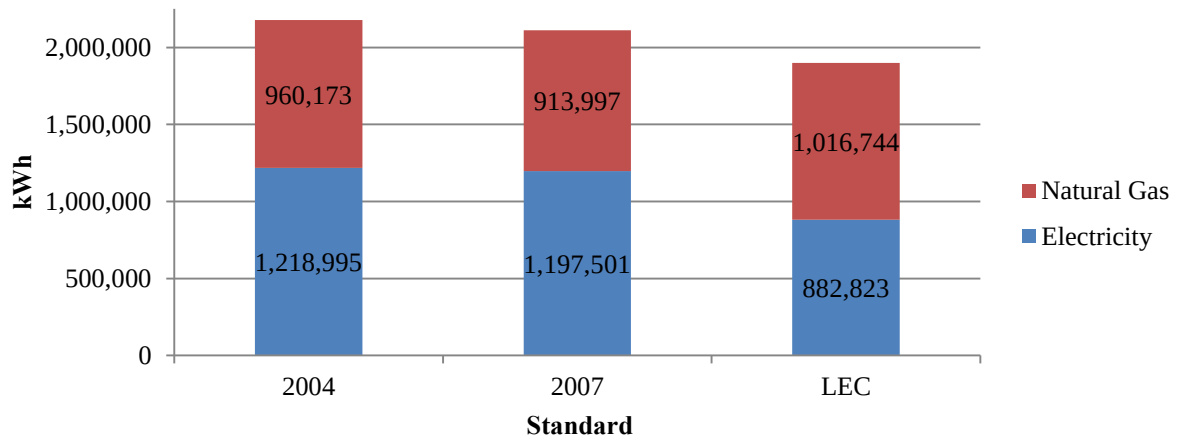
**Table 6-12 Emissions and Energy Costs Associated with Fuel Source Reductions**

| Design |                             | Emissions |         |       | Energy Costs |      |       | Relative to Δ Energy Use |
|--------|-----------------------------|-----------|---------|-------|--------------|------|-------|--------------------------|
|        |                             | Total     | Δ       | Δ%    | Total        | Δ    | Δ%    |                          |
|        | Baseline                    | 49 300    |         |       | 650          |      |       |                          |
| (1)    | Electricity Reduction Heavy | 7 450     | -32 210 | -65 % | 220          | -430 | -66 % | > 50 %                   |
| (2)    | Equal Reduction             | 18 625    | -24 650 | -50 % | 325          | -325 | -50 % | = 50 %                   |
| (3)    | Natural Gas Reduction Heavy | 29 800    | -17 090 | -35 % | 430          | -220 | -34 % | < 50 %                   |

Based on these results there are three potential outcomes. First, if the percentage reduction in electricity is *greater* than the percentage reduction in natural gas consumption, then the percentage reduction in energy costs and carbon emissions are *greater* than the percentage reduction in energy use. Second, if the percentage reduction in electricity is *equal* to the percentage reduction in natural gas consumption, then the percentage reduction in energy costs and carbon emissions are *equal* to the percentage reduction in energy use. Third, if the percentage reduction in electricity is *less* than the percentage reduction in natural gas consumption, then the percentage reductions in energy costs and carbon emissions are *less* than the percentage reduction in energy use.

<sup>18</sup> Average state electricity price is 10¢/kWh; average state natural gas price is 3¢/kWh; average state electricity emissions rate is 745 tCO<sub>2</sub>e/GWh; average state natural gas emissions rate is 241 tCO<sub>2</sub>e/GWh

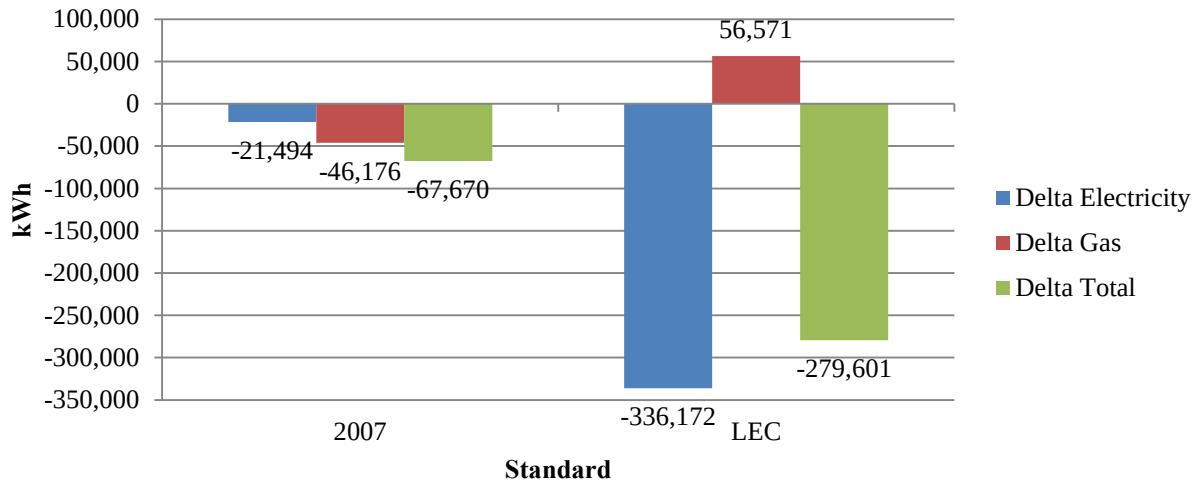
Now consider an example from the BIRDS database: the average energy use for high schools in Tennessee. Figure 6-4 shows the total energy use for Tennessee's baseline building design, *ASHRAE 90.1-2004*, is greater than the energy use for the two building design alternatives, the *ASHRAE 90.1-2007* and LEC designs. However, the fuel source of the changes in total energy use for *ASHRAE 90.1-2007* and LEC designs are quite different.



**Figure 6-4 Total Energy Use – High School – Tennessee**

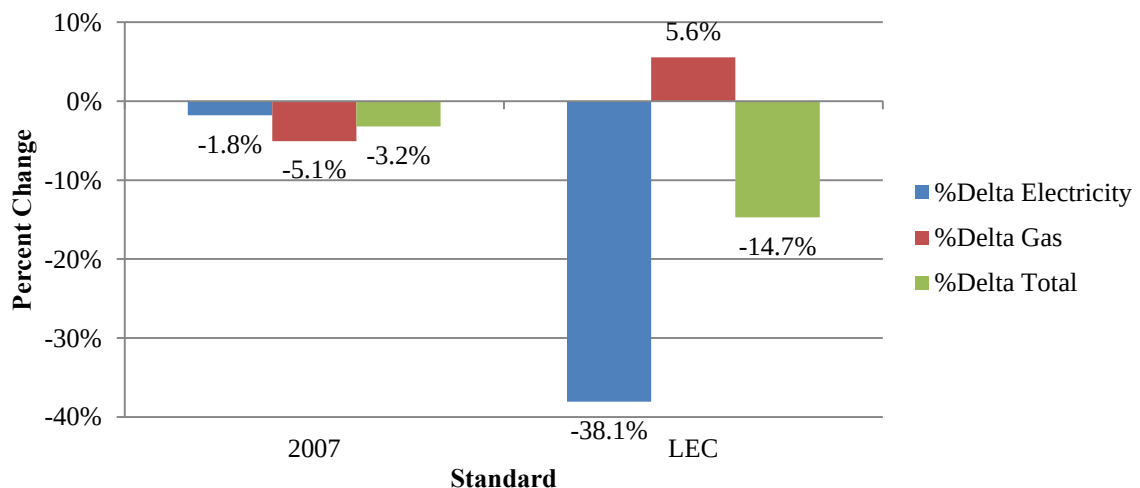
Figure 6-5 shows the change in energy use for both building designs by fuel source. For the *ASHRAE 90.1-2007* design, natural gas consumption realizes a greater total reduction of 13.5 kWh (46 176 Btu) relative to a reduction in electricity consumption of 6.3 kWh (21 494 Btu). Meanwhile, adopting the LEC design leads to a large reduction in electricity consumption 95.5 kWh (336 172 Btu) while increasing natural gas consumption 16.6 kWh (56 571 Btu). Not only is electricity the primary fuel source for total energy use reductions, there is a shift in fuel consumption from electricity to natural gas.





**Figure 6-5 Change in Energy Use – High School – Tennessee**

Figure 6-6 shows the percentage change in energy use for both building designs and fuel sources. For the *ASHRAE 90.1-2007* design, natural gas consumption realizes a greater percentage reduction (5.1 %) than electricity consumption (1.8 %), which implies that the percentage reduction in energy use will be greater than the percentage reductions in energy costs and carbon emissions. Adopting the LEC design leads to a large percentage decrease in electricity consumption (-38.1 %) and a small percentage increase natural gas consumption (5.6 %). Not only does electricity consumption decrease by a greater percentage than natural gas, electricity accounts for greater than 100 % of the reduction in total energy use, which implies that the percentage reduction in energy costs and carbon emissions will be greater than the reduction in energy use.

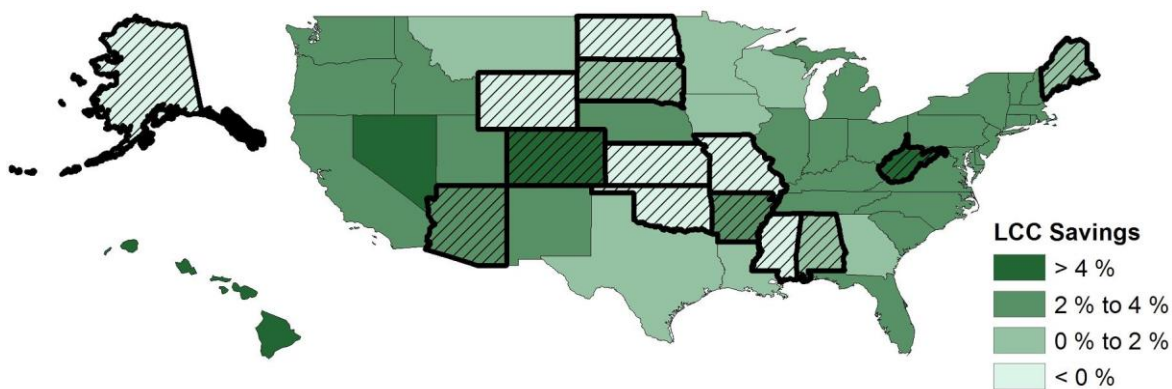


**Figure 6-6 Percentage Change in Energy Use – High School – Tennessee**

For the LEC design, some of the reduction in electricity consumption is “offset” by an increase in natural gas consumption. A “positive offset” occurs when electricity consumption decreases and natural gas consumption increases. A “negative offset” occurs when both electricity and natural gas consumption decrease. The greater the percentage “offset,” the greater the percentage reduction in energy costs and carbon emissions per percentage reduction in energy use. The offset will be discussed in more detail in Section 6.3.1.

#### 6.1.4.2 Life-Cycle Cost Savings

Figure 6-7 overlays Figure 6-2 with the average life-cycle cost savings for the 3-story office building over 10 years by state from adopting the LEC design. The resulting map shows two interesting trends. First, all states that realize an increase in life-cycle costs on an average percentage basis as a result of adopting the LEC design as its state energy code currently have no state energy code. The energy cost savings of the more efficient LEC design are not enough to overwhelm the additional construction and MRR costs associated with the required energy efficiency measures. Second, states located in the central and southern U.S. tend to realize life-cycle cost savings less than 2 %. States located in the West and Northeast U.S. tend to realize life-cycle cost savings greater than 2 %, which may be a result of greater energy cost savings due to higher energy prices.



**Figure 6-7 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year**

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

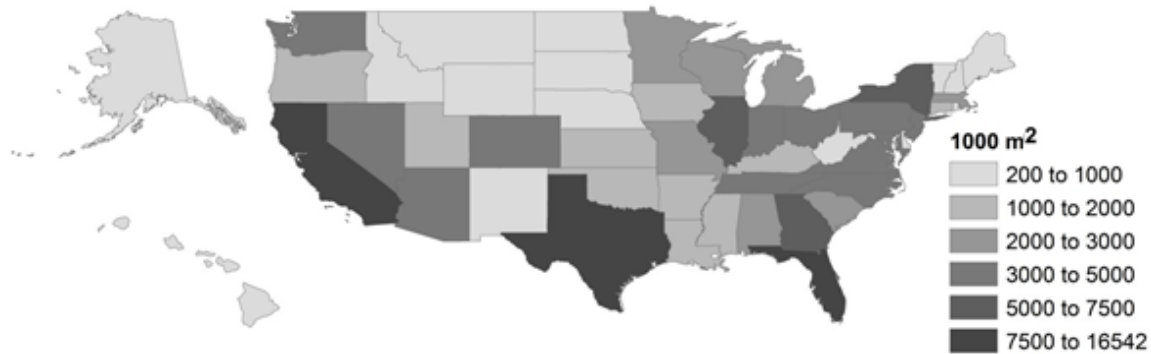
## 6.2 Total Changes

The average percentage changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs reported in Section 6.1 do not account for the amount of new floor area for each building type in a state, which may have a significant impact on the results.

### 6.2.1 State-Level Total Savings

Estimating the magnitude of the total impacts in a state controls for new floor area and determines which states would benefit the most from adopting the LEC design as their state energy code. The total changes in the four impacts from adopting the LEC design for a state are calculated using Formula 1 defined in Section 5.4. Based on this formula, two variables impact the magnitude of the total changes in a state: the amount of new commercial building construction and the average changes per unit of floor area.

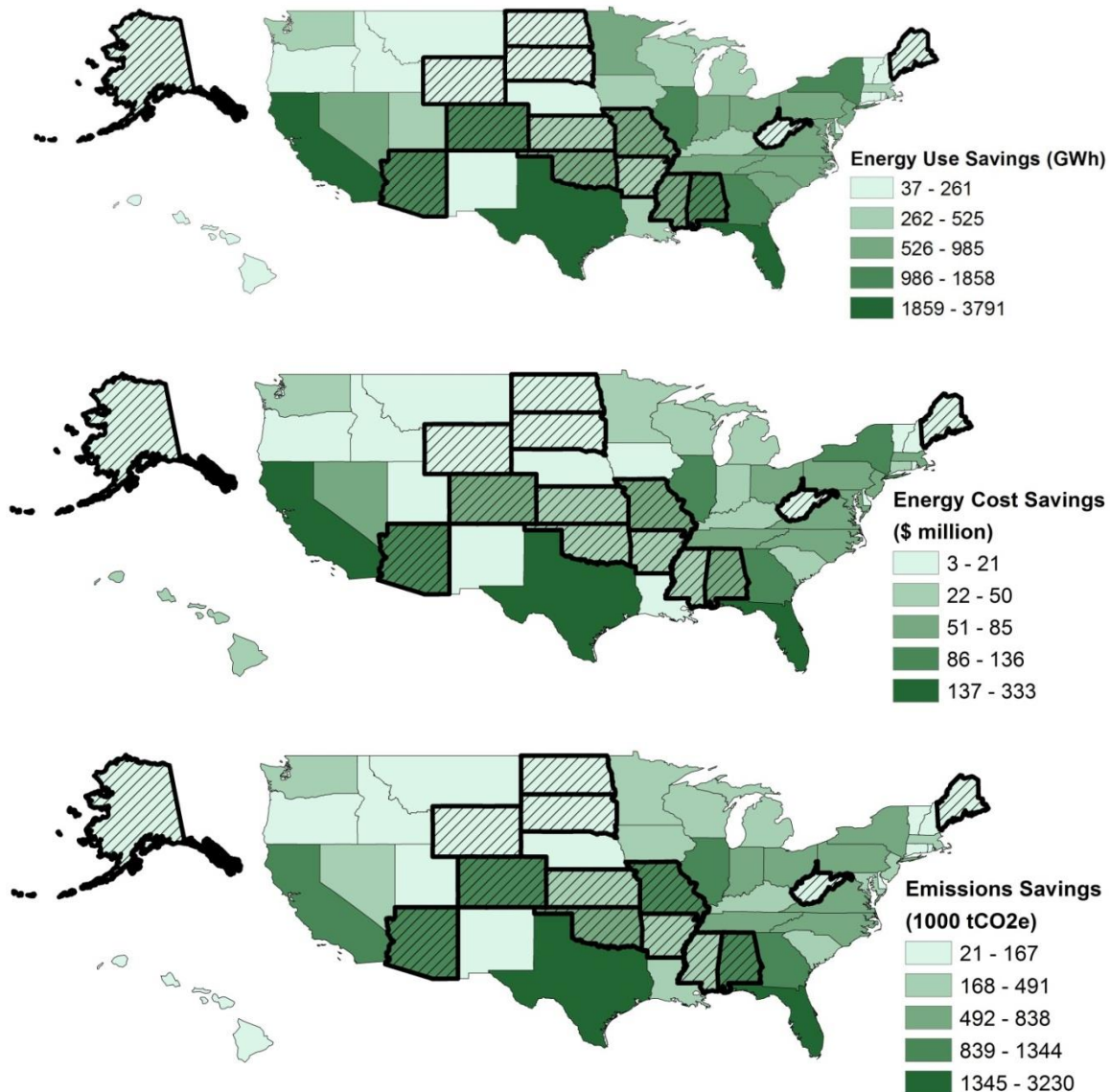
Figure 6-8 shows the amount of new floor area (1000 m<sup>2</sup>) constructed annually for each of the 50 states from 2003 to 2007. States with a greater amount of new floor area constructed (California, Florida, and Texas) are expected to realize greater reductions in energy use, energy costs, and carbon emissions.



**Figure 6-8 Average Annual New Floor Area by State**

Table C-1 in Appendix C 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 all 50 states for a 10-year study period. In general, the greater the amount of new floor area, the greater the reductions in energy use, energy costs, and carbon emissions. The relative total changes across states, shown in Figure 6-9, are significantly different than the relative percentage changes shown in Figure 6-3, which emphasizes the importance of controlling for the amount of new floor area for each building type in determining the magnitude of the impacts of adopting the LEC design. The total change in energy use for a state is driven by the amount of new floor area constructed in a state. California, Florida, and Texas realize the greatest reductions in energy use (1.9 TWh to

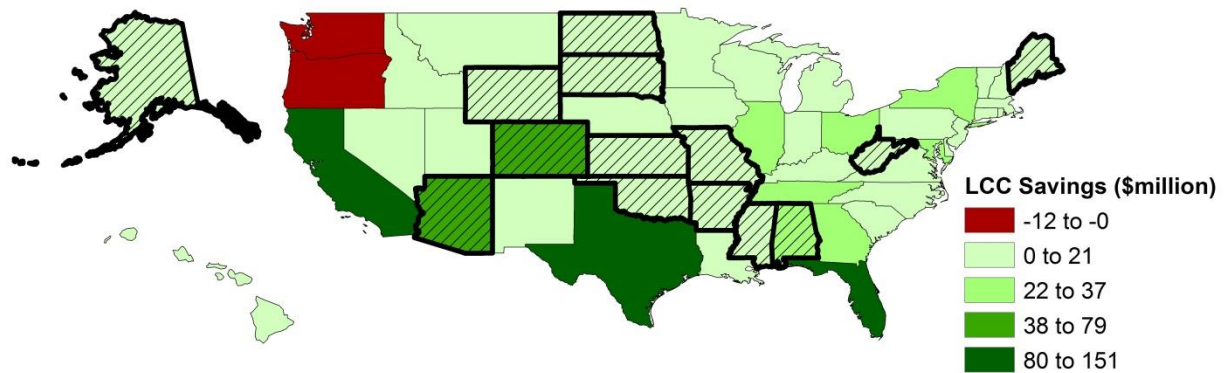
3.8 TWh). In comparison, states with the smallest amount of new floor area (Alaska, Delaware, Montana, Rhode Island, Vermont, and Wyoming) realize savings of less than 0.1 TWh.



**Figure 6-9 Total Energy Use, Energy Costs, and Carbon Emissions Savings by State, 10-Year**

Figure 6-9 shows a strong correlation between total savings in energy use and total savings in energy costs and carbon emissions. California, Florida, and Texas realize the greatest reductions in energy costs while Florida and Texas realize the greatest reductions in carbon emissions. The relative total reductions in energy costs and carbon emissions vary from total reductions in energy use to some extent. The reasons for this variation will be discussed in Section 6.3.1.3 and Section 6.3.1.4, respectively.

Figure 6-10 shows a strong correlation between total savings in energy use shown in Figure 6-9 and total savings in life-cycle costs. California, Florida, and Texas realize the greatest total life-cycle cost savings. The relative total reductions in life-cycle costs vary from total reductions in energy use to some extent, particularly for states with no energy code. The reasons for this variation will be discussed in Section 6.3.1.2 and Section 6.4.2.



**Figure 6-10 Total Life-Cycle Cost Savings by State, 10-Year**

Only two states realize an increase in life-cycle costs (Oregon and Washington). Neither of these two states realized an increase in life-cycle costs on a percentage basis. Additionally, seven states that realize an increase in life-cycle costs on a percentage basis for the 3-story office building (see Figure 6-7) realize a total life-cycle cost decrease (Alaska, Kansas, Mississippi, Missouri, North Dakota, Oklahoma, and Wyoming). These results emphasize the importance of accounting for the building types associated with the new floor area constructed in a state to determine where adopting the LEC design is life-cycle cost-effective.

## 6.2.2 Regional and National Total Savings

The nationwide changes in the four impacts from adopting the LEC design are calculated using Formula 2 from Section 5.4, where the state-level savings are summed across all fifty states for each impact.

Table 6-13 shows the total changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for one year's worth of construction for a 10-year study period aggregated at the Census region and national level. The greater the amount of new floor area constructed in a Census region, the greater the total reduction in energy use, energy costs, and life-cycle costs. This condition does not strictly hold for the total reduction in carbon emissions because the total reduction in the Midwest Census Region is greater than the total reduction in the West Census Region. The reason for this variation will be discussed in Section 6.3. The nationwide reductions total 34.4 TWh in energy consumption, \$2.8 billion in energy costs, 26.3 million metric tons in

energy-related carbon emissions, and \$1.0 billion in life-cycle costs for a 10-year study period.

**Table 6-13 Total Reductions by Census Region from Adoption of the LEC Design, 10-Year**

| <b>Census Region</b> | <b>Average Annual New Floor Area<br/>1000 m<sup>2</sup> (1000 ft<sup>2</sup>)</b> | <b>Energy Use<br/>(GWh)</b> | <b>Energy Costs<br/>(\$million)</b> | <b>Carbon<br/>(1000 tCO<sub>2</sub>e)</b> | <b>LCC<br/>(\$million)</b> |
|----------------------|-----------------------------------------------------------------------------------|-----------------------------|-------------------------------------|-------------------------------------------|----------------------------|
| Northeast            | 22 395 (241 056)                                                                  | 3437                        | 399                                 | 2332                                      | 125                        |
| Midwest              | 29 510 (317 641)                                                                  | 6621                        | 459                                 | 6219                                      | 136                        |
| South                | 67 299 (724 394)                                                                  | 16 427                      | 1208                                | 12 890                                    | 488                        |
| West                 | 36 144 (389 056)                                                                  | 7956                        | 703                                 | 4878                                      | 300                        |
| <b>Total</b>         | <b>155 348 (1 672 147)</b>                                                        | <b>34 441</b>               | <b>2769</b>                         | <b>26 319</b>                             | <b>1048</b>                |

### 6.3 Changes per Unit of Floor Area and Energy Use Savings

Total savings in energy use, energy costs, carbon emissions, and life-cycle costs are highly correlated. However, there are a number of factors that lead to significant variation in relative savings, each of which will be discussed in this section.

#### 6.3.1 State Level Changes

There is significant variation in relative savings across states for each of the four impacts for a number of reasons, including current state energy code requirements, newly constructed building stock mix and size, climate zone, electricity costs, electricity production fuel mix (average emissions rate), and the relative percentage changes in fuel types consumed by the building.

##### 6.3.1.1 Energy Use Savings per Unit of Floor Area

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.

Table C-2 shows the 10-year reduction in energy use per unit of newly constructed floor area sorted by state in decreasing order. The reduction in energy use per unit of floor area is primarily driven by the state's adopted energy code for commercial buildings. Fourteen of the fifteen states with the greatest per unit reduction from adoption of the LEC design have no state energy code or have *ASHRAE 90.1-2001* as their state energy code.



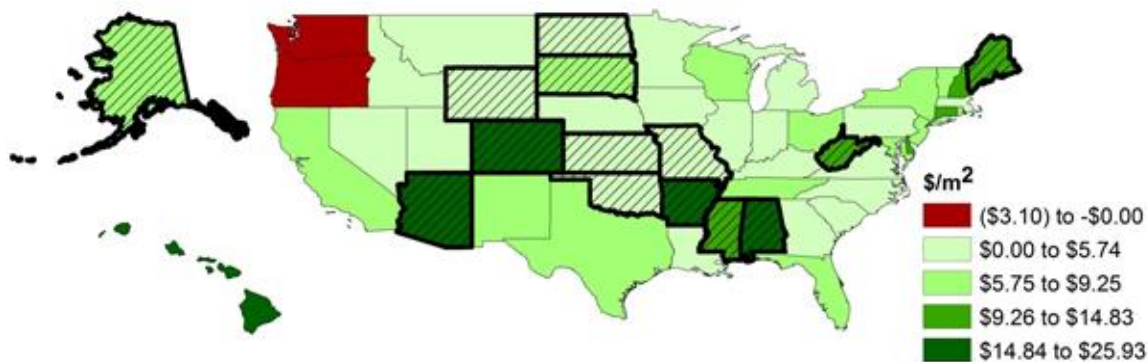
Additionally, only two of the top 21 states, in terms of per unit savings, have adopted *ASHRAE 90.1-2007*. These results, shown in Figure 6-11, can be compared to the average percentage changes in energy use in Figure 6-3. After controlling for the amount of new floor area, the relative savings across states correlates much closer to the relative average percentage changes in energy use. However, the correlation is not perfect because the total changes weight building types based on new floor area constructed in a state.



**Figure 6-11 Energy Use Savings per Unit of Floor Area by State, 10-Year**

### 6.3.1.2 Life-Cycle Cost Savings per Unit of Floor Area

The relative change in life-cycle costs per unit of new floor area is shown in Table C-3. After controlling for the amount of new floor area, states that have adopted *ASHRAE 90.1-2001* as their state energy code (Arkansas, Colorado, and West Virginia) realize some of the greatest relative life-cycle cost savings of adopting the LEC design. There is significant variation in life-cycle cost savings for the ten states with no state energy code, with the relative ranking ranging from 4<sup>th</sup> (Arizona) to 48<sup>th</sup> (North Dakota). These results, shown in Figure 6-12, can be compared to the average percentage changes in life-cycle costs in Figure 6-7. Once controlling for the amount of new floor area, the relative savings across states correlates better with the relative percentage changes in energy use. However, the correlation is not perfect because the total changes weight building types based on new floor area constructed.



**Figure 6-12 Life-Cycle Cost Savings per Unit of Floor Area by State, 10-Yr**

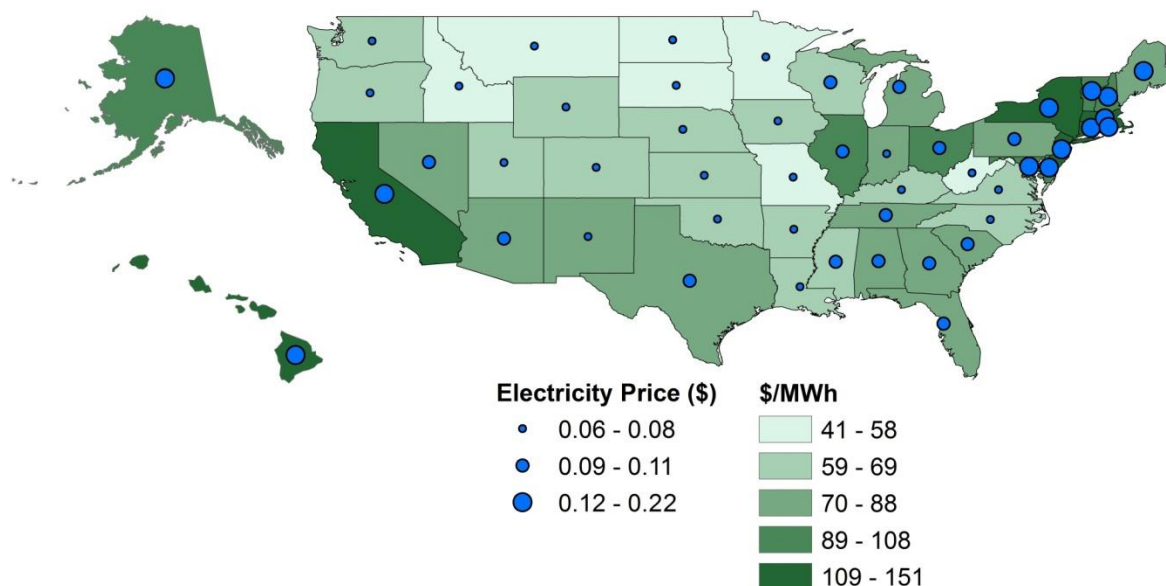
### 6.3.1.3 Energy Cost Savings per Unit of Energy Use Savings

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 costs of electricity and natural gas and the fuel mix of the reductions in energy use in a state. Table C-4 shows each state's reduction in energy costs per unit of reduction in energy use, natural gas rate, electricity rate, and the fraction of electricity consumption reductions offset by increases in natural gas consumption.<sup>19</sup> 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 have minimal impacts on the relative reduction because natural gas prices are fairly constant across states (excluding Hawaii), and are significantly cheaper per unit of energy for all fifty states.

The correlation between a state's average electricity price and the savings in energy costs per unit of energy reduced is shown in Figure 6-13. States in the Northeast, Great Lakes area, California, Hawaii, and Alaska have the highest average electricity prices and realize the greatest savings in energy costs per unit of savings in energy use. Meanwhile, states with the lowest average electricity prices (Northern Central U.S.) realize the smallest energy cost savings per unit of energy use savings.

<sup>19</sup> 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.

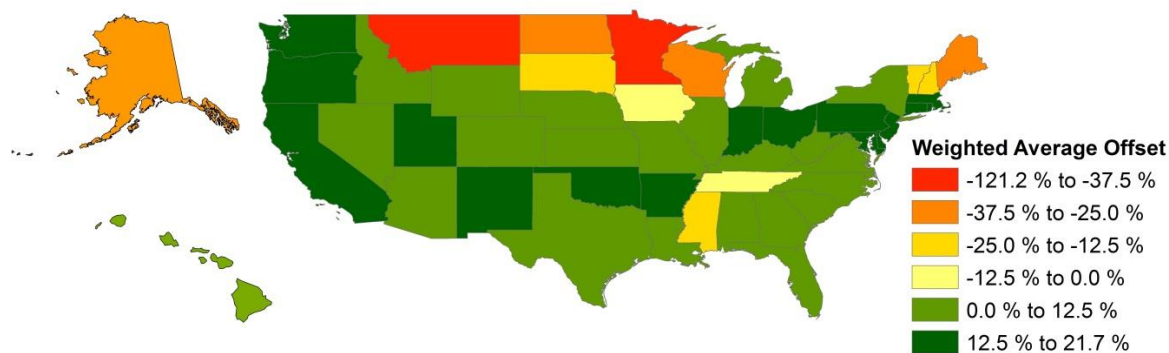




**Figure 6-13 Energy Cost Savings per Unit of Energy Use Savings and Average Electricity Price by State**

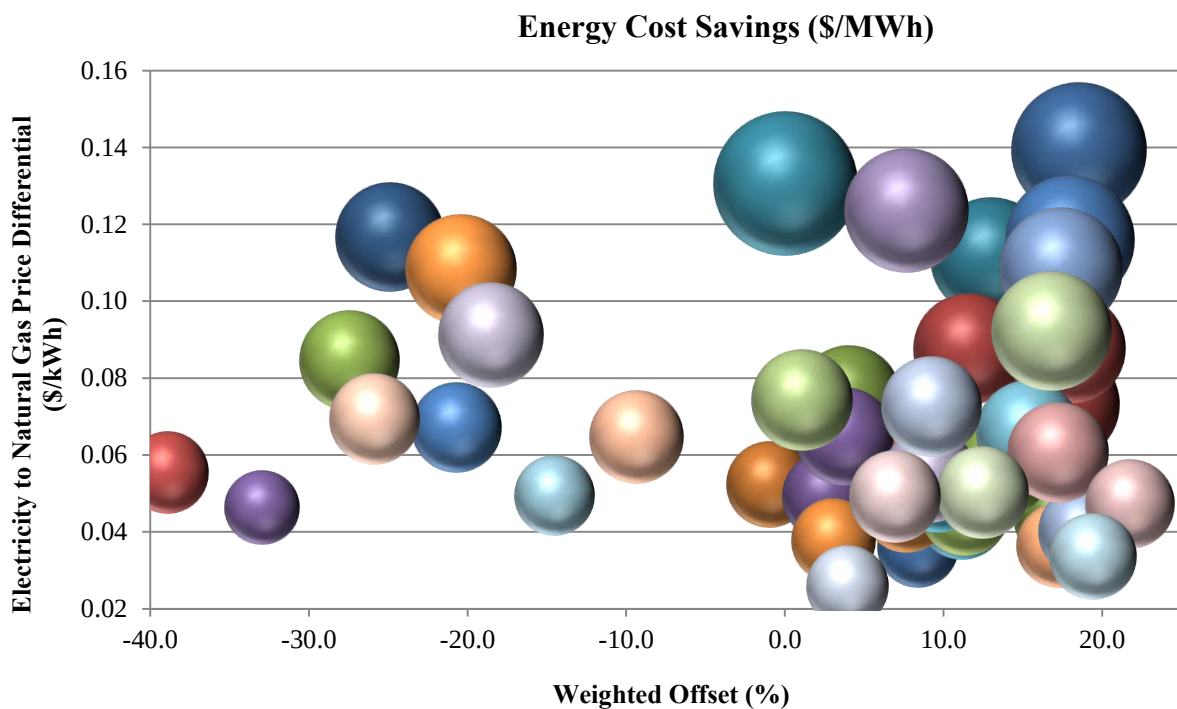
The electricity price does not explain all the variation across states in energy cost savings per unit of energy use savings because there are two sources of energy cost savings: the energy cost savings from total energy use reduction, and the energy cost savings from the shift of fuel consumption from more expensive electricity to cheaper natural gas. The savings from the shift in fuels is a result of two factors: the energy cost savings per unit of energy shifted from electricity to natural gas consumption (energy price differential) and the amount of energy shifted from electricity to natural gas consumption. The energy cost savings increases as the energy price differential increases because the cost savings for each unit of electricity “offset” by a unit of natural gas is greater. The greater the fraction of electricity consumption shifted to natural gas consumption, or offset, the greater the energy cost savings per unit of total energy use savings.

The metric used to explain the shift in fuel consumption is the “weighted average offset,” which is the average percentage offset weighted by the amount of new floor area for each building type in a state. Figure 6-14 shows the weighted average offset for each state. Most states realize a positive offset (38 of 50). The northern-most states realize the smallest offset values (-121.2 % to -25.0 %). The greatest offset values are spread across the United States: from the West Coast to the southern central U.S. states to the East North Central and Middle Atlantic Census Divisions.



**Figure 6-14 Weighted Average Offset by State**

Figure 6-15 shows the savings in energy costs per unit of savings in energy use (\$/MWh) based on the price differential between electricity and natural gas (\$/kWh) and the weighted average offset (%) for each state. States with a greater energy price differential combined with a greater weighted average offset realize the greatest energy cost savings per unit of energy use savings.



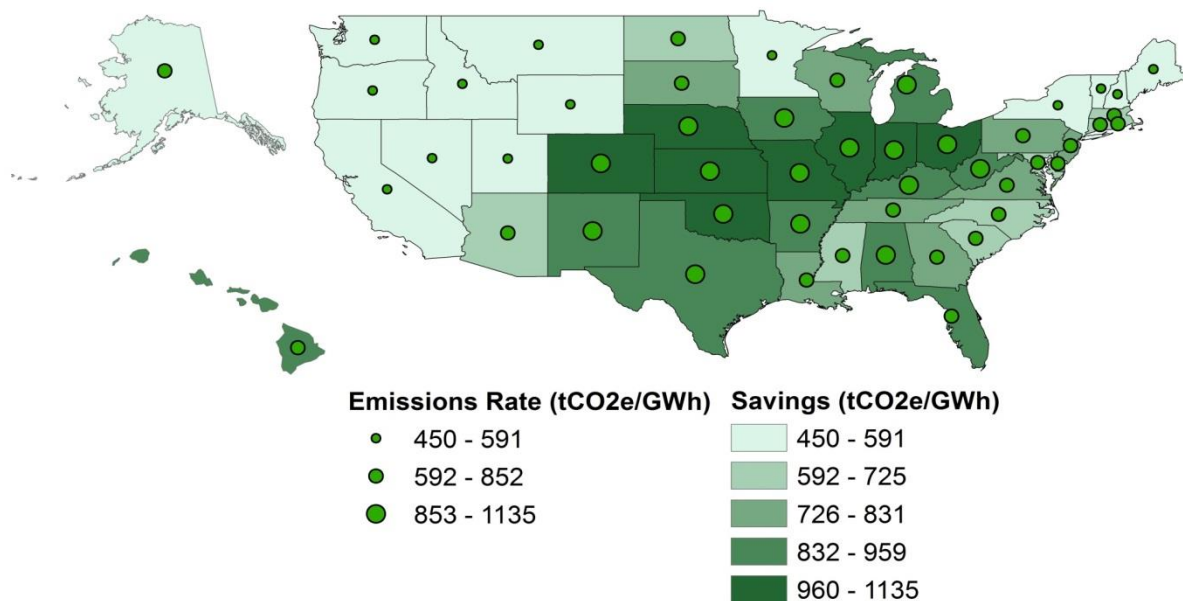
**Figure 6-15 Average State Energy Cost Savings per Unit of Energy Use Savings by Weighted Average Offset and Energy Price Differential**

#### 6.3.1.4 Carbon Emissions Savings per Unit of Energy Use Savings

In general, the states that realize the greatest reductions in energy use also realize the greatest reductions in energy-related carbon emissions. However, reductions in carbon

emissions are also impacted by the per unit emissions rates of electricity and natural gas and the fuel mix of the reductions in energy use in a state. Table C-5 shows the weighted average fraction of electricity consumption offset by a change in natural gas consumption, the average CO<sub>2</sub> emission rates for electricity and natural gas, and the reduction in cradle-to-grave energy-related carbon emissions per unit of reduction in energy use for all 50 states.<sup>20</sup> States with the highest emissions rates for electricity generation tend to realize the greatest reductions in carbon emissions per unit of reduction in energy use. Relative to electricity emissions rates, natural gas has minimal impact on the relative reduction because natural gas emissions rates are constant across states and are significantly lower per unit of energy for all fifty states.

The correlation between a state's average electricity emissions rate and the savings in energy-related emissions per unit of energy reduced is shown in Figure 6-16. States in the central U.S. and the Rust Belt have the highest average electricity emissions rates and realize the greatest savings in carbon emissions per unit of savings in energy use. Meanwhile, states with the lowest average electricity emissions rates (most of the states in the West Census Region and New England Census Division) realize the smallest carbon emissions savings per unit of energy use savings.

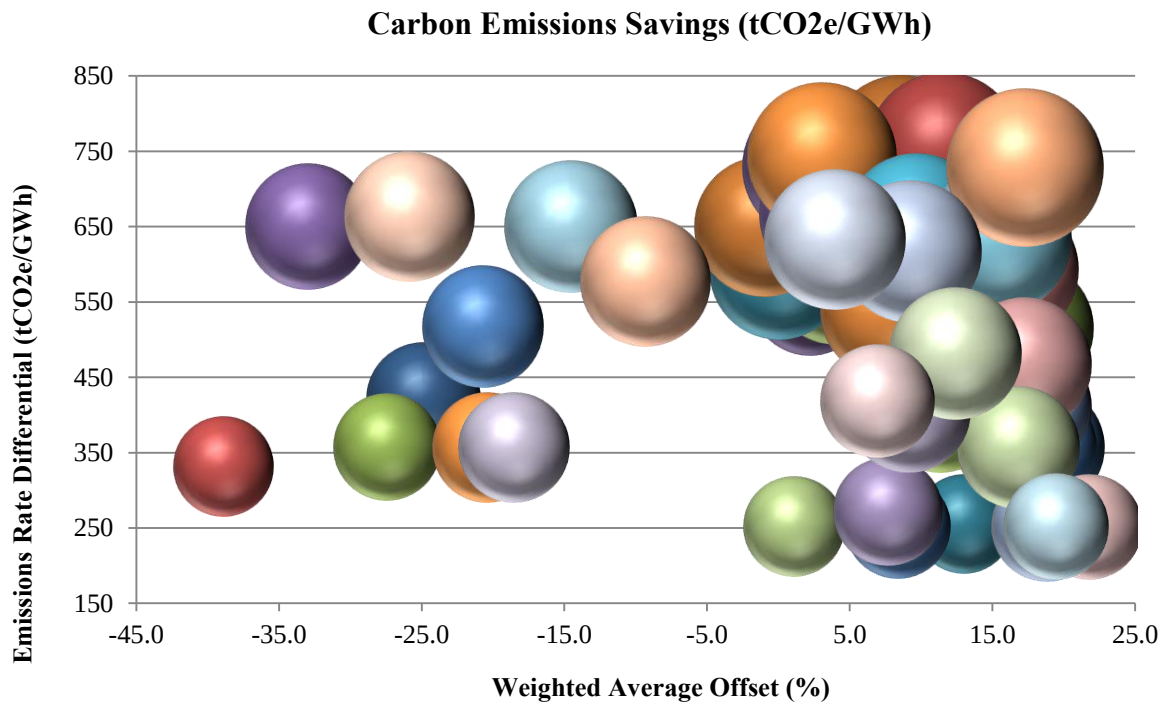


**Figure 6-16 Energy-related Carbon Emissions Savings per Unit of Energy Use Savings and Average Electricity Emissions Rate by State**

<sup>20</sup> The fraction of electricity offset by natural gas consumption is greater than 100 % when natural gas consumption increases by a greater amount than electricity consumption decreases. The fraction of electricity offset by natural gas consumption is less than -100 % when natural gas consumption decreases by a greater amount than electricity consumption decreases.

The electricity emissions rate does not explain all the variation across states in energy-related carbon emissions savings per unit of energy use savings because there are two sources of carbon emission savings: the carbon emissions savings from total energy use reduction, and the carbon emissions savings from the shifting of fuel consumption from the more carbon intensive electricity to less carbon intensive natural gas. The carbon emissions savings increase as the emissions rate differential increases because the carbon emissions savings for each unit of electricity “offset” by a unit of natural gas is greater. The greater the fraction of electricity consumption reductions offset by increases in natural gas consumption, the greater the carbon emissions savings per unit of energy use savings.

Figure 6-17 shows the savings in carbon emissions per unit of savings in energy use ( $\text{tCO}_2\text{e/GWh}$ ) based on the emissions rate differential between electricity and natural gas ( $\text{tCO}_2\text{e/GWh}$ ) and the weighted average offset (%) for each state. States with a greater carbon emissions rate differential combined with a greater weighted average offset realize the greatest carbon emissions savings per unit of energy use savings.



**Figure 6-17 Average State Carbon Emissions Savings per Unit of Floor Area by Weighted Average Offset and Energy Emissions Rate Differential**

### 6.3.2 Regional and National Level Changes

Table 6-14 shows the reduction in energy use per unit of newly constructed floor area from adopting the LEC design by Census region. States in the South Census Region realize the greatest reduction while states in the Northeast Census Region realize the

smallest reduction in energy use per unit of floor area. The nationwide weighted average reduction in energy use per unit of floor area is 222 kWh/m<sup>2</sup> (21 kWh/ft<sup>2</sup>).

**Table 6-14 Energy Use Reduction per Unit of Floor Area for Adoption of the LEC Design by Census Region, 10-Year**

| State        | Average Annual New Floor Area<br>1000 m <sup>2</sup> (1000 ft <sup>2</sup> ) | Energy Use<br>(GWh) | kWh/m <sup>2</sup> | kWh/ft <sup>2</sup> |
|--------------|------------------------------------------------------------------------------|---------------------|--------------------|---------------------|
| South        | 67 299 (724 394)                                                             | 16 427              | 244                | 23                  |
| Midwest      | 29 510 (317 641)                                                             | 6621                | 224                | 21                  |
| West         | 36 144 (389 056)                                                             | 7956                | 220                | 20                  |
| Northeast    | 22 395 (241 056)                                                             | 3437                | 153                | 14                  |
| <b>Total</b> | <b>155 348 (1 672 147)</b>                                                   | <b>34 441</b>       | <b>222</b>         | <b>21</b>           |

Table 6-15 shows each Census Region's natural gas rate, electricity rate, weighted average fraction of the reduction in electricity consumption offset by the change in natural gas consumption, and average reduction in energy costs from adopting the LEC design. The Northeast Census Region has the highest average electricity rate and weighted average offset, and realizes the greatest reductions in energy costs per unit of reduction in energy use. Meanwhile, the Midwest Census Region has the smallest average electricity rate and weighted average offset, and realizes the smallest reductions in energy costs per unit of reduction in energy use.

**Table 6-15 Energy Cost Reduction per kWh of Energy Use Reduction for Adoption of the LEC Design by Census Region, 10-Year**

| State                                       | Offset*<br>(%) | Electricity<br>Rate*<br>(\$/kWh) | Natural Gas<br>Rate*<br>(\$/kWh) | Energy Cost<br>Reduction<br>(\$/kWh) |
|---------------------------------------------|----------------|----------------------------------|----------------------------------|--------------------------------------|
| Northeast                                   | 11.6           | 0.14                             | 0.03                             | 0.12                                 |
| West                                        | 10.3           | 0.10                             | 0.03                             | 0.09                                 |
| South                                       | 7.3            | 0.09                             | 0.03                             | 0.07                                 |
| Midwest                                     | -4.6           | 0.09                             | 0.03                             | 0.07                                 |
| <b>Total</b>                                | <b>6.4</b>     | <b>0.10</b>                      | <b>0.03</b>                      | <b>0.08</b>                          |
| *Weighted by energy use savings for a state |                |                                  |                                  |                                      |

Table 6-16 shows each Census Region's natural gas emissions rate, electricity emissions rate, weighted average fraction of the reduction in electricity consumption offset by the change in natural gas consumption, and average reduction in carbon emissions from adopting the LEC design. The Midwest Census Region has the highest average electricity emissions rate, and realizes the greatest reductions in carbon emissions per unit of reduction in energy use. Even though the West Census Region does not have the smallest average electricity emissions rate, it realizes the smallest reductions in carbon emissions

per unit of reduction in energy use. The Northeast Census Region has a greater offset than the West Census Region, leading to the Northeast realizing greater carbon emissions savings per unit of energy use savings.

**Table 6-16 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the LEC Design by Census Region, 10-Year**

| State                                       | Offset* (%) | CO <sub>2</sub> e Emissions Rate for Electricity* (t/GWh) | CO <sub>2</sub> e Emissions Rate for Natural Gas (t/GWh) | CO <sub>2</sub> e Reduction (t/GWh) |
|---------------------------------------------|-------------|-----------------------------------------------------------|----------------------------------------------------------|-------------------------------------|
| Midwest                                     | -4.6        | 928                                                       | 241                                                      | 939                                 |
| South                                       | 7.3         | 805                                                       | 241                                                      | 785                                 |
| Northeast                                   | 11.6        | 606                                                       | 241                                                      | 678                                 |
| West                                        | 10.3        | 653                                                       | 241                                                      | 613                                 |
| <b>Total</b>                                | <b>3.7</b>  | <b>805</b>                                                | <b>241</b>                                               | <b>764</b>                          |
| *Weighted by energy use savings for a state |             |                                                           |                                                          |                                     |

Table 6-17 shows the average life-cycle cost reduction per unit of new floor area by Census Region. The combination of greater energy use savings per unit of floor area and higher electricity rates tends to lead to greater life-cycle cost savings from adopting the LEC design. The West Census Region realizes the greatest life-cycle cost savings per unit of floor area because it has the 2<sup>nd</sup> greatest energy use savings per unit of floor area and the 2<sup>nd</sup> highest electricity price. Meanwhile the Census regions with the lowest electricity rate (Midwest) and the smallest energy use savings per unit of floor area (Northeast) realize the lowest and 2<sup>nd</sup>-lowest life-cycle cost savings per unit of floor area, respectively. Other factors that impact life-cycle cost savings include the energy codes and local construction costs.

**Table 6-17 Life-Cycle Cost Reductions per Unit of New Floor Area for Adoption of the LEC Design by Census Region, 10-Year**

| State        | Energy Use Savings (kWh/m <sup>2</sup> ) | Electricity Rate (\$/kWh) | LCC Savings (\$million) | LCC Savings (\$/m <sup>2</sup> ) | LCC Savings (\$/ft <sup>2</sup> ) |
|--------------|------------------------------------------|---------------------------|-------------------------|----------------------------------|-----------------------------------|
| West         | 220                                      | 0.10                      | 300                     | 8.29                             | 0.77                              |
| South        | 244                                      | 0.09                      | 488                     | 7.24                             | 0.67                              |
| Northeast    | 153                                      | 0.14                      | 125                     | 5.59                             | 0.52                              |
| Midwest      | 224                                      | 0.09                      | 136                     | 4.60                             | 0.43                              |
| <b>Total</b> | <b>222</b>                               | <b>0.10</b>               | <b>1048</b>             | <b>6.75</b>                      | <b>0.63</b>                       |

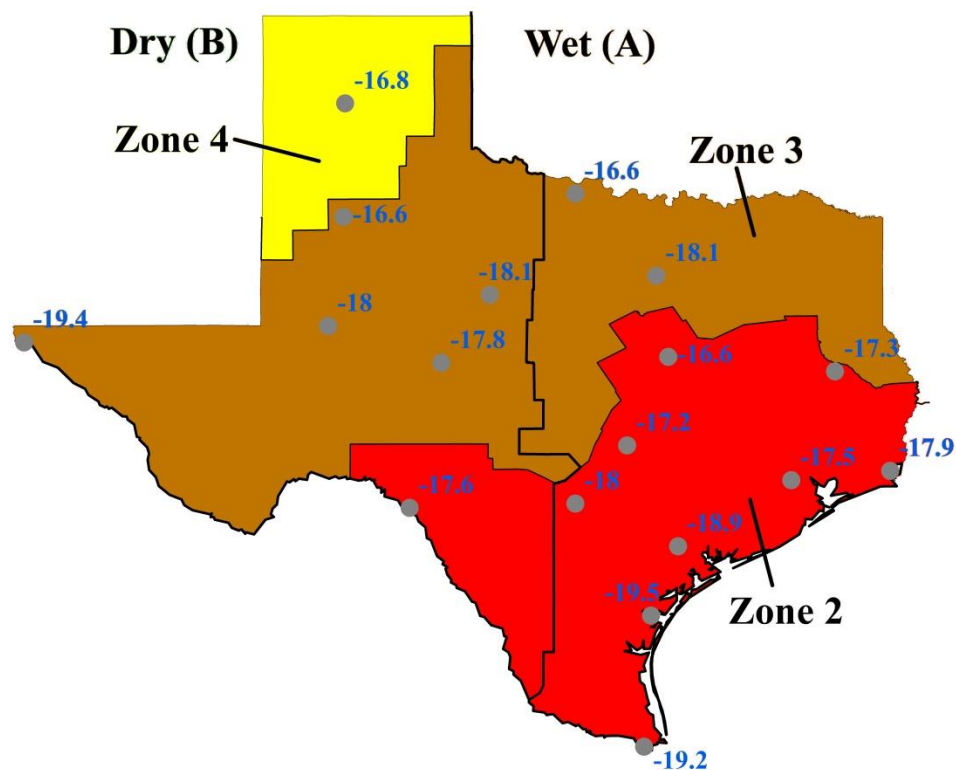


## 6.4 Within-State Impacts of Adopting Low Energy Case Design

So far, the analysis in this report has focused on across-state, regional, and national variations. However, there is variation in the results across cities within a state. This section will implement a more rigorous statistical approach to analyze the results at the city level: regression analysis using a Least Squares Dummy Variable (LSDV) model.

### 6.4.1 Energy Use Savings across Cities

As shown in Section 6.1.3, two primary drivers of variation in impacts are the energy code and climate zone of a city. Most cities are required to meet the building requirements of its state energy code, which vary for a given edition of *ASHRAE 90.1* depending on the city's climate zone. However, this does not explain all the variation in the percentage change in energy use across cities. For example, Figure 6-18 shows the average percentage change in energy use for each city in Texas considered in this study. For climate zones in Texas with multiple cities, there is variation in the percentage change in energy use. Consider the cities in Climate Zone 3B, where the variation in energy use savings is 2.8 percentage points (16.6 % to 19.4 %).



**Figure 6-18 Average Percentage Change in Energy Use by City - Texas**

Since each climate zone is a bin of heating degree day (HDD) and cooling degree day (CDD) combinations (see *ASHRAE 90.1 Standard*), a city's local climate could vary

significantly from other cities' climates even if they are located in the same climate zone. For example, there are five cities in the BIRDS database located in Climate Zone 3B within the state of Texas. Across these five cities, heating varies up to 907 degree days and cooling varies by 606 degree days, which is 35.1 % and 26.6 % of the median city's degree days, respectively. These results are shown in Table 6-18.

**Table 6-18 Variation in Energy Use, Heating Degree Days, and Cooling Degree Days for Cities located in Climate Zone 3B in Texas**

| Cities                            | Climate Subzone | Low Energy Case                 |                      |                      |
|-----------------------------------|-----------------|---------------------------------|----------------------|----------------------|
|                                   |                 | Percentage Change in Energy Use | Cooling Degree Days* | Heating Degree Days* |
| Abilene                           | 3B              | -18.1                           | 2410                 | 2558                 |
| El Paso                           | 3B              | -19.4                           | 2331                 | 2473                 |
| Lubbock                           | 3B              | -16.6                           | 1804                 | 3380                 |
| Midland                           | 3B              | -18.0                           | 2278                 | 2673                 |
| San Angelo                        | 3B              | -17.8                           | 2269                 | 2582                 |
| <b>Variation</b>                  |                 | <b>2.8</b>                      | <b>606</b>           | <b>907</b>           |
| <b>Variation from Median City</b> |                 | <b>15.6 %</b>                   | <b>26.6 %</b>        | <b>35.1 %</b>        |
| <b>*Base 18.3 °C (65 °F)</b>      |                 |                                 |                      |                      |

In order to determine the impact of this variation in HDDs and CDDs across cities, it is necessary to use regression analysis. An LSDV model is used to estimate the impact of a city's HDDs and CDDs on the percentage change in energy use realized from adoption of the LEC design while controlling for a city's energy code-climate zone combination. An interaction of the standard edition adopted and climate zone of a city is included in the model because the impact of each standard edition could vary across climate zones due to the different building requirements in each zone.

The LSDV model is defined as:

*ENERGY USE CHANGE*

$$= \beta_0 + \beta_{k,h}(STD_{k,i} * ZONE_{h,i}) + \beta_1 * HDD65_i + \beta_2 * CDD65_i + \beta_3 * HDD65SQ_i + \beta_4 * CDD65SQ_i$$

Where *ENERGY USE CHANGE* = percentage change in energy use from LEC design adoption

*STD<sub>k</sub>* = binary variables indicating the energy standard edition that a city must meet in building construction

*ZONE<sub>h</sub>* = binary variables indicating the *ASHRAE* climate zone in which a city is located

*HDD65* = number of heating degree days at base 18.3 °C (65°F) for a city

*CDD65* = number of cooling degree days at base 18.3 °C (65°F) for a city

*HDD65SQ* = *HDD65* squared

*CDD65SQ* = *CDD65* squared



$k = \{1999, 2001, 2004, 2007\}$

$h = \{1,2,3,4,5,6,7,8\}$

$i = \text{index for cities used in analysis}$

The marginal effect (impact) of variable  $x_i$  is the change in ENERGY USE CHANGE as a result of changing variable  $x_i$  holding all other variable values constant

$$\left( \frac{\partial \text{ENERGY USE CHANGE}}{\partial x_i} = \beta_i \right).$$

Seven of the potential 32 energy code-climate zone combinations nationwide are excluded from the model because not all energy standard editions are adopted for each climate zone. For example, *ASHRAE 90.1-2001* is only adopted in three states, which span four climate zones. Of the 25 energy code-climate zone interaction variables shown in Table 6-19, only 24 have coefficient values because the 25<sup>th</sup> coefficient value is contained in the constant coefficient as a result of variable multicollinearity (the dummy variable trap), and is the baseline against which the other 24 coefficients are compared. In this model *STD2004\*ZONE1* is the baseline.

The 25 energy code-climate zone interaction variable coefficients estimate the impact a city's baseline energy code has on ENERGY USE CHANGE by adopting the LEC design. The coefficients on the STD1999 and STD2001 interaction variables are all negative and statistically significant. Relative to cities that build to meet *ASHRAE 90.1-2004* located in Zone 1, cities that build to meet *ASHRAE 90.1-1999* and *-2001* decrease the percentage change in energy use by 11.5 to 17.4 percentage points and 10.4 to 11.6 percentage points, respectively, depending on the climate zone. Only two of the STD2004 interaction variable coefficients are statistically significant and decrease the percentage change in energy use (6.2 percentage points in Zone 2 and 12.9 percentage points in Zone 7). None of the STD2007 interaction variables are statistically significant. Based on these results, the older the edition of *ASHRAE 90.1* to which a city must build, the greater the percentage decrease in energy use. Additionally, the climate zone in which a city is located impacts the magnitude of the decrease. Both of these results reiterate the previous interpretations in this report.

**Table 6-19 Regression Analysis – Percentage Change in Energy Use from Adopting the LEC Design by City**

| ENERGY USE CHANGE                                                                                                       |                   |
|-------------------------------------------------------------------------------------------------------------------------|-------------------|
| Variables                                                                                                               | Coefficient       |
| HDD65                                                                                                                   | <b>0.00177***</b> |
| HDD65SQ                                                                                                                 | -1.52e-09         |
| CDD65                                                                                                                   | <b>0.00185**</b>  |
| CDD65SQ                                                                                                                 | -3.45e-07         |
| STD1999 * ZONE2                                                                                                         | <b>-17.36***</b>  |
| STD1999 * ZONE3                                                                                                         | <b>-15.26***</b>  |
| STD1999 * ZONE4                                                                                                         | <b>-12.89***</b>  |
| STD1999 * ZONE5                                                                                                         | <b>-13.72***</b>  |
| STD1999 * ZONE6                                                                                                         | <b>-11.47***</b>  |
| STD1999 * ZONE7                                                                                                         | <b>-14.08***</b>  |
| STD1999 * ZONE8                                                                                                         | <b>-12.65**</b>   |
| STD2001 * ZONE3                                                                                                         | <b>-10.40***</b>  |
| STD2001 * ZONE4                                                                                                         | <b>-11.57***</b>  |
| STD2001 * ZONE5                                                                                                         | <b>-11.54***</b>  |
| STD2001 * ZONE6                                                                                                         | <b>-10.85***</b>  |
| STD2004 * ZONE1                                                                                                         |                   |
| STD2004 * ZONE2                                                                                                         | <b>-6.246**</b>   |
| STD2004 * ZONE3                                                                                                         | -1.046            |
| STD2004 * ZONE4                                                                                                         | -3.626            |
| STD2004 * ZONE5                                                                                                         | -4.882            |
| STD2004 * ZONE6                                                                                                         | -6.198            |
| STD2004 * ZONE7                                                                                                         | <b>-12.90***</b>  |
| STD2007 * ZONE1                                                                                                         | 2.111             |
| STD2007 * ZONE2                                                                                                         | 1.903             |
| STD2007 * ZONE3                                                                                                         | -0.113            |
| STD2007 * ZONE4                                                                                                         | 1.010             |
| STD2007 * ZONE5                                                                                                         | -0.501            |
| STD2007 * ZONE6                                                                                                         | -2.692            |
| STD2007 * ZONE7                                                                                                         | -1.796            |
| CONSTANT                                                                                                                | <b>-24.83***</b>  |
| Observations                                                                                                            | 228               |
| Adj. R-squared                                                                                                          | 0.785             |
| <p>Bolded coefficients are statistically significant at the following:<br/> *** p&lt;0.01, ** p&lt;0.05, * p&lt;0.1</p> |                   |

Four variables are included in the model to control for local climate. Two of the variables are the total HDDs at base 18.3 °C (65°F) (HDD65) and total CDDs at base 18.3 °C (65°F) (CDD65) for a city. Additionally, two higher ordered terms (HDD65SQ and

CDD65SQ) are included in the model to control for potential non-linear impacts of heating and cooling degree days. The coefficients for HDD65 and CDD65 are positive and statistically significant, with a two standard deviation increase in HDD65 (5358) and CDD65 (2066) leading to a 9.3 percentage point increase and 3.8 percentage point increase in the percentage change in energy use, respectively. The coefficient for HDD65SQ is statistically insignificant, and the coefficient for CDD65SQ is negative and nearly significant at the 10 % level.<sup>21</sup>

Consider the example of the five cities in Climate Zone 3B in Texas. Based on the coefficients for the four HDD and CDD variables and the HDD and CDD values for Lubbock and El Paso, the model predicts that El Paso's energy use change should be 1.4 percentage points lower than in Lubbock, which is half the observed variation.<sup>22</sup> The squared partial correlation for the HDD and CDD variables (HDD65, CDD65, HDD65SQ, and CDD65SQ), which is the proportion of variance in the dependent variable (ENERGY USE CHANGE) not associated with any other explanatory variables in the model that is explained by the HDD and CDD variables, is 10.6 %. The model appears to explain a significant portion (two-thirds) of the observed variation in ENERGY USE CHANGE for the cities in Climate Zone 3B in Texas (15.6 %).

#### **6.4.2 Life-Cycle Cost Savings across Cities**

Similar to energy use, the energy code and climate zone are important factors in determining the percentage change in life-cycle costs for a city. Additionally, the state-level energy prices for a city will drive variation across states. However, there is some variation across cities within the same energy code-climate zone combination because local construction costs vary across cities as measured by the city construction cost index discussed in Section 3.1. Consider the same five cities in Climate Zone 3B in Texas discussed in the previous Section 6.4.1. Table 6-20 shows that the percentage change in life-cycle costs and the city construction cost index varies across cities, although to a lesser extent than do heating degree days and cooling degree days for energy use.

---

<sup>21</sup> Non-linearity in the degree day variables was suspected because when cities building to meet *ASHRAE 90.1-2007* were excluded from the regression, CDD65 became statistically significant in the model.

<sup>22</sup> The model predicts a nationwide average impact for a variable, which means that the predicted impact will not necessarily match the observed impact for the comparison of two specific data points.

**Table 6-20 Regression Analysis, Within State Variation in Life-Cycle Costs**

| Cities                            | Climate Subzone | Low Energy Case                       |                              |
|-----------------------------------|-----------------|---------------------------------------|------------------------------|
|                                   |                 | Percentage Change in Life-cycle Costs | City Construction Cost Index |
| Abilene                           | 3B              | -1.3                                  | 0.783                        |
| El Paso                           | 3B              | -1.4                                  | 0.775                        |
| Lubbock                           | 3B              | -1.3                                  | 0.795                        |
| Midland                           | 3B              | -1.4                                  | 0.779                        |
| San Angelo                        | 3B              | -1.4                                  | 0.757                        |
| <b>Max – Min</b>                  |                 | <b>0.1</b>                            | <b>0.038</b>                 |
| <b>Variation from Median City</b> |                 | <b>7 %</b>                            | <b>5 %</b>                   |

Similar to the model estimating energy use, an LSDV model is used to estimate the impact of a city's local construction cost index value on the percentage change in life-cycle costs while controlling for a city's energy code-climate zone combination and state-level energy prices. An interaction of the standard edition adopted and climate zone of a city is included in the model because the impact of each standard edition could vary across climate zones due to the different building requirements in each zone.

The LSDV model is defined as:

$$LCC\ CHANGE = \beta_0 + \beta_{k,h}(STD_{k,i} * ZONE_{h,i}) + \beta_1 * ELECT\ PRICE_i + \beta_2 * GAS\ PRICE_i + \beta_3 * CITY\ COST\ INDEX_i$$

Where  $LCC\ CHANGE$  = percentage change in life-cycle costs from LEC design adoption  
 $STD_k$  = binary variables indicating the energy standard edition that a city must meet in building construction  
 $ZONE_h$  = binary variables indicating the *ASHRAE* climate zone in which a city is located  
 $ELECT\ PRICE$  = state average electricity price  
 $GAS\ PRICE$  = state average natural gas price  
 $CITY\ COST\ INDEX$  = local city construction cost index  
 $k = \{1999, 2001, 2004, 2007\}$   
 $h = \{1,2,3,4,5,6,7,8\}$   
 $i$  = index for cities used in analysis

The marginal effect (impact) of variable  $x_i$  is the change in  $LCC\ CHANGE$  as a result of changing variable  $x_i$  holding all other variable values constant  $\left(\frac{\partial LCC\ CHANGE}{\partial x_i} = \beta_i\right)$ .

Seven of the potential 32 energy code-climate zone combinations nationwide are excluded from the model because not all energy standard editions are adopted for each climate zone. For example, *ASHRAE 90.1-2001* is only adopted in three states, which span four climate zones. Of the 25 energy code-climate zone interaction variables shown

in Table 6-21, only 24 have coefficient values because the 25<sup>th</sup> coefficient value is contained in the constant coefficient as a result of variable multicollinearity (the dummy variable trap), and is the baseline against which the other 24 coefficients are compared. In this model *STD2007\*ZONE7* is the baseline.

The 25 energy code-climate zone interaction variable coefficients estimate the impact a city's baseline energy code has on LCC CHANGE. The coefficients on the STD2001 interaction variables are negative and statistically significant. Four, three, and one coefficient for the STD2004, STD1999, and STD2007 interaction variables are negative and statistically significant. Cities building to meet *ASHRAE 90.1-2001* realize greater additional percentage point reductions (2.0 to 2.8) in life-cycle costs relative to cities building to meet *ASHRAE 90.1-1999* (0.0 to 1.7), *ASHRAE 90.1-2004* (0.0 to 2.2), and *ASHRAE 90.1-2007* (0.0 to 1.0). The magnitude of the impacts varies depending on the climate zone of the city.

The coefficient on a state's electricity price (ELECT PRICE) is statistically significant while the coefficient on natural gas price (GAS PRICE) is statistically insignificant. A greater electricity price leads to lower life-cycle costs, with a two standard deviation in electricity price (5.3¢/kWh) decreasing life-cycle costs by 0.9 percentage points. The squared partial correlation for ELECT PRICE, which is the proportion of variance in the dependent variable (LCC CHANGE) not associated with any other explanatory variables in the model that is explained by ELECT PRICE, is greater than any other variable in the model at 47.3 %. There is a strong correlation between a city's average electricity price and its percentage change in life-cycle costs realized from adoption of the LEC design.

**Table 6-21 Regression Analysis – Percentage Change in Life-cycle Costs from Adopting the LEC Design by City**

| LCC CHANGE                                                                                            |                  |
|-------------------------------------------------------------------------------------------------------|------------------|
| Variables                                                                                             | Coefficient      |
| Elect Price                                                                                           | <b>-16.62***</b> |
| Gas Price                                                                                             | 6.490            |
| City Cost Index                                                                                       | <b>1.824***</b>  |
| STD1999 * ZONE2                                                                                       | <b>-1.698***</b> |
| STD1999 * ZONE3                                                                                       | <b>-0.714***</b> |
| STD1999 * ZONE4                                                                                       | 0.102            |
| STD1999 * ZONE5                                                                                       | <b>-0.598*</b>   |
| STD1999 * ZONE6                                                                                       | -0.0128          |
| STD1999 * ZONE7                                                                                       | -0.0910          |
| STD1999 * ZONE8                                                                                       | 0.436            |
| STD2001 * ZONE3                                                                                       | <b>-2.752***</b> |
| STD2001 * ZONE4                                                                                       | <b>-2.048***</b> |
| STD2001 * ZONE5                                                                                       | <b>-2.349***</b> |
| STD2001 * ZONE6                                                                                       | <b>-2.198***</b> |
| STD2004 * ZONE1                                                                                       | <b>-2.172***</b> |
| STD2004 * ZONE2                                                                                       | <b>-1.971***</b> |
| STD2004 * ZONE3                                                                                       | -0.261           |
| STD2004 * ZONE4                                                                                       | <b>-0.604**</b>  |
| STD2004 * ZONE5                                                                                       | <b>-0.816**</b>  |
| STD2004 * ZONE6                                                                                       | -0.458           |
| STD2004 * ZONE7                                                                                       | -0.503           |
| STD2007 * ZONE1                                                                                       | <b>-1.009***</b> |
| STD2007 * ZONE2                                                                                       | -0.168           |
| STD2007 * ZONE3                                                                                       | -0.134           |
| STD2007 * ZONE4                                                                                       | -0.238           |
| STD2007 * ZONE5                                                                                       | -0.0394          |
| STD2007 * ZONE6                                                                                       | 0.0868           |
| STD2007 * ZONE7                                                                                       |                  |
| Constant                                                                                              | <b>-1.052***</b> |
| Observations                                                                                          | 228              |
| Adj. R-squared                                                                                        | 0.813            |
| Bolded coefficients are statistically significant at the following:<br>*** p<0.01, ** p<0.05, * p<0.1 |                  |

The coefficient for the local city construction cost index (CITY COST INDEX) is statistically significant, with a two standard deviation in the index (0.21) leading to a 0.4 percentage point increase in life-cycle costs. The more expensive it is to construct a building, the smaller the decrease in life-cycle costs. Once again consider the example of the five cities in Climate Zone 3B in Texas. Based on the regression results, the variation in the city construction cost index (0.038) leads to a predicted variation of 0.07

percentage points in the change in life-cycle costs, or 70 % of the observed variation.<sup>23</sup> The squared partial correlation for CITY COST INDEX, which is the proportion of variance in the dependent variable (LCC CHANGE) not associated with any other explanatory variables in the model that is explained by the CITY COST INDEX, is 14.8 % compared to the 7 % observed variation in LCC CHANGE for the cities in Climate Zone 3B in Texas. The city construction cost index accounts for more than enough variation in the model to explain the observed variation in the percentage change in life-cycle costs for cities located Zone 3B in Texas.

---

<sup>23</sup> The percentage change data have been rounded to one decimal, which leads to some uncertainty as to the impact explained by the city cost index. Also, the model predicts a nationwide average impact for a variable, which means that the predicted impact will not necessarily match the observed impact for the comparison of two specific data points.





## **7 Nationwide Impacts of Adopting ASHRAE 90.1-2007**

This section analyzes benefits from nationwide adoption of the *ASHRAE 90.1-2007* design relative to the current collection of state energy codes. Benefits are evaluated across several dimensions: time, building type, geography (climate zone and state), and energy code. There are three metrics used to analyze the results: percentage changes, total changes, and changes per unit of floor area. The analysis only includes states that have not yet adopted *ASHRAE 90.1-2007*.

### **7.1 Percentage Changes**

The initial metrics used to estimate the impacts of adopting the *ASHRAE 90.1-2007* design are the average percentage changes in energy use, energy costs, carbon emissions, and life-cycle costs. Impacts are evaluated across four dimensions: study period length, building type, climate zone, and state energy code.

#### **7.1.1 Results by Study Period Length**

It is important to consider how the study period length – representing the time horizon of the investor -- impacts energy use, energy costs, energy-related carbon emissions, and life-cycle costs. Nine study periods are analyzed: 1 year, 5 years, 10 years, 15 years, 20 years, 25 years, 30 years, 35 years, and 40 years.

The average reduction in energy use from adoption of *ASHRAE 90.1-2007* is constant over all study period lengths because energy efficiency is assumed to be constant over time. Table 7-1 shows that the national average change in energy use across the 73 cities in the analysis ranges from -15.6 % to 0.5 %, depending on the building type, with an overall national average of -9.6 %. The 16-story office building realizes a percentage increase in energy use because the relaxation of the window requirements overwhelms the impacts from the other energy efficiency measures required by *ASHRAE 90.1-2007*.

**Table 7-1 Nationwide Average Percentage Change in Energy Use from Adoption of ASHRAE 90.1-2007 by Building Type**

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

As shown in Table 7-2, savings in energy costs vary slightly, in percentage terms, over increasing study period lengths. The national average change in energy costs across all location-building type combinations ranges from -12.3 % to -12.0 % for all study period lengths. There is minor variation of up to 0.6 percentage points for some building types across study periods as a result of the escalation rates used to adjust future energy prices, which vary by U.S. Census Region.

**Table 7-2 Nationwide Average Percentage Change in Energy Costs from Adoption of ASHRAE 90.1-2007 by Building Type and Study Period Length**

| Building Type  | Study Period Length |              |              |              |              |              |              |              |              |
|----------------|---------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                | 1                   | 5            | 10           | 15           | 20           | 25           | 30           | 35           | 40           |
| APART04        | -16.9               | -16.7        | -16.7        | -16.6        | -16.5        | -16.4        | -16.3        | -16.3        | -16.3        |
| APART06        | -16.6               | -16.4        | -16.3        | -16.2        | -16.2        | -16.1        | -16.0        | -16.0        | -16.0        |
| DORMI04        | -17.4               | -17.3        | -17.2        | -17.1        | -17.1        | -17.0        | -16.9        | -16.9        | -16.9        |
| DORMI06        | -16.5               | -16.4        | -16.3        | -16.2        | -16.1        | -16.0        | -16.0        | -16.0        | -16.0        |
| HOTEL15        | -8.3                | -8.2         | -8.1         | -8.0         | -8.0         | -7.9         | -7.8         | -7.8         | -7.8         |
| HIGHS02        | -7.8                | -7.7         | -7.7         | -7.7         | -7.6         | -7.6         | -7.6         | -7.6         | -7.6         |
| OFFIC03        | -10.6               | -10.6        | -10.6        | -10.6        | -10.6        | -10.7        | -10.7        | -10.7        | -10.7        |
| OFFIC08        | -9.5                | -9.5         | -9.5         | -9.5         | -9.5         | -9.5         | -9.5         | -9.5         | -9.5         |
| OFFIC16        | -0.9                | -0.8         | -0.8         | -0.8         | -0.8         | -0.8         | -0.7         | -0.7         | -0.7         |
| RETAIL1        | -15.1               | -15.1        | -15.1        | -15.1        | -15.1        | -15.1        | -15.1        | -15.1        | -15.1        |
| RSTRNT1        | -15.5               | -15.5        | -15.5        | -15.5        | -15.5        | -15.5        | -15.5        | -15.5        | -15.5        |
| <b>Average</b> | <b>-12.3</b>        | <b>-12.2</b> | <b>-12.2</b> | <b>-12.1</b> | <b>-12.1</b> | <b>-12.1</b> | <b>-12.0</b> | <b>-12.0</b> | <b>-12.0</b> |

Since the national average reduction in energy use across all location-building type combinations is constant over all study period lengths, the average change in energy-related carbon emissions is also constant at -15.6 %. The national average change in carbon emissions ranges from -17.9 % to -0.9 % depending on the building type, as shown in Table 7-3.

**Table 7-3 Nationwide Average Percentage Change in Carbon Emissions from Adoption of ASHRAE 90.1-2007 by Building Type**

| Building Type  | Percentage Change |
|----------------|-------------------|
| APART04        | -17.4             |
| APART06        | -17.1             |
| DORMI04        | -17.9             |
| DORMI06        | -17.1             |
| HOTEL15        | -8.8              |
| HIGHS02        | -8.2              |
| OFFIC03        | -10.5             |
| OFFIC08        | -9.3              |
| OFFIC16        | -0.9              |
| RETAIL1        | -15.0             |
| RSTRNT1        | -15.6             |
| <b>Average</b> | <b>-12.4</b>      |

Table 7-4 shows that the percentage change in life-cycle costs varies slightly over increasing study period lengths, with the average change across all location-building type combinations ranging from -1.9 % for a 1-year study period to -0.7 % for a 10-year study period. The national average change in life-cycle costs ranges from -6.7 % to 2.3 % depending on the building type for a 1-year study period. The nationwide change in life-cycle costs averages -0.7 % for a 10-year study period length, ranging from -1.7 % to 0.5 % depending on the building type. As the study period length increases from 10 years to 40 years, the percentage reduction in national average life-cycle costs increases, with an overall average percentage change of -0.7 % to -1.1 %, respectively. Also, the number of building types that realize reductions in life-cycle costs increases from 7 for a 20-year study period to 10 for a 40-year study period.

**Table 7-4 National Average Percentage Change in Life-Cycle Costs from Adoption of ASHRAE 90.1-2007 by Building Type and Study Period Length**

| Building Type  | Study Period Length |             |             |             |             |             |             |             |             |
|----------------|---------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                | 1                   | 5           | 10          | 15          | 20          | 25          | 30          | 35          | 40          |
| APART04        | -1.8                | -1.8        | -1.7        | -1.8        | -1.9        | -1.9        | -1.9        | -2.0        | -2.0        |
| APART06        | -1.1                | -1.6        | -1.6        | -1.8        | -1.8        | -1.9        | -1.9        | -2.0        | -2.0        |
| DORMI04        | -4.1                | -1.1        | -0.9        | -1.0        | -1.1        | -1.2        | -1.2        | -1.3        | -1.4        |
| DORMI06        | -2.1                | -2.1        | -2.0        | -2.1        | -2.1        | -2.2        | -2.2        | -2.3        | -2.3        |
| HOTEL15        | -1.4                | -1.3        | -1.2        | -1.2        | -1.2        | -1.2        | -1.2        | -1.2        | -1.2        |
| HIGHS02        | -1.4                | -0.8        | -0.8        | -0.9        | -0.9        | -1.0        | -1.1        | -1.1        | -1.1        |
| OFFIC03        | -3.1                | 0.4         | 0.5         | 0.3         | 0.2         | 0.1         | 0.1         | 0.0         | -0.1        |
| OFFIC08        | 0.2                 | 0.6         | 0.5         | 0.3         | 0.1         | -0.0        | -0.0        | -0.1        | -0.2        |
| OFFIC16        | -1.5                | -0.3        | -0.1        | 0.1         | 0.1         | 0.2         | 0.2         | 0.2         | 0.3         |
| RETAIL1        | -6.7                | -1.2        | -0.9        | -1.1        | -1.2        | -1.3        | -1.4        | -1.4        | -1.5        |
| RSTRNT1        | 2.3                 | 0.8         | 0.4         | 0.0         | -0.2        | -0.4        | -0.5        | -0.6        | -0.7        |
| <b>Average</b> | <b>-1.9</b>         | <b>-0.8</b> | <b>-0.7</b> | <b>-0.8</b> | <b>-0.9</b> | <b>-1.0</b> | <b>-1.0</b> | <b>-1.1</b> | <b>-1.1</b> |

### 7.1.2 Results by Building Type

Table 7-5 shows the simple average changes, in percentage terms, from adopting *ASHRAE 90.1-2007* by building type for a 10-year study period length. The tallest buildings realize the lowest reductions in energy use. The only building type that realizes an increase in energy use is the 16-story office building. The hotel and high school realize reductions in energy use of 3.2 % and 5.8 %, respectively. The remaining building types all realize reductions in energy use greater than 9.8 %. All building types realize reductions in energy costs, ranging from 0.8 % to 17.2 %. The 16-story office building realizes small reductions in energy costs even though its energy use increases because energy use is shifted from electricity to natural gas. The apartments and dormitories realize the greatest reductions in energy costs. All building types realize reductions in energy-related carbon emissions, ranging from 0.9 % to 17.9 %. The greatest reductions in carbon emissions are realized by the apartment buildings and dormitories at over 15.0 % while the smallest reductions are realized by the 16-story office building. Of the 11 building types, 8 realize a decrease in life-cycle costs. The greatest reductions in life-cycle costs are realized by the 6-story dormitory (2.0 %) and 4-story apartment building (1.7 %). The greatest life-cycle cost increases are realized by the 3-and 8-story office buildings (0.5 % each) and the restaurant (0.4 %).

**Table 7-5 Nationwide Percentage Change for *ASHRAE 90.1-2007* by Building Type, 10-Year**

| Building Type  | Percentage Change |              |              |             |
|----------------|-------------------|--------------|--------------|-------------|
|                | Energy Use        | Energy Cost  | Carbon       | LCC         |
| APART04        | -11.4             | -16.7        | -17.4        | -1.7        |
| APART06        | -11.0             | -16.3        | -17.1        | -1.6        |
| DORMI04        | -12.3             | -17.2        | -17.9        | -0.9        |
| DORMI06        | -10.7             | -16.3        | -17.1        | -2.0        |
| HOTEL15        | -3.2              | -8.1         | -8.8         | -1.2        |
| HIGHS02        | -5.8              | -7.7         | -8.2         | -0.8        |
| OFFIC03        | -11.4             | -10.6        | -10.5        | 0.5         |
| OFFIC08        | -9.8              | -9.5         | -9.3         | 0.5         |
| OFFIC16        | 0.5               | -0.8         | -0.9         | -0.1        |
| RETAIL1        | -15.2             | -15.1        | -15.0        | -0.9        |
| RSTRNT1        | -15.6             | -15.5        | -15.6        | 0.4         |
| <b>Average</b> | <b>-9.6</b>       | <b>-12.2</b> | <b>-12.4</b> | <b>-0.7</b> |

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

### 7.1.3 Results by Climate Zone

Table 7-6 shows the nationwide average change in energy use by *ASHRAE* climate zone for the adoption of *ASHRAE 90.1-2007* relative to current state energy codes for all building types. The warmest and coldest climate zones, Zone 1 and Zone 8, realize the smallest overall percentage changes in energy use. Zone 8 realizes an increase of energy use of 1.7 % while Zone 1 realizes a small decrease of 1.1 %. Zone 2 realizes the highest reductions in energy use at 16.3 % followed by Zone 3 (12.0 %) and Zone 4 (10.4 %).

**Table 7-6 Average Percentage Change in Energy Use for *ASHRAE 90.1-2007* by Climate Zone**

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

Similar to the LEC design, the current state energy codes are a key driver of these results. The variation across climate zones diverges depending on the state energy code. For locations in states that have not adopted any state energy code or have adopted older editions of *ASHRAE 90.1* (-1999 or -2001), warmer climate zones realize greater percentage reductions in energy use. For states that have no state energy code or have adopted *ASHRAE 90.1-1999*, cities in Zone 2 realize an average percentage reduction of 24.0 % while Zone 8 realizes an increase of 1.7 % from adopting the *ASHRAE 90.1-2007* design. For cities located in states that have adopted *ASHRAE 90.1-2004*, the percentage

reductions in energy use are much smaller, ranging from 1.1 % to 8.6 %, and do not follow the same trend where colder climate zones realize smaller reductions in energy use. Instead the percentage changes are the greatest for cities in Zone 2 followed by Zone 7 and smallest for cities in Zone 1 and Zone 3.

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

**Table 7-7 Average Percentage Change in Energy Costs for *ASHRAE 90.1-2007* by Climate Zone, 10-Year**

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

These results are similar to those realized for reductions in energy use in that they can be better explained after controlling for the current state energy codes. Reductions in energy use can explain some, but not all of the variation in energy costs. The remainder is a result of a shift in energy use from one energy source to another. For example, the adoption of *ASHRAE 90.1-2007* leads to a percentage change in energy use of -24.0 % and 1.7 % for cities in Zone 2 and Zone 8, respectively. Meanwhile, the percentage change in energy costs is -24.1 % and -9.8 %, respectively. The percentage change in

energy use explains the entire percentage change in energy costs for cities in Zone 2. However, cities in Zone 8 realize a percentage increase in energy use and a seemingly contradictory decrease in energy costs. The adoption of *ASHRAE 90.1-2007* decreases electricity consumption, but increases natural gas consumption by a greater amount. Due to the higher cost of electricity for cities in Zone 8, energy use is increased while energy costs are decreased. Similar shifts occur for cities throughout the other climate zones, where the size of the impact depends on the size of the fuel shift and the differential between the average cost of electricity and average cost of natural gas.

Average energy-related carbon emissions are constant across study period lengths. The data reported in Table 7-8 show that the average reduction in energy-related carbon emissions for the *ASHRAE 90.1-2007* design ranges from 1.2 % to 15.3 % depending on the climate zone. Zone 1, Zone 8, and Zone 5 realize the smallest percentage reductions in carbon emissions while Zone 2 and Zone 3 realize the greatest reductions. Similar to reductions in energy costs, reductions in energy use can explain some, but not all of the variation in the reductions in carbon emissions. The remainder is a result of a shift in energy use from one energy source to another. For example, the adoption of *ASHRAE 90.1-2007* leads to a percentage change in energy use of 1.7 % and a percentage change in carbon emissions of -5.8 % for cities in Zone 8. For Alaska, the average carbon emissions rate for electricity is greater than the average carbon emissions rate for natural gas. The shift in energy use from electricity to natural gas leads to an overall decrease in carbon emissions while total energy use increases.

**Table 7-8 Average Change in Energy-related Carbon Emissions for ASHRAE 90.1-2007 by Climate Zone**

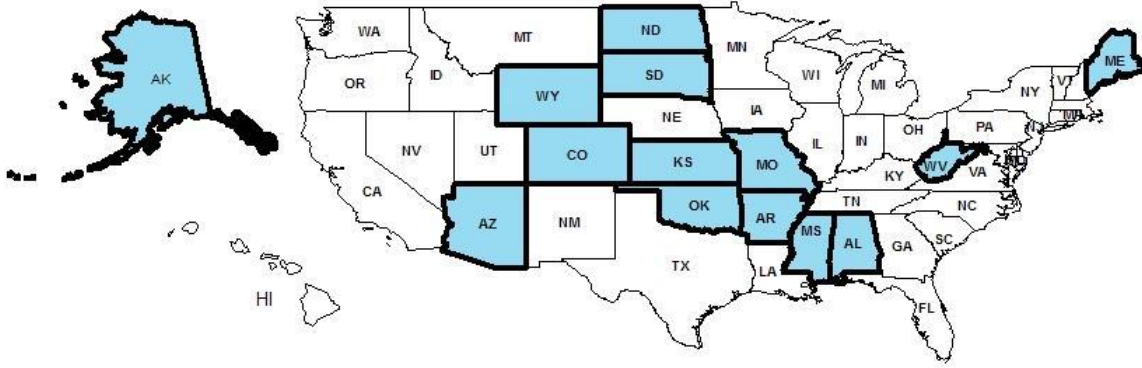
| Climate<br>Zone/Subzone | Percentage Change |              |             |              |
|-------------------------|-------------------|--------------|-------------|--------------|
|                         | 1999              | 2001         | 2004        | All          |
| <b>1</b>              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

#### 7.1.4 Results by State Energy Code

One purpose of this study is to determine which states could benefit the most from adopting a more stringent state energy code for commercial buildings. It would be expected that states with energy codes based on an older edition of *ASHRAE 90.1* (-2001), or no energy code at all, would realize greater benefits from adopting the *ASHRAE 90.1-2007* design because buildings in those states are expected to be built in a less energy efficient manner. Figure 7-1 shows the 14 states with energy codes based on *ASHRAE 90.1 -2001* or that have no state energy code.<sup>24</sup>

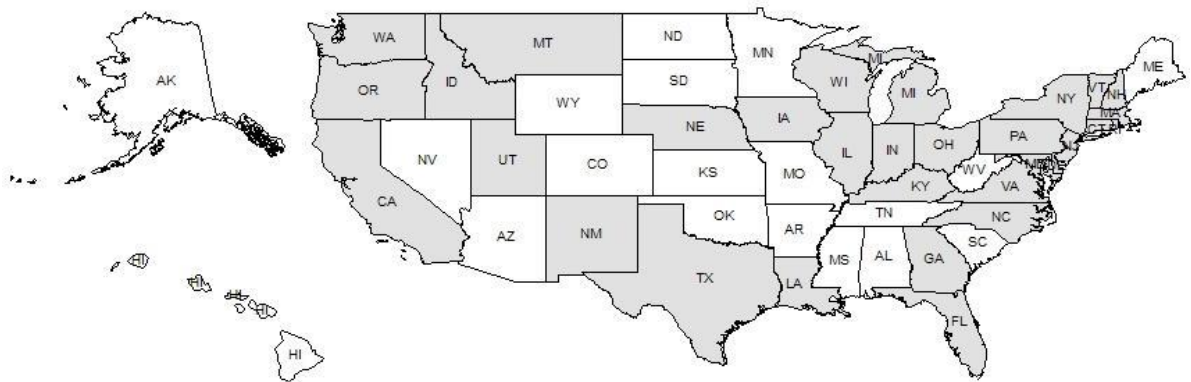
<sup>24</sup> All maps are generated in ArcMap 10.1.





**Figure 7-1 States with Energy Code based on ASHRAE 90.1-2001 or No Energy Code**

The 32 states that have adopted *ASHRAE 90.1-2007*, highlighted gray in Figure 7-2, are spread across the nation. These states are shown in white in the figures in this section, and are excluded from the analysis because there are no impacts to report.



**Figure 7-2 States with Energy Code based on ASHRAE 90.1-2007 (Shown in Gray)**

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

State benefit comparisons are made based on the simple average changes for the cities analyzed in each state by building type. One building type is chosen to illustrate the detailed analysis possible with the powerful BIRDS database compiled for this study. Energy use, energy costs, cradle-to-grave 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 D-1 through Table D-10 in Appendix D. The same interpretations hold for the other ten building types.

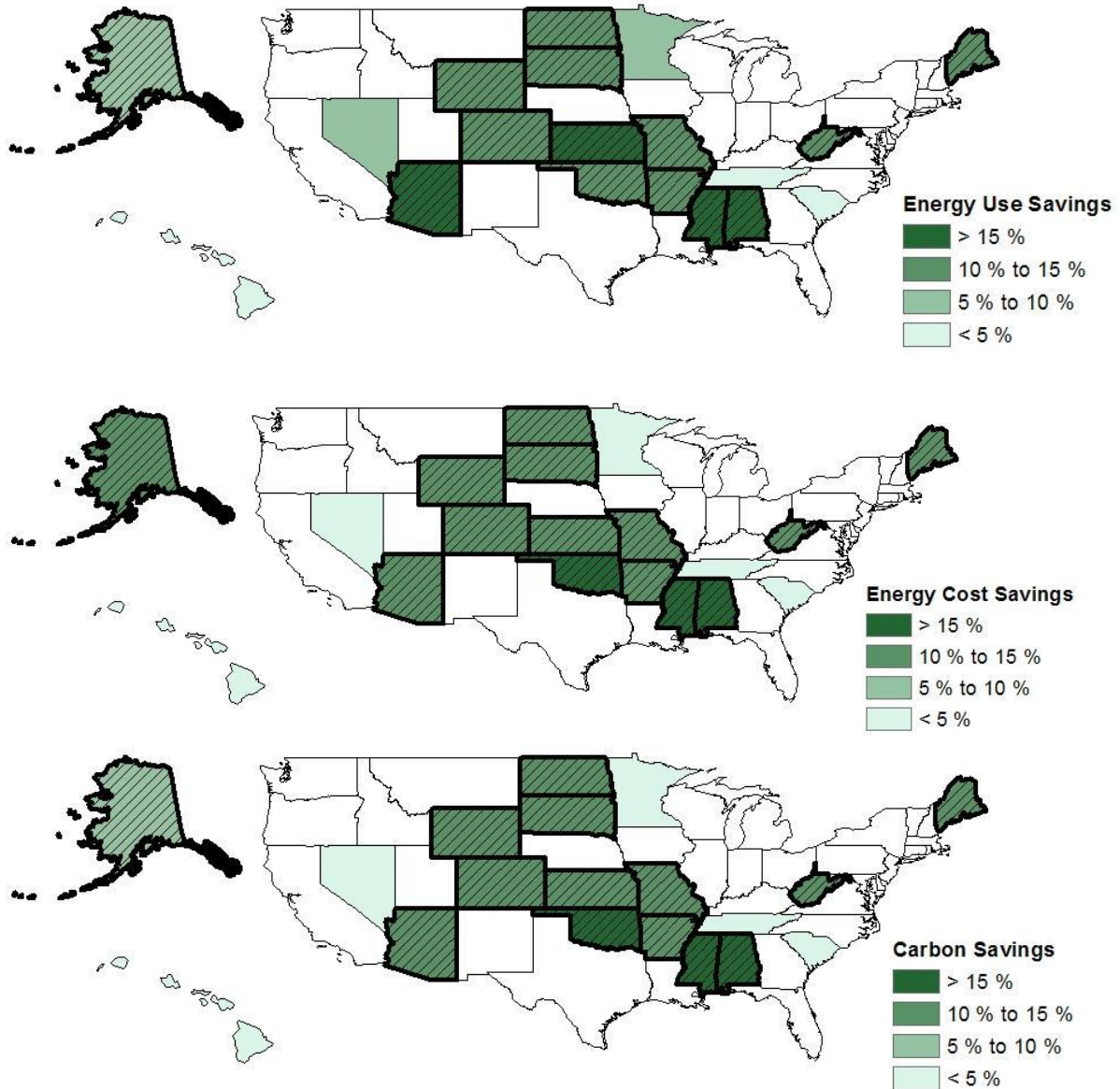
Table 7-9 summarizes the percentage changes in energy use, energy costs, carbon emissions, and life-cycle costs for the 3-story office building for a 10-year study period. On average, adoption of *ASHRAE 90.1-2007* for a 3-story office building decreases energy use, energy costs, and energy-related carbon emissions by over 10 % each while increasing life-cycle costs by 0.5 %, on average. These results exclude the states that have already adopted *ASHRAE 90.1-2007*.

**Table 7-9 Average Percentage Change by State, 3-Story Office Building, 10-Year**

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

Figure 7-3 overlays Figure 7-1 and displays the average percentage changes in energy use, energy costs, and carbon emissions for a 10-year study period by state. The states with codes based on older editions of *ASHRAE 90.1*, or no energy code at all, are shown with cross hatching and bolded state borders. The 31 states that have already adopted *ASHRAE 90.1-2007* are shown in white and are excluded from the analysis. Figure 7-3 shows that 16 of 19 states realize energy use savings greater than 5 % by adopting *ASHRAE 90.1-2007* over their current state energy code. Many of the states that realize the greatest energy use savings are the ones that currently have no energy code or energy codes based on older editions of *ASHRAE 90.1* including all 13 states that realize energy use savings of more than 10 %.

The state average percentage reductions in energy costs and carbon emissions are highly correlated with the percentage reductions in energy use. However, the reduction in energy costs and carbon emissions tend to be slightly less than the reductions in energy use. Twelve of the nineteen states realize smaller percentage changes in energy costs and carbon emissions than percentage changes in energy use. The reason for this result is because the reductions in total energy use resulting from the adoption of *ASHRAE 90.1-2007* for those twelve states are driven primarily by reductions in natural gas, as discussed in the example in Section 6.1.4.1. Since natural gas is cheaper and has a lower average emissions rate than electricity for those states, the percentage changes in energy costs and carbon emissions are smaller than the percentage changes in energy use.

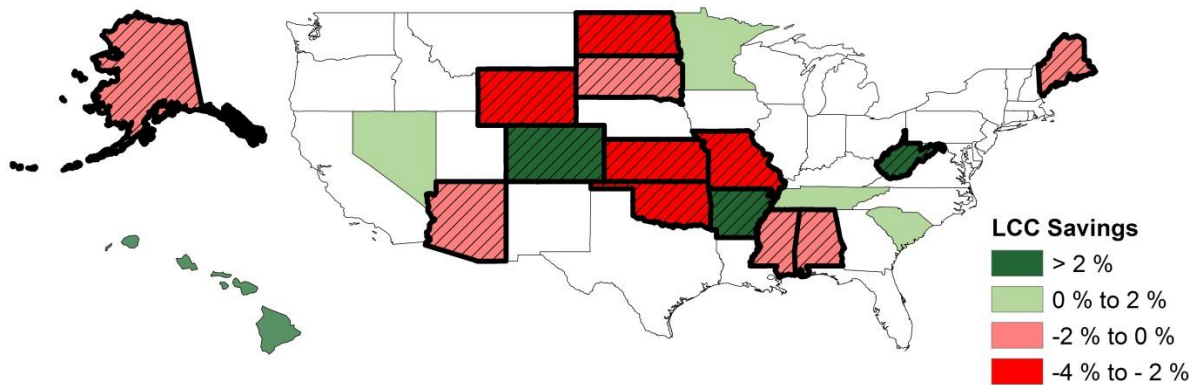


**Figure 7-3 Average Energy Use Savings by State, 3-Story Office Building, 10-Year**

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

Figure 7-4 overlays Figure 7-1 with the average percentage change in life-cycle costs over 10 years by state from adopting the *ASHRAE 90.1-2007* design. Of the 19 states, 8 realize an average decrease in life-cycle costs. The three states that have energy codes

based on *ASHRAE 90.1-2001* realize the greatest percentage decreases in life-cycle costs ( $> 2\%$ ). The five states that have adopted *ASHRAE 90.1-2004* as their state energy code realize reductions in life-cycle costs of less than  $2\%$ . The ten states that currently have no energy code realize an average percentage increase in life-cycle costs, five of which realize an increase greater than  $2\%$ . The additional energy efficiency measures required to bring buildings up to the *ASHRAE 90.1-2007* design from the *ASHRAE 90.1-1999* baseline design for these states add enough construction costs to offset the energy cost savings from the energy efficiency gains.



**Figure 7-4 Average Life-Cycle Cost Savings by State, 3-Story Office Building, 10-Year**

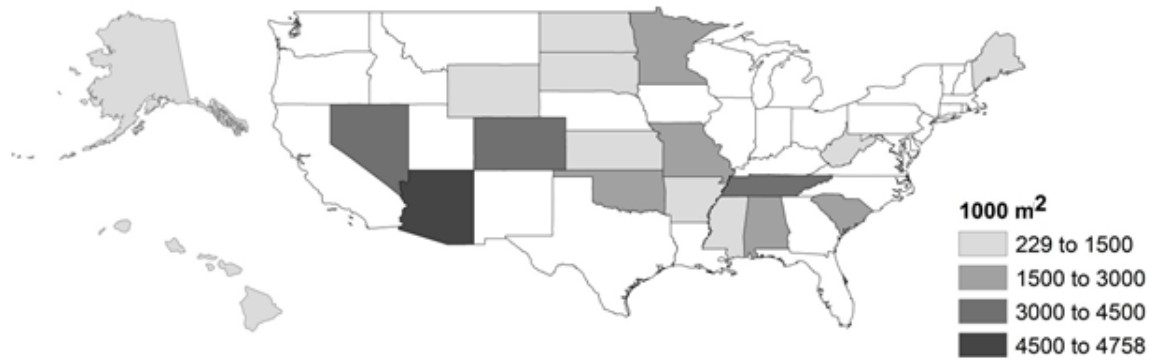
## 7.2 Total Changes

The average percentage changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs reported in Section 7.1 do not account for the amount of new floor area for each building type in a state, which may have a significant impact on the results.

### 7.2.1 State-Level Total Savings

Estimating the magnitude of the total impacts in a state controls for new floor area and determines which states would benefit the most from adopting the *ASHRAE 90.1-2007* design as their state energy code. The total changes in the four impacts from adopting the *ASHRAE 90.1-2007* design for a state are calculated using Formula 1 defined in Section 5.4. Based on the formula, two variables impact the magnitude of the total changes in a state: the amount of new commercial building construction and the average changes per unit of floor area.

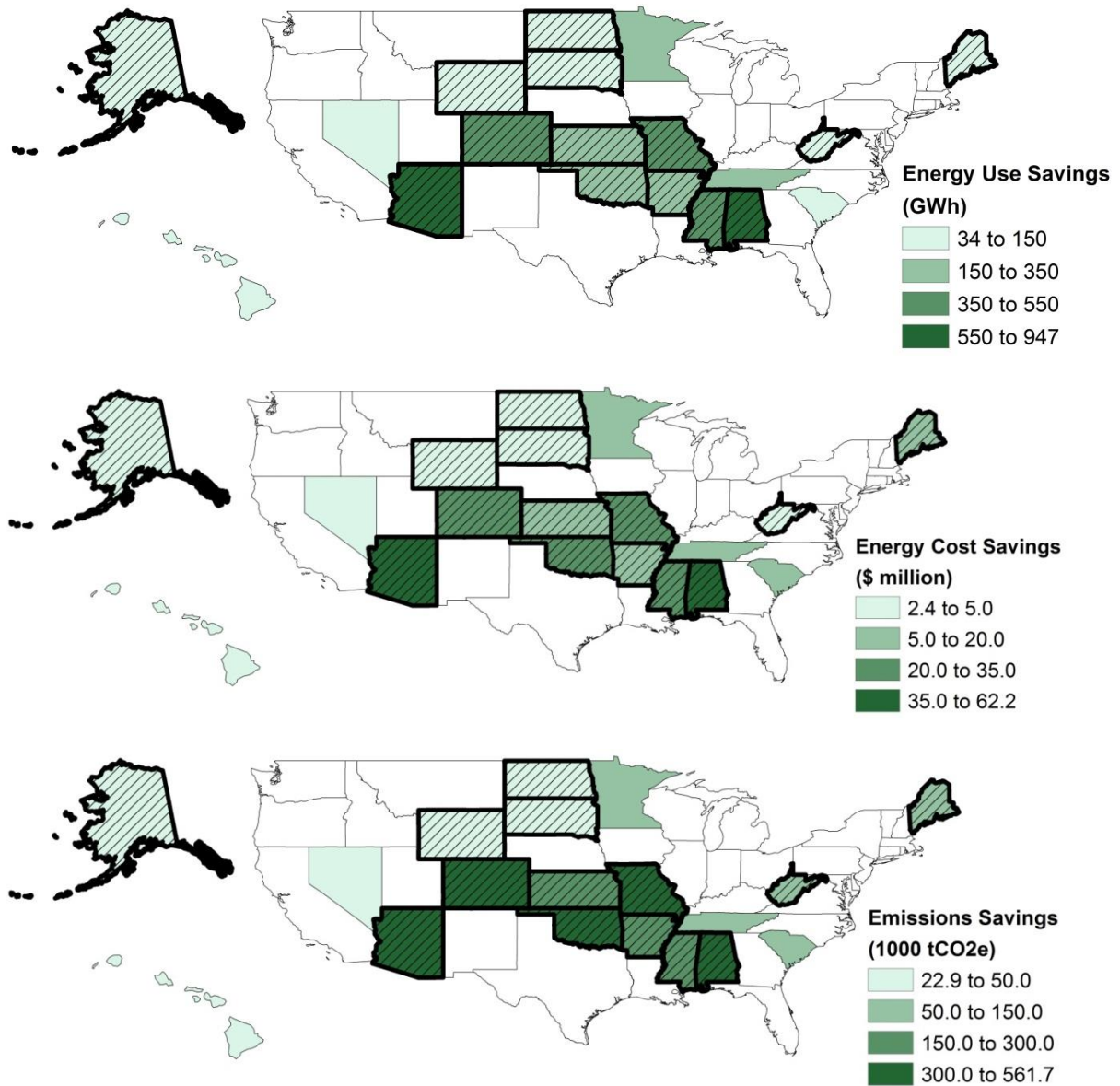
Figure 7-5 shows the average amount of new floor area constructed annually ( $1000 \text{ m}^2$ ) for each of the 19 states from 2003 to 2007. States with a greater amount of new floor area constructed (Arizona, Colorado, Nevada, and Tennessee) are expected to realize greater total reductions in energy use, energy costs, and carbon emissions.



**Figure 7-5 Average Annual New Floor Area by State**

Table E-1 in Appendix E shows the total changes in energy use, energy costs, carbon emissions, and life-cycle costs from adopting the *ASHRAE 90.1-2007* design as the commercial building energy code for all 19 states for a 10-year study period. The relative total changes across states, shown in Figure 7-6, are significantly different than the relative percentage changes shown in Figure 7-3, which emphasizes the importance of controlling for the amount of new floor area for each building type in determining the magnitude of the impacts of adopting the *ASHRAE 90.1-2007* design. The total change in energy use for a state is driven partially by the amount of new floor area constructed in a state. Arizona realizes the greatest reductions in energy use (946 GWh). In comparison, states with the smallest amount of new floor area (Alaska, Hawaii, Maine, North Dakota, South Dakota, and Wyoming) realize savings of less than 106 GWh. However, the state energy code is also a significant driver of the results. For example, Nevada, South Carolina, and Tennessee are in the top five in total new floor area, but are not in the top ten in total energy use savings.

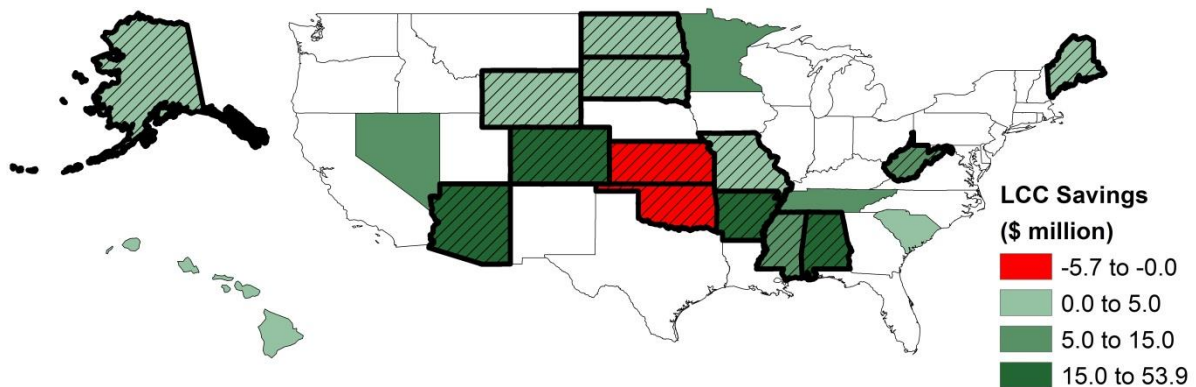




**Figure 7-6 Total Energy Use, Energy Cost, and Carbon Emissions Savings by State, 10-Year**

Figure 7-6 shows a correlation between total savings in energy use and total savings in energy costs and carbon emissions. Alabama, Arizona, Missouri, and Colorado realize the greatest savings while South Dakota, North Dakota, Wyoming, Nevada, Hawaii, Alaska, Maine, and South Carolina realize the smallest savings in energy costs. Arizona, Alabama, Colorado, Oklahoma, and Missouri realize the greatest reductions while South Dakota, North Dakota, Wyoming, and Nevada realize the smallest reductions in carbon emissions. The relative total reductions in energy costs and carbon emissions vary from total reductions in energy use to some extent. The reasons for this variation will be discussed in Section 7.3.

Figure 7-7 shows a correlation between total savings in energy use and total savings in life-cycle costs. Arizona, Colorado, Arkansas, and Alabama realize the greatest total life-cycle cost savings. Only two states realize an increase in life-cycle costs (Kansas and Oklahoma) while the other nine states that realize an increase in life-cycle costs on a percentage basis (see Figure 7-4) realize a total life-cycle cost decrease. These results emphasize the importance of accounting for the building types associated with the new floor area constructed in a state to determine where adopting the *ASHRAE 90.1-2007* design is life-cycle cost-effective. The relative total reductions in life-cycle costs vary from total reductions in energy use to some extent. The reasons for this variation will be discussed in Section 7.3.



**Figure 7-7 Total Life-Cycle Cost Savings by State, 10-Year**

### 7.2.2 Regional and National Total Savings

The nationwide changes in the four impacts from adopting the *ASHRAE 90.1-2007* design are calculated using Formula 2 defined in Section 5.4, where the state-level savings for each impact are summed across all nineteen states that have not yet adopted *ASHRAE 90.1-2007*.

Table 7-10 shows the total changes in energy use, energy costs, energy-related carbon emissions, and life-cycle costs for one year's worth of construction for a 10-year study period aggregated at the Census region and national levels. The greater the amount of new floor area constructed in the states within a Census region that have not yet adopted *ASHRAE 90.1-2007*, the greater the total reduction in energy use, energy costs, and carbon emissions. This condition does not strictly hold for the total reduction in life-cycle costs because the total reduction in the West Census Region is greater than total reduction in the South Census Region. The reason for this variation will be discussed in Section 7.3. The nationwide reductions total 4.9 TWh in energy consumption, \$312.4 million in energy costs, 3.8 million metric tons in energy-related carbon emissions, and \$173.3 million in life-cycle costs for the 10-year study period.

**Table 7-10 Total Reductions by Census Region from Adoption of the ASHRAE 90.1-2007 Design, 10-Year**

| Census Region | Number of States | Average Annual New Floor Area<br>1000 m <sup>2</sup> (1000 ft <sup>2</sup> ) | Energy Use<br>(GWh) | Energy Costs<br>(\$million) | Carbon<br>(1000 tCO <sub>2</sub> e) | LCC<br>(\$million) |
|---------------|------------------|------------------------------------------------------------------------------|---------------------|-----------------------------|-------------------------------------|--------------------|
| Northeast     | 1                | 497 (5349)                                                                   | 105.5               | 9.4                         | 58.8                                | 3.3                |
| Midwest       | 5                | 6296 (67 767)                                                                | 1139.5              | 54.5                        | 867.1                               | 7.7                |
| South         | 7                | 12 750 (137 243)                                                             | 1968.2              | 139.4                       | 1707.2                              | 67.4               |
| West          | 6                | 12 622 (135 861)                                                             | 1667.6              | 109.1                       | 1183.4                              | 94.9               |
| <b>Total</b>  | <b>19</b>        | <b>32 165 (346 220)</b>                                                      | <b>4880.8</b>       | <b>312.4</b>                | <b>3816.5</b>                       | <b>173.3</b>       |

### 7.3 Changes per Unit of Floor Area and Energy Use Savings

Total savings in energy use, energy costs, carbon emissions, and life-cycle costs are correlated. However, there are a number of factors that lead to significant variation in relative savings, each of which will be discussed in this section.

#### 7.3.1 State Level Changes

There is significant variation in relative savings across states for each of the four impacts for a number of reasons, including current state energy code requirements, newly constructed building stock mix and size, climate zone, electricity costs, electricity production fuel mix (average emissions rate), and the relative percentage changes in fuel types consumed by the building.

##### 7.3.1.1 Energy Use Savings per Unit of Floor Area

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 tend to realize greater reductions in energy use than the states located in colder climate zones. Third, a state's current state energy code for commercial buildings drives variation in energy use.

Table E-2 shows the 10-year reduction in energy use per unit of newly constructed floor area sorted by energy savings per unit of new floor area in descending order. The reduction in energy use per unit of floor area is primarily driven by the state's adopted energy code for commercial buildings. The top thirteen states with the greatest per unit reduction from adoption of the ASHRAE 90.1-2007 design have no state energy code or have ASHRAE 90.1-2001 as their state energy code. These results, shown in Figure 7-8, can be compared to the average percentage changes in energy use in Figure 7-3. After controlling for the amount of new floor area, the relative savings across states correlates much closer to the relative average percentage changes in energy use. However, the



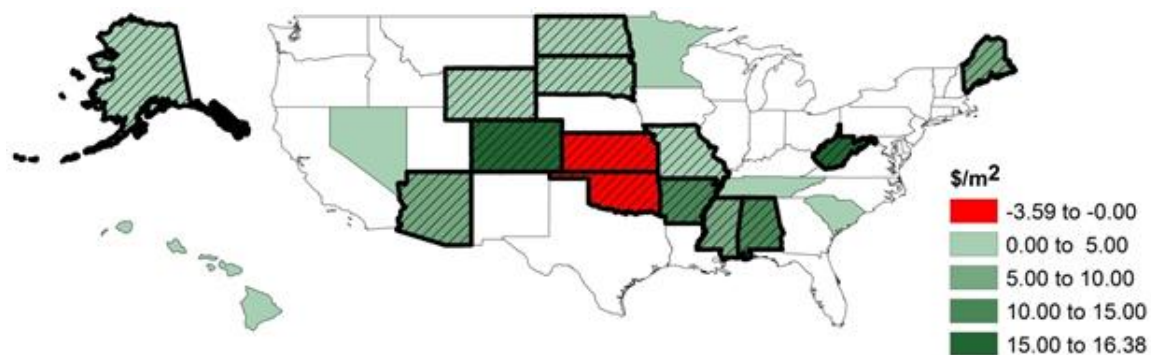
correlation is not perfect because the total changes weight building types based on new floor area constructed.



**Figure 7-8 Energy Use Savings per Unit of Floor Area by State, 10-Year**

### 7.3.1.2 Life-Cycle Cost Savings per Unit of Floor Area

The relative change in life-cycle costs per unit of new floor area is shown in Table E-3. After controlling for the amount of new floor area, there is a correlation between the state energy code and the relative life-cycle cost savings of adopting the *ASHRAE 90.1-2007* design. States that have adopted *ASHRAE 90.1-2001* (Arkansas, Colorado, and West Virginia) realize the greatest life-cycle cost savings. These results, shown in Figure 7-9, can be compared to the average percentage changes in life-cycle costs in Figure 7-4. After controlling for the amount of new floor area, the relative savings across states correlates better with the relative percentage changes in energy use. However, the correlation is not perfect because the total changes weight building types based on new floor area constructed.



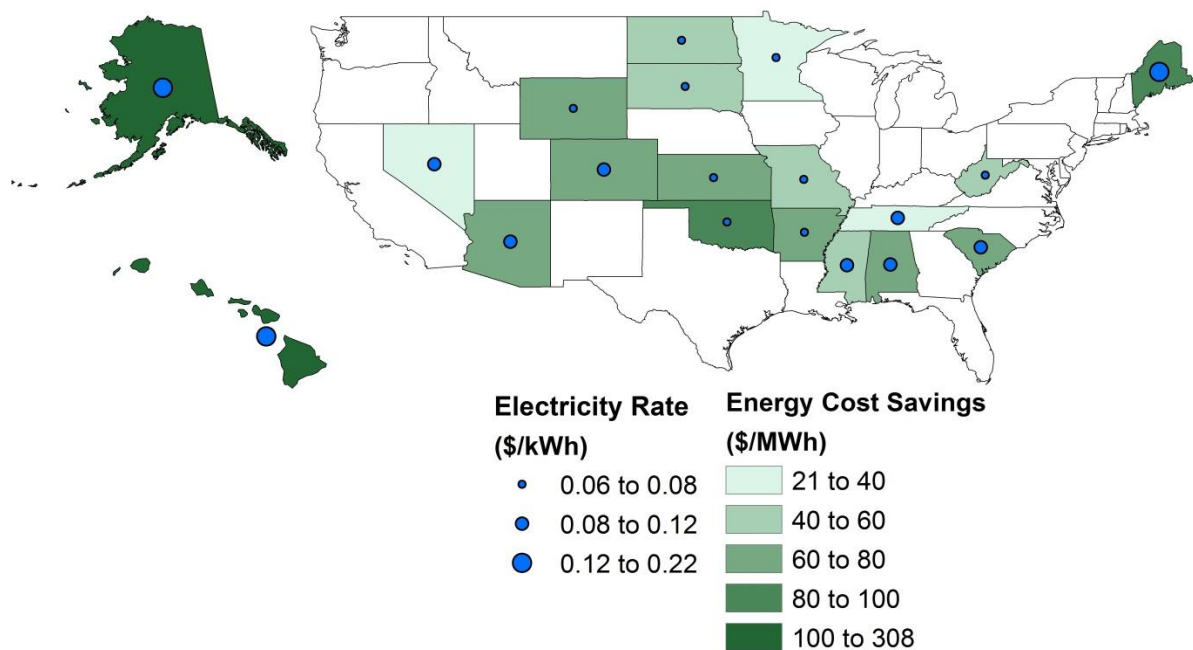
**Figure 7-9 Life-Cycle Cost Savings per Unit of Floor Area by State, 10-Yr**

### 7.3.1.3 Energy Cost Savings per Unit of Energy Use Savings

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 costs of electricity and natural gas and the fuel mix of the reductions in total energy use in a state. Table E-4 shows each state's reduction in energy costs per unit of reduction in energy use, natural gas rate, electricity rate, and the fraction of electricity consumption reductions offset by increases in natural gas consumption.<sup>25</sup> 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 has minimal impacts on the relative reduction because natural gas prices are fairly constant across states (excluding Hawaii) and are significantly cheaper per unit of energy for all nineteen states.

The correlation between a state's average electricity price and the savings in energy costs per unit of energy use savings is shown in Figure 7-10. States with the highest electricity prices (Alaska, Hawaii, and Maine) realize the greatest savings in energy costs per unit of savings in energy use.

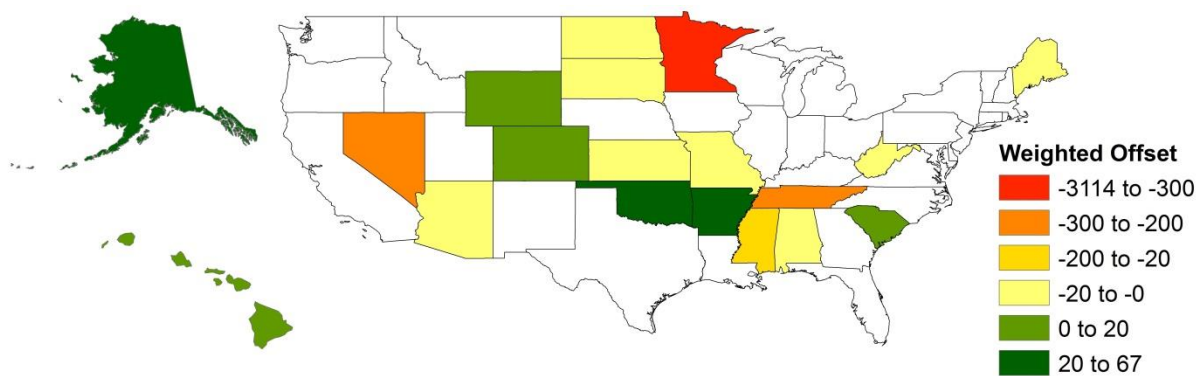


**Figure 7-10 Energy Cost Savings per Unit of Energy Use Savings and Average Electricity Price by State**

<sup>25</sup> The fraction of electricity offset by natural gas consumption is greater than 100 % when natural gas consumption increases by a greater amount than electricity consumption decreases. The fraction of electricity offset by natural gas consumption is less than -100 % when natural gas consumption increases (decreases) by a greater amount than electricity consumption decreases. For some states (e.g. Minnesota) the magnitude of the offset is large because the change in electricity is minimal, leading to the change in natural gas to be large in comparison on a percentage change basis.

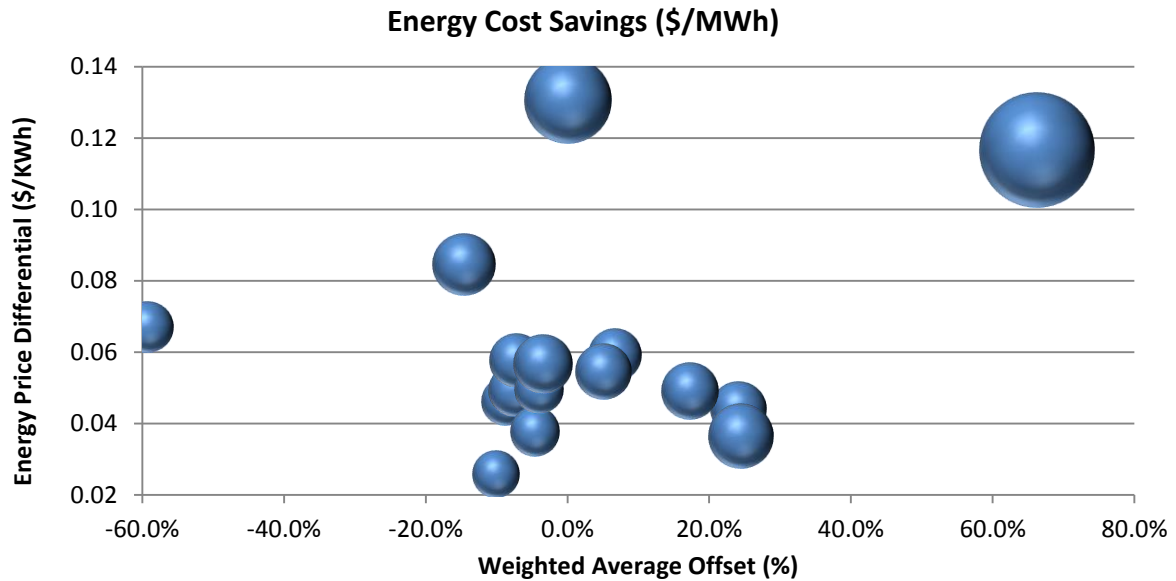
The electricity price does not explain all the variation across states in energy cost savings per unit of energy use savings because there are two sources of energy cost savings: the energy costs savings from total energy use reduction, and the energy cost savings from the shift of fuel consumption from more expensive electricity to cheaper natural gas. The savings from the shift in fuels is a result of two factors: the energy cost savings per unit of energy shifted from electricity to natural gas consumption (energy price differential) and the amount of energy shifted from electricity to natural gas consumption. The energy cost savings increases as the energy price differential increases because the cost savings for each unit of electricity “offset” by a unit of natural gas is greater. The greater the fraction of electricity consumption shifted to natural gas consumption, or offset, the greater the energy cost savings per unit of total energy use savings.

The metric used to explain the shift in fuel consumption is the “weighted average offset,” which is the average percentage offset weighted by the amount of new floor area for each building type in a state. Figure 7-11 shows the weighted average offset for each state, with twelve of nineteen states realizing a negative offset.



**Figure 7-11 Weighted Average Offset by State**

Figure 7-12 shows the savings in energy costs per unit of savings in energy use (\$/MWh) based on the price differential between electricity and natural gas (\$/kWh) and the weighted average offset (%) for each state. States with a greater energy price differential combined with a greater weighted average offset realize the greatest energy cost savings per unit of energy use savings.

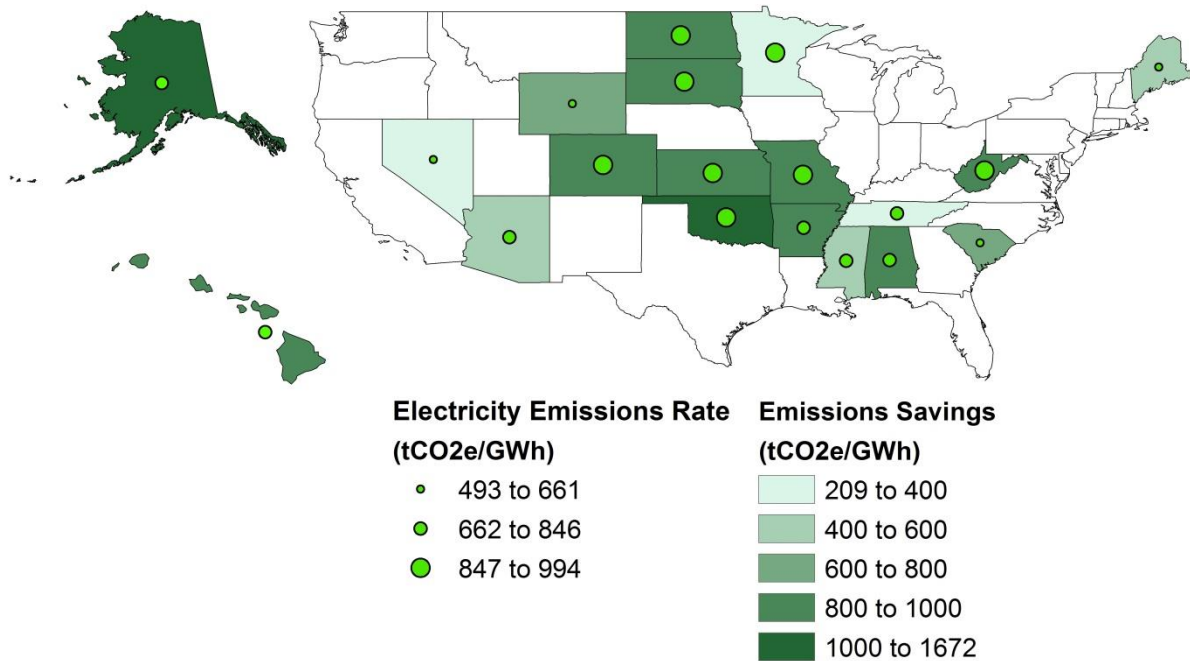


**Figure 7-12 Average State Energy Cost Savings per Unit of Energy Use Savings by Weighted Average Offset and Energy Price Differential**

#### **7.3.1.4 Carbon Emissions Savings per Unit of Energy Use Savings**

In general, the states that realize the greatest reductions in energy use also realize the greatest reductions in energy-related carbon emissions. 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 E-5 shows the weighted average fraction of electricity consumption offset by a change in natural gas consumption, the average CO<sub>2</sub> emissions rates 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 nineteen states in this study. States with the highest emissions rates for electricity generation tend to realize the greatest reductions in carbon emissions per unit of reduction in energy use. Relative to electricity emissions rates, natural gas has minimal impact on the relative reduction because natural gas emissions rates are constant across states and are significantly lower per unit of energy for all nineteen states.

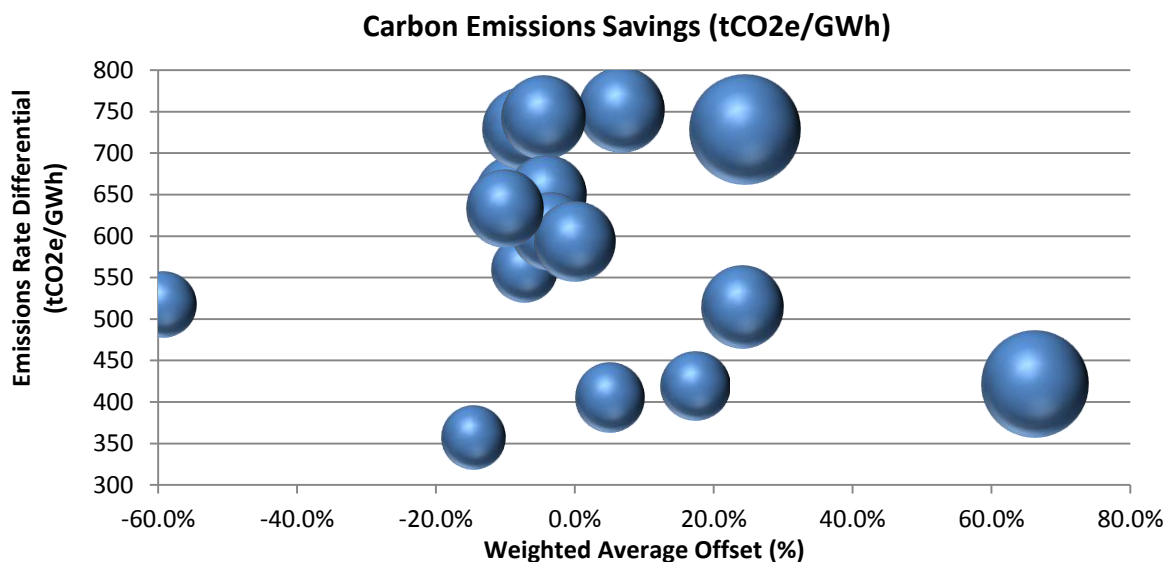
The correlation between a state's average electricity emissions rate and the savings in energy-related emissions per unit of energy reduced is shown in Figure 7-13. States in the central U.S. and West Virginia have the highest average electricity emissions rates and tend to realize the greatest savings in carbon emissions per unit of savings in energy use. Meanwhile, states with the lowest average electricity emissions rates (e.g., Nevada) realize the smallest carbon emissions savings per unit of energy use savings.



**Figure 7-13 Energy-related Carbon Emissions Savings per Unit of Energy Use Savings and Average Electricity Emissions Rate by State**

The electricity emissions rate does not explain all the variation across states in energy-related carbon emissions savings per unit of energy use savings because there are two sources of carbon emission savings: the carbon emissions savings from total energy use reduction, and the carbon emissions savings from the shifting of fuel consumption from the more carbon intensive electricity to less carbon intensive natural gas. The carbon emissions savings increase as the emissions rate differential increases because the carbon emissions savings for each unit of electricity “offset” by a unit of natural gas is greater. The greater the fraction of electricity consumption reductions offset by increases in natural gas consumption, the greater the carbon emissions savings per unit of energy use savings.

Figure 7-14 shows the savings in carbon emissions per unit of savings in energy use (tCO<sub>2</sub>e/GWh) based on the emissions rate differential between electricity and natural gas (tCO<sub>2</sub>e/GWh) and the weighted average offset (%) for each state. States with a greater carbon emissions rate differential combined with a greater weighted average offset realize the greatest carbon emissions savings per unit of energy use savings.



**Figure 7-14 Average State Carbon Emissions Savings per Unit of Energy Use by Weighted Average Offset and Energy Emissions Rate Differential**

### 7.3.2 Regional and National Level Changes

Table 7-11 shows the reduction in energy use per unit of newly constructed floor area from adopting the *ASHRAE 90.1-2007* design by Census region. The only state in the Northeast Census Region (Maine) realizes the greatest reduction while states in the West Census Region realize the smallest reduction in energy use per unit of floor area. The nationwide weighted average reduction in energy use per unit of floor area is 152 kWh/m<sup>2</sup> (14 kWh/ft<sup>2</sup>). The variation across Census regions is a result of a number of factors, including a location's energy code and climate zone.

**Table 7-11 Energy Use Reduction per Unit of Floor Area for Adoption of the *ASHRAE 90.1-2007* Design by Census Region, 10-Year**

| State        | Average Annual New Floor Area<br>1000 m <sup>2</sup> (1000 ft <sup>2</sup> ) | Energy Use<br>(GWh) | kWh/m <sup>2</sup> | kWh/ft <sup>2</sup> |
|--------------|------------------------------------------------------------------------------|---------------------|--------------------|---------------------|
| Northeast    | 497 (5349)                                                                   | 106                 | 212                | 20                  |
| Midwest      | 6296 (67 767)                                                                | 1140                | 181                | 17                  |
| South        | 12 750 (137 243)                                                             | 1968                | 154                | 14                  |
| West         | 12 622 (135 861)                                                             | 1668                | 132                | 12                  |
| <b>Total</b> | <b>32 165 (346 220)</b>                                                      | <b>4881</b>         | <b>152</b>         | <b>14</b>           |

Table 7-12 shows each Census Region's natural gas rate, electricity rate, weighted average fraction of the reduction in electricity consumption offset by the change in natural gas consumption, and average reduction in energy costs from adopting the *ASHRAE 90.1-2007* design. The Northeast Census Region has the highest average

electricity rate, and realizes the greatest reductions in energy costs per unit of reduction in energy use. Meanwhile, the Midwest Census Region has the smallest average electricity rate, and realizes the smallest reductions in energy costs per unit of reduction in energy use.

**Table 7-12 Energy Cost Reduction per kWh of Energy Use Reduction for Adoption of the ASHRAE 90.1-2007 Design by Census Region, 10-Year**

| State                                       | Offset* (%) | Electricity Rate* (\$/kWh) | Natural Gas Rate* (\$/kWh) | Energy Cost Reduction (\$/kWh) |
|---------------------------------------------|-------------|----------------------------|----------------------------|--------------------------------|
| Northeast                                   | -15         | 0.13                       | 0.04                       | 0.09                           |
| South                                       | -69         | 0.09                       | 0.04                       | 0.07                           |
| West                                        | -66         | 0.09                       | 0.03                       | 0.07                           |
| Midwest                                     | -1123       | 0.07                       | 0.03                       | 0.06                           |
| <b>Total</b>                                | <b>-276</b> | <b>0.09</b>                | <b>0.03</b>                | <b>0.06</b>                    |
| *Weighted by energy use savings for a state |             |                            |                            |                                |

Table 7-13 shows each Census Region's natural gas emissions rate, electricity emissions rate, weighted average fraction of the reduction in electricity consumption offset by the change in natural gas consumption, and average reduction in carbon emissions from adopting the ASHRAE 90.1-2007 design. The only state in the Northeast Census Region (Maine) has the lowest average electricity emissions rate, and realizes the smallest reductions in carbon emissions per unit of reduction in energy use. Even though the South Census Region does not have the largest average electricity emissions rate, it realizes the greatest reductions in carbon emissions per unit of reduction in energy use. This is because it has a greater (smaller negative) offset than the Midwest Census Region, leading to the South realizing greater carbon emissions savings per unit of energy use savings.

**Table 7-13 Carbon Reduction per GWh of Energy Use Reduction for Adoption of the ASHRAE 90.1-2007 Design by Census Region, 10-Year**

| State                                       | Offset* (%) | CO <sub>2</sub> e Emissions Rate for Electricity* (t/GWh) | CO <sub>2</sub> e Emissions Rate for Natural Gas (t/GWh) | CO <sub>2</sub> e Reduction (t/GWh) |
|---------------------------------------------|-------------|-----------------------------------------------------------|----------------------------------------------------------|-------------------------------------|
| South                                       | -69         | 825                                                       | 241                                                      | 867                                 |
| Midwest                                     | -1123       | 950                                                       | 241                                                      | 761                                 |
| West                                        | -66         | 838                                                       | 241                                                      | 710                                 |
| Northeast                                   | -15         | 599                                                       | 241                                                      | 557                                 |
| <b>Total</b>                                | <b>-276</b> | <b>854</b>                                                | <b>241</b>                                               | <b>774</b>                          |
| *Weighted by energy use savings for a state |             |                                                           |                                                          |                                     |



Table 7-14 shows the average life-cycle cost reduction per unit of new floor area by Census Region. The combination of greater energy use savings per unit of floor area and higher electricity rates tends to lead to greater life-cycle cost savings from adopting the *ASHRAE 90.1-2007* design. The Census regions with the lowest electricity rate (Midwest) and the smallest energy use savings per unit of floor area (South) realize the lowest and 2<sup>nd</sup>-lowest life-cycle cost savings per unit of floor area, respectively. The West Census Region realizes greater life-cycle cost savings per unit of floor area than the Northeast Census Region, which may be driven by a number of factors, including baseline energy codes and local construction costs across the two regions.

**Table 7-14 Life-Cycle Cost Reductions per Unit of New Floor Area for Adoption of the *ASHRAE 90.1-2007* Design by Census Region, 10-Year**

| State        | Energy Use Savings (kWh/m <sup>2</sup> ) | Electricity Rate* (\$/kWh) | LCC Savings (\$million) | LCC Savings (\$/m <sup>2</sup> ) | LCC Savings (\$/ft <sup>2</sup> ) |
|--------------|------------------------------------------|----------------------------|-------------------------|----------------------------------|-----------------------------------|
| West         | 132                                      | 0.09                       | 94.9                    | 7.52                             | 0.70                              |
| Northeast    | 212                                      | 0.13                       | 3.3                     | 6.64                             | 0.62                              |
| South        | 154                                      | 0.09                       | 67.4                    | 5.29                             | 0.49                              |
| Midwest      | 181                                      | 0.07                       | 7.7                     | 1.22                             | 0.11                              |
| <b>Total</b> | <b>156</b>                               | <b>0.09</b>                | <b>173.3</b>            | <b>5.39</b>                      | <b>0.50</b>                       |



## 8 Incremental Impacts from Adopting More Stringent Standard Editions

This chapter estimates the incremental changes for a state adopting a more recent edition of *ASHRAE 90.1* or the LEC design. Section 8.1 will consider incremental impacts on energy use at the state level. Section 8.2 will consider the incremental impacts on life-cycle costs at the state level. The analysis focuses on the nineteen states that have not yet adopted *ASHRAE 90.1-2007*.

### 8.1 Energy Use Savings

In order to determine the incremental impacts of the adoption of more recent standard editions (a.k.a. impact from adopting the next edition), it is necessary to compare the total savings from adopting each design alternative for the 19 states analyzed in Chapter 7.

Table 8-1 shows the incremental change in total energy use (GWh) by state from adopting the next edition of *ASHRAE 90.1*. The incremental impact from adopting *ASHRAE 90.1-2001* is marginal relative to the more recent editions of *ASHRAE 90.1* or the LEC design. The adoption of *ASHRAE 90.1-2007* tends to realize a smaller increment in savings than adoption of the *ASHRAE 90.1-2004* or LEC designs.

**Table 8-1 Incremental Change in Energy Use by State and Building Design, 10-Year**

| State                                                                                                                                      | Code | Incremental Change in Energy Use (GWh) |                         |                         |                 |
|--------------------------------------------------------------------------------------------------------------------------------------------|------|----------------------------------------|-------------------------|-------------------------|-----------------|
|                                                                                                                                            |      | <i>ASHRAE 90.1-2001</i>                | <i>ASHRAE 90.1-2004</i> | <i>ASHRAE 90.1-2007</i> | Low Energy Case |
| AK                                                                                                                                         | None | 1.1                                    | -3.0                    | 15.8                    | 85.4            |
| ND                                                                                                                                         | None | 3.2                                    | 9.7                     | 32.7                    | 58.9            |
| WY                                                                                                                                         | None | 2.7                                    | 19.4                    | 12.9                    | 41.7            |
| SD                                                                                                                                         | None | 3.4                                    | 25.6                    | 28.5                    | 64.8            |
| ME                                                                                                                                         | None | 5.6                                    | 41.3                    | 58.5                    | 111.2           |
| OK                                                                                                                                         | None | 38.1                                   | 220.6                   | 41.7                    | 297.6           |
| KS                                                                                                                                         | None | 23.4                                   | 122.2                   | 83.8                    | 209.1           |
| MO                                                                                                                                         | None | 35.3                                   | 309.8                   | 178.9                   | 460.6           |
| AL                                                                                                                                         | None | 48.9                                   | 469.5                   | 113.2                   | 419.0           |
| MS                                                                                                                                         | None | 34.3                                   | 302.5                   | 133.8                   | 218.9           |
| AZ*                                                                                                                                        | None |                                        | 449.2                   | 497.1                   | 911.2           |
| AR                                                                                                                                         | 2001 |                                        | 173.6                   | 30.7                    | 221.8           |
| CO                                                                                                                                         | 2001 |                                        | 308.8                   | 234.1                   | 570.0           |
| WV                                                                                                                                         | 2001 |                                        | 58.7                    | 37.7                    | 80.7            |
| HI                                                                                                                                         | 2004 |                                        |                         | 12.1                    | 126.3           |
| SC                                                                                                                                         | 2004 |                                        |                         | 92.2                    | 502.3           |
| NV                                                                                                                                         | 2004 |                                        |                         | 117.3                   | 591.7           |
| TN                                                                                                                                         | 2004 |                                        |                         | 172.6                   | 635.2           |
| MN                                                                                                                                         | 2004 |                                        |                         | 282.7                   | 534.0           |
| Total                                                                                                                                      |      | 196.0                                  | 2507.9                  | 2176.3                  | 6140.4          |
| *Excludes incremental changes from adopting <i>ASHRAE 90.1-2001</i> because three cities in Arizona have adopted <i>ASHRAE 90.1-2004</i> . |      |                                        |                         |                         |                 |

Incremental change comparisons across states are not possible because the amount of new floor area varies across states. To control for this, Table 8-2 shows the reduction in energy use per unit of new floor area for each building design. On average, going beyond *ASHRAE 90.1-2007* and adopting the LEC design leads to the greatest reductions (202 kWh/m<sup>2</sup> (19 kWh/ft<sup>2</sup>)) followed by the incremental reductions from adopting *ASHRAE 90.1-2004* (112 kWh/m<sup>2</sup> (11 kWh/ft<sup>2</sup>)), *ASHRAE 90.1-2007* (71 kWh/m<sup>2</sup> (7 kWh/ft<sup>2</sup>)), and *ASHRAE 90.1-2001* (16 kWh/m<sup>2</sup> (1 kWh/ft<sup>2</sup>)).

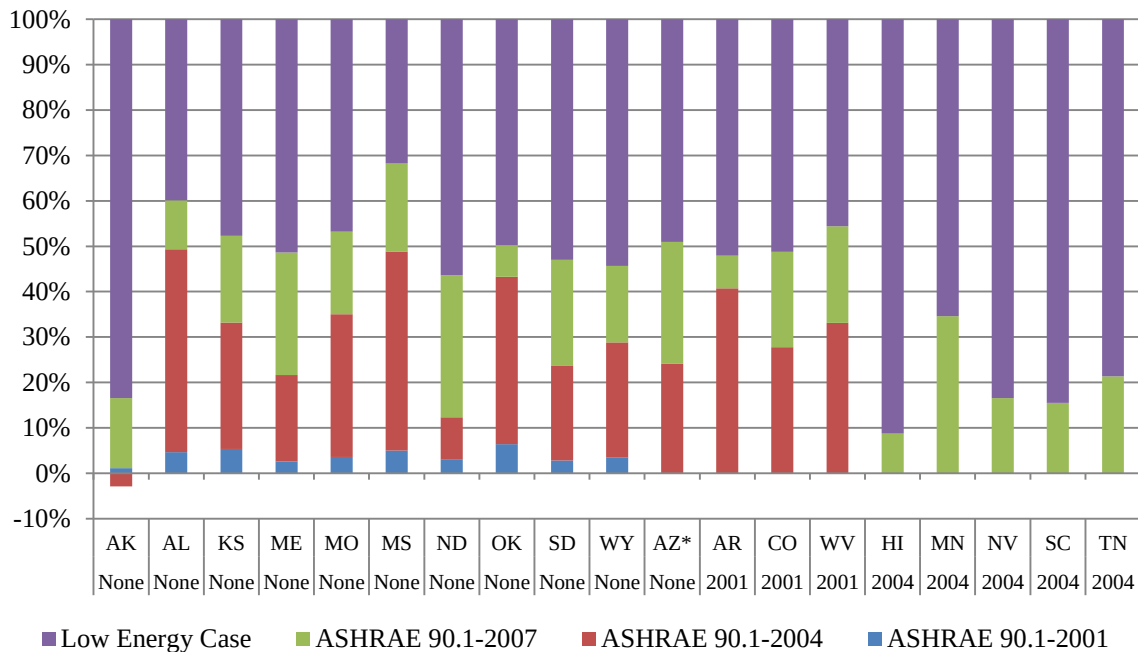
**Table 8-2 Change in Energy Use per Unit of Floor Area by State and Building Design, 10-Year**

| State                                                                                                                                      | Code | Energy Use Savings per Unit of Floor Area |                     |                         |                     |                         |                     |                    |                     |
|--------------------------------------------------------------------------------------------------------------------------------------------|------|-------------------------------------------|---------------------|-------------------------|---------------------|-------------------------|---------------------|--------------------|---------------------|
|                                                                                                                                            |      | <i>ASHRAE 90.1-2001</i>                   |                     | <i>ASHRAE 90.1-2004</i> |                     | <i>ASHRAE 90.1-2007</i> |                     | Low Energy Case    |                     |
|                                                                                                                                            |      | kWh/m <sup>2</sup>                        | kWh/ft <sup>2</sup> | kWh/m <sup>2</sup>      | kWh/ft <sup>2</sup> | kWh/ft <sup>2</sup>     | kWh/ft <sup>2</sup> | kWh/m <sup>2</sup> | kWh/ft <sup>2</sup> |
| AK                                                                                                                                         | None | 4                                         | 0                   | -10                     | -1                  | 54                      | 5                   | 294                | 27                  |
| AL                                                                                                                                         | None | 22                                        | 2                   | 208                     | 19                  | 50                      | 5                   | 186                | 17                  |
| KS                                                                                                                                         | None | 22                                        | 2                   | 113                     | 11                  | 78                      | 7                   | 194                | 18                  |
| ME                                                                                                                                         | None | 11                                        | 1                   | 83                      | 8                   | 118                     | 11                  | 224                | 21                  |
| MO                                                                                                                                         | None | 15                                        | 1                   | 131                     | 12                  | 76                      | 7                   | 195                | 18                  |
| MS                                                                                                                                         | None | 27                                        | 3                   | 242                     | 22                  | 107                     | 10                  | 175                | 16                  |
| ND                                                                                                                                         | None | 14                                        | 1                   | 42                      | 4                   | 143                     | 13                  | 257                | 24                  |
| OK                                                                                                                                         | None | 24                                        | 2                   | 139                     | 13                  | 26                      | 2                   | 187                | 17                  |
| SD                                                                                                                                         | None | 11                                        | 1                   | 84                      | 8                   | 94                      | 9                   | 214                | 20                  |
| WY                                                                                                                                         | None | 12                                        | 1                   | 84                      | 8                   | 56                      | 5                   | 181                | 17                  |
| AZ*                                                                                                                                        | None |                                           |                     | 94                      | 9                   | 104                     | 10                  | 192                | 18                  |
| AR                                                                                                                                         | 2001 |                                           |                     | 146                     | 14                  | 26                      | 2                   | 187                | 17                  |
| CO                                                                                                                                         | 2001 |                                           |                     | 94                      | 9                   | 71                      | 7                   | 173                | 16                  |
| WV                                                                                                                                         | 2001 |                                           |                     | 123                     | 11                  | 79                      | 7                   | 168                | 16                  |
| HI                                                                                                                                         | 2004 |                                           |                     |                         |                     | 23                      | 2                   | 236                | 22                  |
| MN                                                                                                                                         | 2004 |                                           |                     |                         |                     | 121                     | 11                  | 229                | 21                  |
| NV                                                                                                                                         | 2004 |                                           |                     |                         |                     | 33                      | 3                   | 168                | 16                  |
| SC                                                                                                                                         | 2004 |                                           |                     |                         |                     | 34                      | 3                   | 185                | 17                  |
| TN                                                                                                                                         | 2004 |                                           |                     |                         |                     | 53                      | 5                   | 194                | 18                  |
| Average                                                                                                                                    |      | 16                                        | 1                   | 112                     | 11                  | 71                      | 7                   | 202                | 19                  |
| *Excludes incremental changes from adopting <i>ASHRAE 90.1-2001</i> because three cities in Arizona have adopted <i>ASHRAE 90.1-2004</i> . |      |                                           |                     |                         |                     |                         |                     |                    |                     |

Figure 8-1 shows the incremental energy use savings for each energy standard edition as a fraction of the sum of the positive incremental savings in energy use. For a standard edition that increases energy use (e.g., *ASHRAE 90.1-2004* for Alaska), the impact is estimated as a negative fraction of the total savings from the editions that increase energy use savings (e.g., the *ASHRAE 90.1-2001*, *ASHRAE 90.1-2007*, and LEC designs for Alaska).

The states that have already adopted *ASHRAE 90.1-2004* realize a greater share of their savings from the LEC design (65.4 % to 91.3 %) because the difference between *ASHRAE 90.1-2004* and *ASHRAE 90.1-2007* design requirements are minimal relative to

the additional energy efficiency requirements for the LEC design. For states that have no state energy code or have adopted *ASHRAE 90.1-2001*, the LEC design accounts for 31.8 % to 56.3 % while the *ASHRAE 90.1-2004* design accounts for -2.9 % to 44.7 % of the energy use savings. The *ASHRAE 90.1-2004* design accounts for a greater percentage of energy use savings than the *ASHRAE 90.1-2007* design for 9 of 14 states. There are minimal impacts from adopting *ASHRAE 90.1-2001* because there are few differences in energy efficiency requirements relative to *ASHRAE 90.1-1999*.



**Figure 8-1 Incremental Energy Use Savings by State and Standard Edition**

Since energy costs and energy-related carbon emissions are highly correlated with energy use, the same trends and interpretations hold for the incremental changes in energy costs and carbon emissions. Variation from energy use is due to a state's energy prices, energy emissions rates, and the relative changes in energy use for electricity and natural gas consumption discussed in Section 6.2 and Section 7.2.

## 8.2 Life-Cycle Cost Savings

In order to determine the incremental life-cycle cost impacts of the adoption of more recent standard editions, it is necessary to compare the total life-cycle costs from adopting each design alternative for the 19 states analyzed in Chapter 7.

Table 8-3 shows the incremental change in life-cycle cost savings (\$ million) by state and building design. Adopting *ASHRAE 90.1-2001* can lead to significant increases in life-cycle costs (\$2.9 million to \$37.3 million) for all states, which is a result of the

high-cost HVAC efficiency requirement increases relative to *ASHRAE 90.1-1999*. Adopting *ASHRAE 90.1-2004* can lead to significant decreases in life-cycle costs relative to *ASHRAE 90.1-2001* (\$3.6 million to \$91.1 million) for all nine states and offsets most, if not all of the additional life-cycle costs from adopting *ASHRAE 90.1-1999*. Five of the nine states with no state energy code realize a net decrease in life-cycle costs from adopting *ASHRAE 90.1-2004*.<sup>26</sup> The adoption of the *ASHRAE 90.1-2007* design realize much smaller savings relative to *ASHRAE 90.1-2004* (-\$0.2 million to \$46.6 million). The adoption of the LEC design realizes similar incremental savings relative to *ASHRAE 90.1-2007* (-\$0.2 million to \$48.3 million). At the margin, adopting the *ASHRAE 90.1-2007* and LEC designs increase life-cycle costs for two states (Oklahoma and Arkansas) and one state (West Virginia), respectively.

**Table 8-3 Incremental Change in Life-Cycle Cost Reductions by State and Building Design, 10-Year**

| State                                                                                                                                      | Code | Incremental Change in Life-Cycle Cost Savings<br>(\$ million) |                         |                         |                 |
|--------------------------------------------------------------------------------------------------------------------------------------------|------|---------------------------------------------------------------|-------------------------|-------------------------|-----------------|
|                                                                                                                                            |      | <i>ASHRAE 90.1-2001</i>                                       | <i>ASHRAE 90.1-2004</i> | <i>ASHRAE 90.1-2007</i> | Low Energy Case |
| AK                                                                                                                                         | None | -3.8                                                          | 4.6                     | 0.6                     | 0.9             |
| AL                                                                                                                                         | None | -30.1                                                         | 48.7                    | 7.2                     | 11.3            |
| KS                                                                                                                                         | None | -22.3                                                         | 15.4                    | 3.9                     | 5.2             |
| ME                                                                                                                                         | None | -7.9                                                          | 9.2                     | 1.9                     | 3.1             |
| MO                                                                                                                                         | None | -37.3                                                         | 32.2                    | 7.0                     | 0.8             |
| MS                                                                                                                                         | None | -21.4                                                         | 26.7                    | 7.0                     | 2.5             |
| ND                                                                                                                                         | None | -3.4                                                          | 2.6                     | 0.8                     | 0.0             |
| OK                                                                                                                                         | None | -26.2                                                         | 20.6                    | -0.2                    | 6.4             |
| SD                                                                                                                                         | None | -2.9                                                          | 3.6                     | 0.7                     | 0.9             |
| WY                                                                                                                                         | None | -3.9                                                          | 3.7                     | 0.7                     | 0.2             |
| AZ*                                                                                                                                        | None |                                                               | 91.1                    | 46.6                    | 48.3            |
| AR                                                                                                                                         | 2001 |                                                               | 17.7                    | -0.1                    | 2.8             |
| CO                                                                                                                                         | 2001 |                                                               | 46.1                    | 7.8                     | 5.8             |
| WV                                                                                                                                         | 2001 |                                                               | 5.6                     | 1.8                     | -0.2            |
| HI                                                                                                                                         | 2004 |                                                               |                         | 2.0                     | 11.9            |
| MN                                                                                                                                         | 2004 |                                                               |                         | 7.3                     | 5.1             |
| NV                                                                                                                                         | 2004 |                                                               |                         | 6.3                     | 11.6            |
| SC                                                                                                                                         | 2004 |                                                               |                         | 2.9                     | 9.3             |
| TN                                                                                                                                         | 2004 |                                                               |                         | 7.5                     | 20.6            |
| Total                                                                                                                                      |      | -159.2                                                        | 327.8                   | 111.7                   | 146.5           |
| *Excludes incremental changes from adopting <i>ASHRAE 90.1-2001</i> because three cities in Arizona have adopted <i>ASHRAE 90.1-2004</i> . |      |                                                               |                         |                         |                 |

Incremental change comparisons across states are not possible because the amount of new floor area varies across states. Table 8-4 shows the reduction in life-cycle costs per unit of new floor area for each building design. On average, adopting the *ASHRAE 90.1-*

<sup>26</sup> Excluding Arizona.

2004 design leads to the greatest marginal reductions (\$15.52/m<sup>2</sup> (\$1.44/ft<sup>2</sup>)) followed by the LEC design (\$4.24/m<sup>2</sup> (\$0.39/ft<sup>2</sup>)), *ASHRAE 90.1-2007* (\$3.04/m<sup>2</sup> (\$0.28/ft<sup>2</sup>)), and *ASHRAE 90.1-2001* (-\$15.39/m<sup>2</sup> (-\$1.43/ft<sup>2</sup>)). There is significant variation in incremental life-cycle cost savings per unit of floor area within each building design.

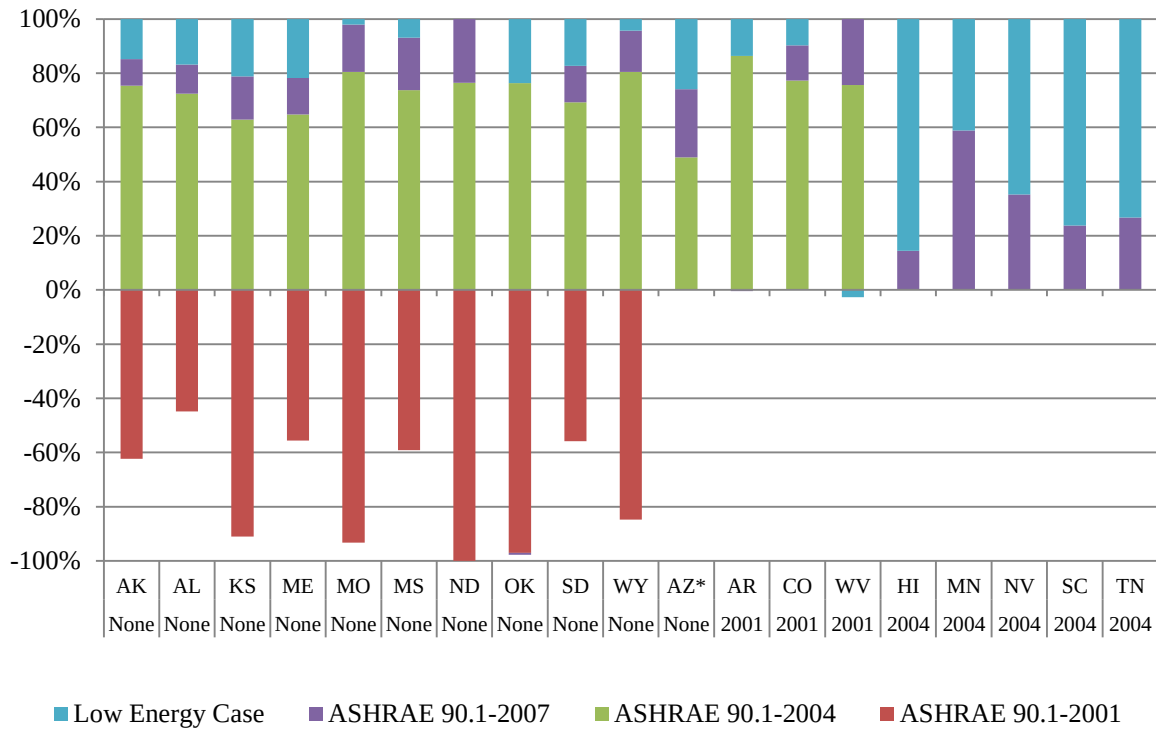
**Table 8-4 Incremental Change in Life-Cycle Cost Reductions per Unit of New Floor Area by State and Building Design, 10-Year**

| State                                                                                                                                      | Code | Incremental Change in Life-cycle Cost Savings<br>per Unit of Floor Area |        |                         |        |                         |        |                 |        |
|--------------------------------------------------------------------------------------------------------------------------------------------|------|-------------------------------------------------------------------------|--------|-------------------------|--------|-------------------------|--------|-----------------|--------|
|                                                                                                                                            |      | <i>ASHRAE 90.1-2001</i>                                                 |        | <i>ASHRAE 90.1-2004</i> |        | <i>ASHRAE 90.1-2007</i> |        | Low Energy Case |        |
|                                                                                                                                            |      | \$/m2                                                                   | \$/ft2 | \$/m2                   | \$/ft2 | \$/m2                   | \$/ft2 | \$/m2           | \$/ft2 |
| AK                                                                                                                                         | None | -13.10                                                                  | -1.22  | 15.86                   | 1.48   | 2.07                    | 0.19   | 3.10            | 0.29   |
| --AL                                                                                                                                       | None | -13.35                                                                  | -1.24  | 21.61                   | 2.01   | 3.19                    | 0.30   | 5.01            | 0.47   |
| KS                                                                                                                                         | None | -20.71                                                                  | -1.92  | 14.30                   | 1.33   | 3.62                    | 0.34   | 4.83            | 0.45   |
| ME                                                                                                                                         | None | -15.90                                                                  | -1.48  | 18.51                   | 1.72   | 3.82                    | 0.36   | 6.24            | 0.58   |
| MO                                                                                                                                         | None | -15.82                                                                  | -1.47  | 13.66                   | 1.27   | 2.97                    | 0.28   | 0.34            | 0.03   |
| MS                                                                                                                                         | None | -17.11                                                                  | -1.59  | 21.34                   | 1.98   | 5.60                    | 0.52   | 2.00            | 0.19   |
| ND                                                                                                                                         | None | -14.85                                                                  | -1.38  | 11.35                   | 1.06   | 3.49                    | 0.32   | 0.00            | 0.00   |
| OK                                                                                                                                         | None | -16.48                                                                  | -1.53  | 12.96                   | 1.20   | -0.13                   | -0.01  | 4.03            | 0.37   |
| SD                                                                                                                                         | None | -9.57                                                                   | -0.89  | 11.88                   | 1.10   | 2.31                    | 0.21   | 2.97            | 0.28   |
| WY                                                                                                                                         | None | -16.96                                                                  | -1.57  | 16.09                   | 1.49   | 3.04                    | 0.28   | 0.87            | 0.08   |
| AZ*                                                                                                                                        | None |                                                                         |        | 19.15                   | 1.78   | 9.79                    | 0.91   | 10.15           | 0.94   |
| AR                                                                                                                                         | 2001 |                                                                         |        | 14.92                   | 1.39   | -0.08                   | -0.01  | 2.36            | 0.22   |
| CO                                                                                                                                         | 2001 |                                                                         |        | 14.00                   | 1.30   | 2.37                    | 0.22   | 1.76            | 0.16   |
| WV                                                                                                                                         | 2001 |                                                                         |        | 11.69                   | 1.09   | 3.76                    | 0.35   | -0.42           | -0.04  |
| HI                                                                                                                                         | 2004 |                                                                         |        |                         |        | 3.73                    | 0.35   | 22.20           | 2.06   |
| MN                                                                                                                                         | 2004 |                                                                         |        |                         |        | 3.13                    | 0.29   | 2.19            | 0.20   |
| NV                                                                                                                                         | 2004 |                                                                         |        |                         |        | 1.79                    | 0.17   | 3.30            | 0.31   |
| SC                                                                                                                                         | 2004 |                                                                         |        |                         |        | 1.07                    | 0.10   | 3.42            | 0.32   |
| TN                                                                                                                                         | 2004 |                                                                         |        |                         |        | 2.29                    | 0.21   | 6.30            | 0.58   |
| Average                                                                                                                                    |      | -15.39                                                                  | -1.43  | 15.52                   | 1.44   | 3.04                    | 0.28   | 4.24            | 0.39   |
| *Excludes incremental changes from adopting <i>ASHRAE 90.1-2001</i> because three cities in Arizona have adopted <i>ASHRAE 90.1-2004</i> . |      |                                                                         |        |                         |        |                         |        |                 |        |

Figure 8-2 shows the incremental life-cycle cost savings for each energy standard edition as a fraction of the sum of the positive incremental savings in life-cycle costs. For a standard edition that increases life-cycle costs (e.g., *ASHRAE 90.1-2001*), the impact is estimated as a negative fraction of the total savings from the editions that increase life-cycle cost savings (e.g., the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs).

The fraction of the life-cycle cost savings resulting from adopting the LEC design varies across states that have already adopted *ASHRAE 90.1-2004* (41.1 % to 85.6 %). For states that have no state energy code or have adopted *ASHRAE 90.1-2001*, the *ASHRAE 90.1-2004* design accounts for 49.0 % to 86.3 % while the *ASHRAE 90.1-2007* design accounts for -0.7 % to 58.9 % of the life-cycle cost savings. The *ASHRAE 90.1-2004*

design accounts for the greatest percentage of life-cycle cost savings (49.0 % to 86.3 %). There are significant negative impacts from adopting *ASHRAE 90.1-2001*, which offset 44.8 % to 100.0 % of life-cycle cost savings from adopting the *ASHRAE 90.1-2004*, *ASHRAE 90.1-2007*, and LEC designs.



**Figure 8-2 Incremental Life-cycle Cost Savings by State and Building Design**

## 9 Discussion

This study analyzes the impacts of adopting new, more stringent state energy codes based on the BIRDS database for 11 prototypical building types in 228 U.S. locations. Results are summarized at the state, regional, and national levels. This section will discuss key findings, limitations of the research, and recommended directions for future research.

### 9.1 Key Findings

The key findings from this study are described for each metric used for the analysis: percentage change, total change, and change per unit of floor area. Additionally, incremental changes, both in aggregate and per unit of floor area, will be discussed.

#### 9.1.1 Percentage Changes

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

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

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

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

Over all building types, states located in the warmest climates realize the greatest reductions in energy use from adopting the “Low Energy Case” (LEC) design because several of the energy efficiency improvements (e.g., overhangs and daylighting controls) are more beneficial for warmer climates. However, states in colder climates see greater percentage reductions in energy costs and carbon emissions per percentage reduction in energy use because the energy efficiency measures tend to shift some energy use from electricity to natural gas consumption. Electricity is more expensive per unit of energy and typically has greater CO<sub>2</sub>e emissions per unit of energy relative to natural gas. Therefore the shift of energy consumption from electricity to natural gas can lead to greater reductions in energy costs and energy-related carbon emissions than reductions in total energy use. In an extreme case, cities located in Zone 8 realize a reduction in energy costs and carbon emissions while realizing an increase in total energy use.

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

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



The length of the study period impacts life-cycle cost-effectiveness to some degree. Assuming nationwide adoption of the LEC design, average life-cycle costs decrease by 1.1 %, on average, for all building types and locations over a 10-year study period. The percentage decrease in life-cycle costs is 1.4 % for a 20-year, 1.8 % for a 30-year, and 1.9 % for a 40-year study period. As the study period length increases from 5 years to 40 years, life-cycle cost-effectiveness tends to increase for more energy efficient commercial building designs.

### 9.1.2 Total Changes

By combining the amount of new floor area in a state with its average impacts in a state for each building type, it is possible to estimate the magnitude of the impacts that nationwide adoption of a given building design would have at the state and national levels. States with the most newly constructed commercial building floor area tend to realize the greatest total energy use, energy cost, energy-related carbon emissions, and life-cycle cost reductions from adopting the *ASHRAE 90.1-2007* and LEC designs even if those states do not realize the greatest percentage reductions. California, Florida, and Texas realize the greatest reductions in energy use (>1900 GWh) from adopting the LEC design. In comparison, states with the smallest amount of new floor area (Alaska, Delaware, Montana, Rhode Island, Vermont, and Wyoming) realize savings of less than 100 GWh from adopting the LEC design. For the nineteen states that have not yet adopted the *ASHRAE 90.1-2007* design, Arizona realizes the greatest reductions in energy use (946 GWh) from doing so, while states with the smallest amount of new floor area (Alaska, Wyoming, Hawaii, Maine, North Dakota, South Dakota, and Wyoming) realize savings of less than 106 GWh. Similar trends occur for total energy cost reductions and energy-related carbon emissions savings.

The nationwide adoption of more efficient energy codes decreases total life-cycle costs. Adopting the LEC design decreases total life-cycle costs for 48 of 50 states for a 10-year study period, with Florida (\$151.3 million), California (\$124.9 million), and Texas (\$106.8 million) realizing the greatest life-cycle cost savings. The two states that realize an increase in life-cycle costs are Oregon (\$0.4 million) and Washington (\$11.5 million). For a 10-year study period, adopting the *ASHRAE 90.1-2007* design reduces total life-cycle costs for 17 of 19 states, including 8 of 10 that have adopted an older edition of *ASHRAE 90.1* or have not yet adopted a state energy code for commercial buildings. The greatest life-cycle cost savings are realized by Colorado (\$53.9 million), Arizona (\$30.8 million), and Alabama (\$25.7 million). The two states that realize an increase in total life-cycle costs are Kansas (\$2.9 million) and Oklahoma (\$5.7 million).

The state-level impacts are aggregated to determine the total impact of nationwide adoption of both the *ASHRAE 90.1-2007* and LEC designs. Nationwide adoption of the LEC design leads to reductions totaling 34.4 TWh in energy consumption, \$2.8 billion in

energy costs, 26.3 million metric tons in energy-related carbon emissions, and \$1.0 billion in life-cycle costs for a 10-year study period. Nationwide adoption of the *ASHRAE 90.1-2007* design leads to reductions totaling 4.9 TWh in energy consumption, \$312 million in energy costs, 3.8 million metric tons in energy-related carbon emissions, and \$173 million in life-cycle costs for a 10-year study period. An increase in the study period length increases the total savings for all four impacts because as the length of the study period increases, energy cost savings become a greater fraction of total life-cycle cost savings.

### **9.1.3 Change per Unit of Floor Area**

The total savings estimates are driven primarily by the average annual amount of new floor area in a state. After controlling for the amount of new floor area, the relative savings in energy use, energy costs, carbon emissions, and life-cycle costs per unit of floor area across states is similar to the average percentage changes in each impact. States that have adopted older editions of *ASHRAE 90.1* or have no energy code realize greater per unit savings in energy use, energy costs, and carbon emissions from adopting the LEC design. However, since these per unit changes account for the amount of new floor area for each building type, the results more precisely estimate the impacts. States that have adopted the *ASHRAE 90.1-2001* design realize the greatest life-cycle cost savings per unit of floor area from adopting both the *ASHRAE 90.1-2007* and LEC designs. On the other hand, states that have no state energy code realize varying levels of savings from adopting both the *ASHRAE 90.1-2007* and LEC designs.

In general, the states that realize the greatest reductions in energy use per unit of floor area also realize the greatest reductions in energy costs and energy-related carbon emissions per unit of floor area. However, states with higher average electricity prices and electricity emissions rates, and states that realize a greater shift of fuel consumption from electricity to natural gas, realize greater reductions in energy costs and carbon emissions holding energy use savings constant.

The changes per unit of floor area vary across Census regions, with the same trends holding for adoption of the *ASHRAE 90.1-2007* and LEC designs. The South realizes the greatest energy use savings per unit of floor area because all states in the region are located in warmer climate zones. The West realizes the greatest life-cycle cost savings per unit of floor area, which is a result of a number of factors, including the baseline energy codes for the cities located in the Census region, the regional average electricity price, average energy use savings, and local construction costs. Similar to state-level results, energy costs and carbon emissions savings vary from energy use savings per unit of floor area. The Northeast realizes the greatest energy cost savings per unit energy use savings due to its higher average electricity price. The Midwest realizes the greatest

carbon emissions savings per unit of energy use savings because its average electricity emissions rate is much higher than in the other Census regions.

#### **9.1.4 Incremental Changes from Adopting More Stringent Standard Editions**

The incremental impacts in a state from adopting each newer edition of *ASHRAE 90.1* lead to some interesting conclusions. For the nine states that have no state energy code, adoption of *ASHRAE 90.1-2001* would lead to minimal energy use reductions (16 kWh/m<sup>2</sup>) while significantly increasing total life-cycle costs (\$15.39/m<sup>2</sup>).<sup>27</sup> The reason for this result is that the primary changes in the standard from *ASHRAE 90.1-1999* to *ASHRAE 90.1-2001* target the required efficiencies of HVAC equipment. The additional first costs of increasing the efficiency of HVAC equipment appear to be greater than the energy cost savings realized over the 10-year study period.

The adoption of *ASHRAE 90.1-2004* leads to significant average reductions in energy use (112 kWh/m<sup>2</sup>) while significantly decreasing total life-cycle costs (\$15.52/m<sup>2</sup>), and entirely offsets the increase in life-cycle costs for five of the nine states with no state code. One state, Alaska, realizes an increase in energy use relative to *ASHRAE 90.1-2001*, which is a result of building requirements being relaxed for some cities due to the climate zone consolidation from *ASHRAE 90.1-2001* to *ASHRAE 90.1-2004*.

The adoption of *ASHRAE 90.1-2007* leads to significantly smaller average incremental reductions in energy use (71 kWh/m<sup>2</sup>) and life-cycle costs (\$3.04/m<sup>2</sup>) relative to adopting *ASHRAE 90.1-2004*. Two of the nineteen states (Arkansas and Oklahoma) realize an increase in life-cycle costs relative to *ASHRAE 90.1-2004*.

The adoption of the LEC design leads to the greatest incremental impacts on total energy use (202 kWh/m<sup>2</sup>), and similar incremental impacts on life-cycle costs (\$4.24/m<sup>2</sup>) as *ASHRAE 90.1-2007* for the nineteen states that have not yet adopted *ASHRAE 90.1-2007*. Only one of the nineteen states (West Virginia) realizes an increase in life-cycle costs relative to *ASHRAE 90.1-2007*.

## **9.2 Limitations and Future Research**

The analysis in this study is limited in scope and would be strengthened by including sensitivity analysis, expanding the BIRDS database and metrics, and enabling public access to all the results.

Sensitivity analysis is needed for at least two assumptions in the analysis. First, consider the assumed discount rate. Although 3 % is a reasonable discount rate, in real terms, for

---

<sup>27</sup> Excludes Arizona because three of the six cities in the BIRDS database have adopted *ASHRAE 90.1-2004* as their local energy code.

federal government investment decisions, it may be too low of a value for an expected real return on an alternative investment in the private sector. Sensitivity analysis on the assumed discount rate is needed to determine the robustness of the cost results. Second, the current analysis assumes that the cooling load is met by equipment running on electricity while heating loads are met with equipment running on natural gas, which is not the typical fuel mix for some areas of the nation. The database should be expanded to include alternative fuel source options, such as heating oil use in the New England area.

Additional data are needed to refine and expand the BIRDS database. First, the study uses simple averages to summarize energy use, energy cost, life-cycle cost, and carbon emissions changes across all locations in a state. However, the amount of total floor area constructed will vary significantly from city to city. Future research could develop a weighted average of savings in a state based on the fraction of new construction by city. Second, the 11 prototypical buildings analyzed in this study are likely not representative of the entire building stock for each building type. For example, all high-rise buildings are not 100 % glazed. For this reason, the results should be considered as general magnitudes instead of hard numbers. Future research should include additional prototypes, such as the DOE Benchmark Buildings, in the database. Additionally, since existing buildings account for nearly the entire building stock, prototypes for energy retrofits to buildings should be incorporated into the BIRDS database as well. The state average energy cost rates and energy-related carbon emissions rates do not control for local variation in energy tariffs or electricity fuel mixes. By using utility-level energy cost and emissions rate data, the accuracy of the estimates in BIRDS could be improved.

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

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

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



## References

- ANSI/ASHRAE/USGBC/IES Standard 189.1-2009, Standard for the Design of High-Performance Green Buildings, 2009, ASHRAE, Inc. and U.S. Green Building Council.
- ArcMap 10.1 software, ArcGIS desktop package, ESRI, Redlands, CA, <http://www.esri.com/>.
- ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-1999 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 1999, ASHRAE, Inc.
- ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2001 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2001, ASHRAE, Inc.
- ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2004 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2004, ASHRAE, Inc.
- ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2007 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2007, ASHRAE, Inc.
- ASHRAE/IESNA Standard Project Committee 90.1, ASHRAE 90.1-2010 Standard- Energy Standard for Buildings Except Low-Rise Residential Buildings, 2010, ASHRAE, Inc.
- ASTM International, ASTM Standards of Building Economics: 7th Edition, 2012.
- D.B. Belzer, K.A. Cort, D.W. Winiarski, E.E. Richman, Analysis of Potential Benefits and Costs of Adopting a Commercial Building Energy Standard in South Dakota, March 2005, Pacific Northwest National Laboratory, PNNL-15101.
- Commercial Buildings Energy Consumption Survey (CBECS) database, 2003, accessed June-July 2009, <http://www.eia.doe.gov/emeu/cbecs/>.
- Database of State Incentives for Renewables and Efficiency, Rules, Regulations, and Policies for Energy Efficiency database, building energy codes, accessed summer 2010, [www.dsireusa.org/](http://www.dsireusa.org/).
- Department of Energy, 2009a, Building Technologies Program, EnergyPlus energy simulation software, <http://apps1.eere.energy.gov/buildings/energyplus/>.

- Department of Energy, 2009b, Building Technologies Program, State energy codes at-a-glance, <http://www.energycodes.gov/states/maps/commercialStatus.stm>.
- EnergyPlus Example File Generator, Building Energy Simulation Web Interface for EnergyPlus, accessed Feb. 2009, U.S. Department of Energy National Renewable Energy Laboratory, <http://apps1.eere.energy.gov/buildings/energyplus/>.
- Environmental Protection Agency, 2007 Emissions and Generation Integrated Database.
- S. Fuller, S. Petersen, Life-Cycle Costing Manual for the Federal Energy Management Program, 1996, NIST Handbook 135, 1995 Edition, U.S. Department of Commerce, Technology Administration and NIST.
- M.A. Halverson, K. Gowri, E.E. Richman, Analysis of Energy Savings Impacts of New Commercial Energy Codes for the Gulf Coast, December 2006, Pacific Northwest National Laboratory, PNNL-16282.
- J. Kneifel, Life-cycle Carbon and Cost Analysis of Energy Efficiency Measures in New Commercial Buildings, *Energy and Buildings* 42 (3) (2010) 333-340.
- J. Kneifel, 2011a, Beyond the Code: Energy, Carbon, and Cost Savings using Conventional Technologies, *Energy and Buildings* 43 (2011) 951-959.
- J. Kneifel, 2011b, Prototype Commercial Buildings for Energy and Sustainability Assessment: Whole Building Energy Simulation Design, September 2011, NIST, Technical Note 1716.
- J. Kneifel, 2012, Prototype Commercial Buildings for Energy and Sustainability Assessment: Design Specification, Life-Cycle Costing and Carbon Assessment, January 2012, NIST, Technical Note 1732.
- J. Kneifel, 2013a, Benefits and Costs of Energy Standard Adoption in New Commercial Buildings, February 2013, NIST, Special Publication 1147.
- J. Kneifel, 2013b, Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: Northeast Census Region, February 2013, NIST, Special Publication 1148-1.
- J. Kneifel, 2013c, Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: Midwest Census Region, February 2013, NIST, Special Publication 1148-2.
- J. Kneifel, 2013d, Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: South Census Region, February 2013, NIST, Special Publication 1148-3.



- J. Kneifel, 2013e, Benefits and Costs of Energy Standard Adoption in New Commercial Buildings: West Census Region, March 2013, NIST, Special Publication 1148-4.
- B. Lippiatt, Greig, A., Lavappa, P., Building for Environmental and Economic Sustainability (BEES) Online software, February 2011, NIST, <http://ws680.nist.gov/bees/>.
- National Oceanic and Atmospheric Administration, map of census regions, accessed Dec. 2010, <http://marineeconomics.noaa.gov/>.
- National Renewable Energy Laboratory, 2011, U.S. Department of Energy Commercial Reference Building Models of the National Building Stock, TP-5500-46861.
- Pacific Northwest National Laboratory, 2009, Impacts of Standard 90.1-2007 for Commercial Buildings at State Level, United States Department of Energy Building Energy Codes Program.
- RS Means CostWorks databases, accessed 2009, <http://www.meanscostworks.com/>.
- A. Rushing, B. Lippiatt, Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-April 2008, May 2008, NIST, NISTIR 85-3273-23.
- M. Towers, R. Dotz, L. Romani, The Whitestone Building Maintenance and Repair Cost Reference 2008-2009, 13th Annual Edition, 2008, Whitestone Research.
- U.S. Energy Information Administration, 2010a, Electric power annual state data tables, Accessed 2010, <http://www.eia.doe.gov/fuelelectric.html>.
- U.S. Energy Information Administration, 2010b, Natural Gas Navigator, accessed 2010, [http://www.eia.doe.gov/oil\\_gas/natural\\_gas/info\\_glance/natural\\_gas.html](http://www.eia.doe.gov/oil_gas/natural_gas/info_glance/natural_gas.html).
- U.S. Life-Cycle Inventory Database, 2012, <http://www.nrel.gov/lci/>.
- D. Winiarski, S. Shankle, J. Hail, B. Liu, A. Walker, The Business Case for Sustainable Design in Federal Facilities: Appendix B: Energy and Construction Cost Estimates, August 2003, Pacific Northwest National Laboratory and National Renewable Energy Laboratory.



## A Building Type, New Construction, and Emissions Rates

**Table A-1 CBECS Categories and Subcategories**

| Category               | Subcategory                            | Category                | Subcategory                             |
|------------------------|----------------------------------------|-------------------------|-----------------------------------------|
| Education              | elementary or middle school            | Public Assembly         | social or meeting                       |
|                        | high school                            |                         | recreation                              |
|                        | college or university                  |                         | entertainment or culture                |
|                        | preschool or daycare                   |                         | library                                 |
|                        | adult education                        |                         | funeral home                            |
|                        | career or vocational training          |                         | student activities center               |
|                        | religious education                    |                         | armory                                  |
| Food Sales             | grocery store or food market           |                         | exhibition hall                         |
|                        | gas station with a convenience store;  |                         | broadcasting studio                     |
|                        | convenience store                      |                         | transportation terminal                 |
| Food Service           | fast food                              | Public Order and Safety | police station                          |
|                        | restaurant or cafeteria                |                         | fire station                            |
| Health Care Inpatient  | hospital                               |                         | jail, reformatory, or penitentiary      |
|                        | inpatient rehabilitation               |                         | courthouse or probation office          |
| Health Care Outpatient | medical office (see previous column)   | Religious Worship       | None                                    |
|                        | clinic or other outpatient health care | Service                 | vehicle service or vehicle repair shop  |
|                        | outpatient rehabilitation              |                         | vehicle storage/ maintenance (car barn) |
|                        | veterinarian                           |                         | repair shop                             |
|                        |                                        |                         | dry cleaner or laundromat               |
| Lodging                | motel or inn                           |                         | post office or postal center            |
|                        | hotel                                  |                         | car wash                                |
|                        | dormitory, fraternity, or sorority     |                         | gas station                             |
|                        | retirement home                        |                         | photo processing shop                   |
|                        | nursing home, assisted living, etc.    |                         | beauty parlor or barber shop            |
|                        | convent or monastery                   |                         | tanning salon                           |
|                        | shelter, orphanage, halfway house      |                         | copy center or printing shop            |
|                        |                                        |                         | kennel                                  |

|                     |                                              |                       |                                                    |
|---------------------|----------------------------------------------|-----------------------|----------------------------------------------------|
| Mercantile Non-Mall | retail store                                 | Warehouse and Storage | refrigerated warehouse                             |
|                     | beer, wine, or liquor store                  |                       | non-refrigerated warehouse                         |
|                     | rental center                                |                       | distribution or shipping center                    |
|                     | dealership or showroom for vehicles or boats | Other                 | airplane hangar                                    |
|                     | studio/gallery                               |                       | crematorium                                        |
| Mercantile Malls    | enclosed mall                                |                       | laboratory                                         |
|                     | strip shopping center                        |                       | telephone switching                                |
| Office              |                                              |                       | agricultural with some retail space                |
|                     | administrative or professional office        | Vacant                | manufacturing or industrial with some retail space |
|                     | government office                            |                       | data center or server farm                         |
|                     | 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                                  |                       |                                                    |

**Table A-2 New Commercial Building Construction Volume for 2003 through 2007  
by State and Building Type (S-I)**

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

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

| State | Building Construction Volume (1,000 ft <sup>3</sup> ) |            |         |         |                 |            |           |           |           |              | Total     |
|-------|-------------------------------------------------------|------------|---------|---------|-----------------|------------|-----------|-----------|-----------|--------------|-----------|
|       | Apartment                                             | Healthcare | Hotel   | Office  | Public Assembly | Restaurant | Retail    | School    | Warehouse | No Prototype |           |
| AK    | 201                                                   | 1401       | 1357    | 2428    | 1190            | 137        | 2240      | 2484      | 1356      | 2787         | 15 581    |
| AL    | 8619                                                  | 7587       | 9184    | 16 191  | 6876            | 1821       | 26 748    | 16 514    | 9060      | 18 729       | 121 329   |
| AR    | 1272                                                  | 5000       | 5198    | 6962    | 3611            | 829        | 14 624    | 13 936    | 3609      | 8768         | 63 810    |
| AZ    | 11 223                                                | 16 195     | 11 272  | 43 383  | 12 701          | 2918       | 52 646    | 24 692    | 40 052    | 40 986       | 256 068   |
| CA    | 105 071                                               | 35 633     | 33 678  | 99 228  | 33 281          | 5747       | 114 344   | 76 262    | 143 853   | 132 882      | 779 978   |
| CO    | 21 885                                                | 14 926     | 10 735  | 23 225  | 7618            | 2142       | 31 177    | 17 804    | 16 582    | 31 094       | 177 186   |
| CT    | 6582                                                  | 4333       | 5261    | 6651    | 5485            | 698        | 13 403    | 12 856    | 8798      | 13 679       | 77 746    |
| DC    | 12 636                                                | 769        | 1199    | 15 734  | 1202            | 38         | 1122      | 2051      | 363       | 8934         | 44 047    |
| DE    | 755                                                   | 1672       | 1330    | 2410    | 1282            | 173        | 2551      | 3126      | 1722      | 3480         | 18 501    |
| FL    | 230 315                                               | 36 591     | 32 071  | 97 212  | 33 622          | 7299       | 128 133   | 83 524    | 104 327   | 137 213      | 890 306   |
| GA    | 39 780                                                | 16 699     | 16 254  | 39 076  | 13 043          | 3563       | 63 430    | 60 062    | 80 180    | 57 586       | 389 672   |
| HI    | 13 773                                                | 979        | 989     | 1838    | 630             | 95         | 2939      | 985       | 1417      | 5220         | 28 865    |
| IA    | 1542                                                  | 6875       | 4598    | 10 749  | 7069            | 796        | 14 534    | 13 586    | 6688      | 11 426       | 77 863    |
| ID    | 2506                                                  | 4001       | 2375    | 7703    | 2478            | 493        | 7526      | 6847      | 3876      | 5343         | 43 147    |
| IL    | 78 609                                                | 18 998     | 14 037  | 31 542  | 18 451          | 2497       | 60 928    | 33 180    | 69 674    | 44 977       | 372 893   |
| IN    | 3875                                                  | 18 600     | 9210    | 18 791  | 14 242          | 2747       | 35 539    | 27 535    | 40 591    | 25 992       | 197 123   |
| KS    | 1057                                                  | 5734       | 3795    | 9442    | 3178            | 1039       | 12 076    | 8892      | 5521      | 7216         | 57 950    |
| KY    | 2888                                                  | 8150       | 6922    | 12 558  | 8185            | 1489       | 17 941    | 13 672    | 21 538    | 11 906       | 105 248   |
| LA    | 1823                                                  | 7001       | 8689    | 12 647  | 6386            | 1454       | 18 681    | 9061      | 10 886    | 14 841       | 91 469    |
| MA    | 31 854                                                | 7832       | 9516    | 11 868  | 6808            | 1306       | 19 079    | 14 599    | 9197      | 26 742       | 138 802   |
| MD    | 35 967                                                | 8750       | 8888    | 30 163  | 6242            | 1173       | 16 672    | 16 432    | 21 414    | 36 463       | 182 163   |
| ME    | 687                                                   | 2245       | 1791    | 2411    | 1441            | 368        | 6088      | 3374      | 3021      | 5320         | 26 745    |
| MI    | 4800                                                  | 19 346     | 7671    | 18 251  | 14 629          | 2153       | 34 934    | 22 151    | 9305      | 26 283       | 159 523   |
| MN    | 15 465                                                | 10 954     | 5093    | 17 575  | 5673            | 1098       | 22 985    | 12 643    | 8643      | 25 212       | 125 342   |
| MO    | 9420                                                  | 10 121     | 9483    | 13 197  | 8395            | 1705       | 27 054    | 17 497    | 8818      | 21 226       | 126 915   |
| MS    | 1613                                                  | 3618       | 5153    | 6789    | 4423            | 587        | 12 551    | 7999      | 17 146    | 7447         | 67 326    |
| MT    | 481                                                   | 1313       | 1265    | 1602    | 1007            | 195        | 2723      | 1871      | 821       | 1533         | 12 810    |
| NC    | 17 294                                                | 14 663     | 12 678  | 36 249  | 12 044          | 2481       | 48 139    | 36 794    | 20 559    | 37 891       | 238 792   |
| ND    | 76                                                    | 1265       | 982     | 1490    | 1221            | 155        | 3567      | 1871      | 617       | 1077         | 12 320    |
| NE    | 1586                                                  | 4880       | 3263    | 6790    | 3562            | 577        | 12 369    | 5533      | 3660      | 7279         | 49 498    |
| NH    | 1523                                                  | 2440       | 2437    | 2974    | 1653            | 548        | 6970      | 4421      | 2059      | 4717         | 29 741    |
| NJ    | 30 209                                                | 8563       | 10 145  | 13 295  | 8335            | 1210       | 26 842    | 28 280    | 32 383    | 27 841       | 187 103   |
| NM    | 957                                                   | 2655       | 4499    | 6636    | 3770            | 670        | 8235      | 8097      | 3142      | 5290         | 43 950    |
| NV    | 30 856                                                | 5684       | 31 894  | 17 504  | 12 863          | 1691       | 25 644    | 10 337    | 17 969    | 34 776       | 189 218   |
| NY    | 125 095                                               | 17 639     | 21 083  | 35 842  | 11 572          | 2259       | 39 107    | 24 186    | 13 845    | 36 104       | 326 732   |
| OH    | 6832                                                  | 26 393     | 9959    | 28 780  | 13 630          | 4004       | 55 245    | 47 919    | 36 400    | 34 909       | 264 071   |
| OK    | 1242                                                  | 8547       | 5511    | 8216    | 9450            | 1523       | 14 686    | 12 691    | 10 032    | 13 680       | 85 577    |
| OR    | 13 492                                                | 9885       | 3878    | 9927    | 4118            | 728        | 14 881    | 7004      | 12 291    | 17 738       | 93 941    |
| PA    | 16 177                                                | 20 535     | 15 135  | 26 096  | 14 577          | 2361       | 40 489    | 39 397    | 37 805    | 38 280       | 250 852   |
| RI    | 2559                                                  | 649        | 2069    | 2707    | 877             | 278        | 2990      | 2125      | 1228      | 2540         | 18 021    |
| SC    | 21 321                                                | 8033       | 6056    | 16 562  | 5801            | 1810       | 27 984    | 23 920    | 11 848    | 22 949       | 146 284   |
| SD    | 142                                                   | 1285       | 922     | 2767    | 1354            | 138        | 3668      | 2884      | 950       | 2202         | 16 312    |
| TN    | 10 621                                                | 11 152     | 7347    | 24 718  | 7891            | 2145       | 38 548    | 19 476    | 29 045    | 25 152       | 176 095   |
| TX    | 59 723                                                | 48 519     | 38 437  | 89 641  | 35 794          | 9142       | 141 238   | 136 629   | 114 193   | 104 156      | 777 473   |
| UT    | 6695                                                  | 6123       | 3384    | 14 698  | 5110            | 822        | 15 331    | 13 657    | 13 716    | 12 926       | 92 462    |
| VA    | 37 694                                                | 10 887     | 14 646  | 39 749  | 11 794          | 2149       | 32 438    | 25 691    | 19 659    | 47 422       | 242 129   |
| VT    | 1736                                                  | 1063       | 1030    | 1214    | 765             | 68         | 674       | 1463      | 946       | 1777         | 10 737    |
| WA    | 36 566                                                | 11 683     | 9378    | 26 209  | 8964            | 1147       | 26 954    | 19 817    | 20 236    | 38 731       | 199 685   |
| WI    | 9754                                                  | 16 350     | 6273    | 16 751  | 8030            | 1474       | 26 793    | 12 148    | 9497      | 21 325       | 128 395   |
| WV    | 697                                                   | 2314       | 1592    | 2081    | 1259            | 421        | 7191      | 5215      | 1930      | 3098         | 25 797    |
| WY    | 42                                                    | 774        | 1787    | 713     | 1370            | 97         | 1696      | 2737      | 718       | 2453         | 12 387    |
| Total | 1 077 585                                             | 517 302    | 441 399 | 991 233 | 414 953         | 82 459     | 1 384 339 | 1 015 925 | 1 063 186 | 1 277 597    | 8 265 977 |

**Table A-4 New Commercial Building Construction Share by State and Building Type**

| State | Percentage of Building Construction Volume |            |        |        |                 |            |        |        |           |              | Total   | Rep. by Study |
|-------|--------------------------------------------|------------|--------|--------|-----------------|------------|--------|--------|-----------|--------------|---------|---------------|
|       | Apartment                                  | Healthcare | Hotel  | Office | Public Assembly | Restaurant | Retail | School | Warehouse | No Prototype |         |               |
| AK    | 1.3 %                                      | 9.0 %      | 8.7 %  | 15.6 % | 7.6 %           | 0.9 %      | 14.4 % | 15.9 % | 8.7 %     | 17.9 %       | 100.0 % | 56.8 %        |
| AL    | 7.1 %                                      | 6.3 %      | 7.6 %  | 13.3 % | 5.7 %           | 1.5 %      | 22.0 % | 13.6 % | 7.5 %     | 15.4 %       | 100.0 % | 65.2 %        |
| AR    | 2.0 %                                      | 7.8 %      | 8.1 %  | 10.9 % | 5.7 %           | 1.3 %      | 22.9 % | 21.8 % | 5.7 %     | 13.7 %       | 100.0 % | 67.1 %        |
| AZ    | 4.4 %                                      | 6.3 %      | 4.4 %  | 16.9 % | 5.0 %           | 1.1 %      | 20.6 % | 9.6 %  | 15.6 %    | 16.0 %       | 100.0 % | 57.1 %        |
| CA    | 13.5 %                                     | 4.6 %      | 4.3 %  | 12.7 % | 4.3 %           | 0.7 %      | 14.7 % | 9.8 %  | 18.4 %    | 17.0 %       | 100.0 % | 55.7 %        |
| CO    | 12.4 %                                     | 8.4 %      | 6.1 %  | 13.1 % | 4.3 %           | 1.2 %      | 17.6 % | 10.0 % | 9.4 %     | 17.5 %       | 100.0 % | 60.4 %        |
| CT    | 8.5 %                                      | 5.6 %      | 6.8 %  | 8.6 %  | 7.1 %           | 0.9 %      | 17.2 % | 16.5 % | 11.3 %    | 17.6 %       | 100.0 % | 58.5 %        |
| DC    | 28.7 %                                     | 1.7 %      | 2.7 %  | 35.7 % | 2.7 %           | 0.1 %      | 2.5 %  | 4.7 %  | 0.8 %     | 20.3 %       | 100.0 % | 74.4 %        |
| DE    | 4.1 %                                      | 9.0 %      | 7.2 %  | 13.0 % | 6.9 %           | 0.9 %      | 13.8 % | 16.9 % | 9.3 %     | 18.8 %       | 100.0 % | 55.9 %        |
| FL    | 25.9 %                                     | 4.1 %      | 3.6 %  | 10.9 % | 3.8 %           | 0.8 %      | 14.4 % | 9.4 %  | 11.7 %    | 15.4 %       | 100.0 % | 65.0 %        |
| GA    | 10.2 %                                     | 4.3 %      | 4.2 %  | 10.0 % | 3.3 %           | 0.9 %      | 16.3 % | 15.4 % | 20.6 %    | 14.8 %       | 100.0 % | 57.0 %        |
| HI    | 47.7 %                                     | 3.4 %      | 3.4 %  | 6.4 %  | 2.2 %           | 0.3 %      | 10.2 % | 3.4 %  | 4.9 %     | 18.1 %       | 100.0 % | 71.4 %        |
| IA    | 2.0 %                                      | 8.8 %      | 5.9 %  | 13.8 % | 9.1 %           | 1.0 %      | 18.7 % | 17.4 % | 8.6 %     | 14.7 %       | 100.0 % | 58.8 %        |
| ID    | 5.8 %                                      | 9.3 %      | 5.5 %  | 17.9 % | 5.7 %           | 1.1 %      | 17.4 % | 15.9 % | 9.0 %     | 12.4 %       | 100.0 % | 63.6 %        |
| IL    | 21.1 %                                     | 5.1 %      | 3.8 %  | 8.5 %  | 4.9 %           | 0.7 %      | 16.3 % | 8.9 %  | 18.7 %    | 12.1 %       | 100.0 % | 59.2 %        |
| IN    | 2.0 %                                      | 9.4 %      | 4.7 %  | 9.5 %  | 7.2 %           | 1.4 %      | 18.0 % | 14.0 % | 20.6 %    | 13.2 %       | 100.0 % | 49.6 %        |
| KS    | 1.8 %                                      | 9.9 %      | 6.5 %  | 16.3 % | 5.5 %           | 1.8 %      | 20.8 % | 15.3 % | 9.5 %     | 12.5 %       | 100.0 % | 62.6 %        |
| KY    | 2.7 %                                      | 7.7 %      | 6.6 %  | 11.9 % | 7.8 %           | 1.4 %      | 17.0 % | 13.0 % | 20.5 %    | 11.3 %       | 100.0 % | 52.7 %        |
| LA    | 2.0 %                                      | 7.7 %      | 9.5 %  | 13.8 % | 7.0 %           | 1.6 %      | 20.4 % | 9.9 %  | 11.9 %    | 16.2 %       | 100.0 % | 57.2 %        |
| MA    | 22.9 %                                     | 5.6 %      | 6.9 %  | 8.6 %  | 4.9 %           | 0.9 %      | 13.7 % | 10.5 % | 6.6 %     | 19.3 %       | 100.0 % | 63.6 %        |
| MD    | 19.7 %                                     | 4.8 %      | 4.9 %  | 16.6 % | 3.4 %           | 0.6 %      | 9.2 %  | 9.0 %  | 11.8 %    | 20.0 %       | 100.0 % | 60.0 %        |
| ME    | 2.6 %                                      | 8.4 %      | 6.7 %  | 9.0 %  | 5.4 %           | 1.4 %      | 22.8 % | 12.6 % | 11.3 %    | 19.9 %       | 100.0 % | 55.0 %        |
| MI    | 3.0 %                                      | 12.1 %     | 4.8 %  | 11.4 % | 9.2 %           | 1.3 %      | 21.9 % | 13.9 % | 5.8 %     | 16.5 %       | 100.0 % | 56.4 %        |
| MN    | 12.3 %                                     | 8.7 %      | 4.1 %  | 14.0 % | 4.5 %           | 0.9 %      | 18.3 % | 10.1 % | 6.9 %     | 20.1 %       | 100.0 % | 59.7 %        |
| MO    | 7.4 %                                      | 8.0 %      | 7.5 %  | 10.4 % | 6.6 %           | 1.3 %      | 21.3 % | 13.8 % | 6.9 %     | 16.7 %       | 100.0 % | 61.7 %        |
| MS    | 2.4 %                                      | 5.4 %      | 7.7 %  | 10.1 % | 6.6 %           | 0.9 %      | 18.6 % | 11.9 % | 25.5 %    | 11.1 %       | 100.0 % | 51.5 %        |
| MT    | 3.8 %                                      | 10.2 %     | 9.9 %  | 12.5 % | 7.9 %           | 1.5 %      | 21.3 % | 14.6 % | 6.4 %     | 12.0 %       | 100.0 % | 63.5 %        |
| NC    | 7.2 %                                      | 6.1 %      | 5.3 %  | 15.2 % | 5.0 %           | 1.0 %      | 20.2 % | 15.4 % | 8.6 %     | 15.9 %       | 100.0 % | 64.3 %        |
| ND    | 0.6 %                                      | 10.3 %     | 8.0 %  | 12.1 % | 9.9 %           | 1.3 %      | 29.0 % | 15.2 % | 5.0 %     | 8.7 %        | 100.0 % | 66.1 %        |
| NE    | 3.2 %                                      | 9.9 %      | 6.6 %  | 13.7 % | 7.2 %           | 1.2 %      | 25.0 % | 11.2 % | 7.4 %     | 14.7 %       | 100.0 % | 60.8 %        |
| NH    | 5.1 %                                      | 8.2 %      | 8.2 %  | 10.0 % | 5.6 %           | 1.8 %      | 23.4 % | 14.9 % | 6.9 %     | 15.9 %       | 100.0 % | 63.5 %        |
| NJ    | 16.1 %                                     | 4.6 %      | 5.4 %  | 7.1 %  | 4.5 %           | 0.6 %      | 14.3 % | 15.1 % | 17.3 %    | 14.9 %       | 100.0 % | 58.8 %        |
| NM    | 2.2 %                                      | 6.0 %      | 10.2 % | 15.1 % | 8.6 %           | 1.5 %      | 18.7 % | 18.4 % | 7.1 %     | 12.0 %       | 100.0 % | 66.2 %        |
| NV    | 16.3 %                                     | 3.0 %      | 16.9 % | 9.3 %  | 6.8 %           | 0.9 %      | 13.6 % | 5.5 %  | 9.5 %     | 18.4 %       | 100.0 % | 62.3 %        |
| NY    | 38.3 %                                     | 5.4 %      | 6.5 %  | 11.0 % | 3.5 %           | 0.7 %      | 12.0 % | 7.4 %  | 4.2 %     | 11.1 %       | 100.0 % | 75.8 %        |
| OH    | 2.6 %                                      | 10.0 %     | 3.8 %  | 10.9 % | 5.2 %           | 1.5 %      | 20.9 % | 18.1 % | 13.8 %    | 13.2 %       | 100.0 % | 57.8 %        |
| OK    | 1.5 %                                      | 10.0 %     | 6.4 %  | 9.6 %  | 11.0 %          | 1.8 %      | 17.2 % | 14.8 % | 11.7 %    | 16.0 %       | 100.0 % | 51.3 %        |
| OR    | 14.4 %                                     | 10.5 %     | 4.1 %  | 10.6 % | 4.4 %           | 0.8 %      | 15.8 % | 7.5 %  | 13.1 %    | 18.9 %       | 100.0 % | 53.1 %        |
| PA    | 6.4 %                                      | 8.2 %      | 6.0 %  | 10.4 % | 5.8 %           | 0.9 %      | 16.1 % | 15.7 % | 15.1 %    | 15.3 %       | 100.0 % | 55.7 %        |
| RI    | 14.2 %                                     | 3.6 %      | 11.5 % | 15.0 % | 4.9 %           | 1.5 %      | 16.6 % | 11.8 % | 6.8 %     | 14.1 %       | 100.0 % | 70.6 %        |
| SC    | 14.6 %                                     | 5.5 %      | 4.1 %  | 11.3 % | 4.0 %           | 1.2 %      | 19.1 % | 16.4 % | 8.1 %     | 15.7 %       | 100.0 % | 66.8 %        |
| SD    | 0.9 %                                      | 7.9 %      | 5.7 %  | 17.0 % | 8.3 %           | 0.8 %      | 22.5 % | 17.7 % | 5.8 %     | 13.5 %       | 100.0 % | 64.5 %        |
| TN    | 6.0 %                                      | 6.3 %      | 4.2 %  | 14.0 % | 4.5 %           | 1.2 %      | 21.9 % | 11.1 % | 16.5 %    | 14.3 %       | 100.0 % | 58.4 %        |
| TX    | 7.7 %                                      | 6.2 %      | 4.9 %  | 11.5 % | 4.6 %           | 1.2 %      | 18.2 % | 17.6 % | 14.7 %    | 13.4 %       | 100.0 % | 61.1 %        |
| UT    | 7.2 %                                      | 6.6 %      | 3.7 %  | 15.9 % | 5.5 %           | 0.9 %      | 16.6 % | 14.8 % | 14.8 %    | 14.0 %       | 100.0 % | 59.0 %        |
| VA    | 15.6 %                                     | 4.5 %      | 6.0 %  | 16.4 % | 4.9 %           | 0.9 %      | 13.4 % | 10.6 % | 8.1 %     | 19.6 %       | 100.0 % | 62.9 %        |
| VT    | 16.2 %                                     | 9.9 %      | 9.6 %  | 11.3 % | 7.1 %           | 0.6 %      | 6.3 %  | 13.6 % | 8.8 %     | 16.6 %       | 100.0 % | 57.6 %        |
| WA    | 18.3 %                                     | 5.9 %      | 4.7 %  | 13.1 % | 4.5 %           | 0.6 %      | 13.5 % | 9.9 %  | 10.1 %    | 19.4 %       | 100.0 % | 60.1 %        |
| WI    | 7.6 %                                      | 12.7 %     | 4.9 %  | 13.0 % | 6.3 %           | 1.1 %      | 20.9 % | 9.5 %  | 7.4 %     | 16.6 %       | 100.0 % | 57.0 %        |
| WV    | 2.7 %                                      | 9.0 %      | 6.2 %  | 8.1 %  | 4.9 %           | 1.6 %      | 27.9 % | 20.2 % | 7.5 %     | 12.0 %       | 100.0 % | 66.7 %        |
| WY    | 0.3 %                                      | 6.2 %      | 14.4 % | 5.8 %  | 11.1 %          | 0.8 %      | 13.7 % | 22.1 % | 5.8 %     | 19.8 %       | 100.0 % | 57.1 %        |
| Total | 13.0 %                                     | 6.3 %      | 5.3 %  | 12.0 % | 5.0 %           | 1.0 %      | 16.7 % | 12.3 % | 12.9 %    | 15.5 %       | 100.0 % | 60.4 %        |

**Table A-5 CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O Emissions Rates Electricity Generation by State**

| State | CO <sub>2</sub><br>(t/GWh) | CH <sub>4</sub><br>(t/GWh) | N <sub>2</sub> O<br>(t/GWh) |
|-------|----------------------------|----------------------------|-----------------------------|
| AK    | 603.4                      | 57.9                       | 1.9                         |
| AL    | 804.2                      | 42.7                       | 0.5                         |
| AR    | 695.9                      | 58.6                       | 1.7                         |
| AZ    | 746.9                      | 53.2                       | 1.2                         |
| CA    | 450.0                      | 45.8                       | 1.5                         |
| CO    | 938.8                      | 54.0                       | 0.8                         |
| CT    | 550.4                      | 47.0                       | 1.4                         |
| DE    | 618.7                      | 33.4                       | 0.4                         |
| FL    | 767.5                      | 57.2                       | 1.5                         |
| GA    | 804.2                      | 42.7                       | 0.5                         |
| HI    | 807.1                      | 28.0                       | 0.1                         |
| IA    | 851.1                      | 40.4                       | 0.2                         |
| ID    | 465.6                      | 27.6                       | 0.4                         |
| IL    | 948.3                      | 44.4                       | 0.2                         |
| IN    | 835.7                      | 38.9                       | 0.2                         |
| KS    | 926.0                      | 44.8                       | 0.3                         |
| KY    | 781.9                      | 36.9                       | 0.2                         |
| LA    | 719.2                      | 59.2                       | 1.6                         |
| MA    | 550.4                      | 47.0                       | 1.4                         |
| MD    | 618.7                      | 33.4                       | 0.4                         |
| ME    | 550.4                      | 47.0                       | 1.4                         |
| MI    | 861.4                      | 46.8                       | 0.6                         |
| MN    | 851.1                      | 40.4                       | 0.2                         |
| MO    | 939.4                      | 44.6                       | 0.2                         |
| MS    | 709.8                      | 48.3                       | 1.0                         |

| State | CO <sub>2</sub><br>(t/GWh) | CH <sub>4</sub><br>(t/GWh) | N <sub>2</sub> O<br>(t/GWh) |
|-------|----------------------------|----------------------------|-----------------------------|
| MT    | 542.8                      | 30.1                       | 0.4                         |
| NC    | 616.6                      | 30.5                       | 0.2                         |
| ND    | 851.1                      | 40.4                       | 0.2                         |
| NE    | 851.1                      | 40.4                       | 0.2                         |
| NH    | 550.4                      | 47.0                       | 1.4                         |
| NJ    | 618.7                      | 33.4                       | 0.4                         |
| NM    | 778.5                      | 55.3                       | 1.3                         |
| NV    | 465.6                      | 27.6                       | 0.4                         |
| NY    | 480.7                      | 32.3                       | 0.8                         |
| OH    | 835.7                      | 38.9                       | 0.2                         |
| OK    | 904.8                      | 63.9                       | 1.4                         |
| OR    | 465.6                      | 27.6                       | 0.4                         |
| PA    | 672.9                      | 34.7                       | 0.4                         |
| RI    | 550.4                      | 47.0                       | 1.4                         |
| SC    | 616.6                      | 30.5                       | 0.2                         |
| SD    | 851.1                      | 40.4                       | 0.2                         |
| TN    | 781.9                      | 36.9                       | 0.2                         |
| TX    | 790.9                      | 65.8                       | 1.8                         |
| UT    | 465.6                      | 27.6                       | 0.4                         |
| VA    | 689.6                      | 33.3                       | 0.2                         |
| VT    | 550.4                      | 47.0                       | 1.4                         |
| WA    | 465.6                      | 27.6                       | 0.4                         |
| WI    | 860.7                      | 44.1                       | 0.4                         |
| WV    | 835.7                      | 38.9                       | 0.2                         |
| WY    | 623.7                      | 36.4                       | 0.5                         |



## B Percentage Changes by Building Type for the Nationwide Adoption of the LEC Design

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

| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |             |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|-------------|
|       | Energy Use        | Energy Cost | Carbon | LCC  |             | Energy Use        | Energy Cost  | Carbon       | LCC         |
| AK    | -12.7             | -31.2       | -25.0  | -1.7 | MT          | -9.6              | -15.2        | -14.5        | 0.6         |
| AL    | -35.2             | -40.3       | -42.9  | -3.4 | NC          | -13.5             | -17.0        | -18.1        | 0.4         |
| AR    | -29.0             | -36.6       | -39.4  | -1.8 | ND          | -17.5             | -30.8        | -33.4        | -1.0        |
| AZ    | -26.6             | -31.1       | -32.4  | -1.6 | NE          | -9.8              | -16.3        | -17.2        | 0.7         |
| CA    | -16.1             | -22.5       | -19.8  | 0.2  | NH          | -9.5              | -15.8        | -14.7        | -0.3        |
| CO    | -21.9             | -36.2       | -37.9  | -1.2 | NJ          | -10.3             | -17.8        | -16.0        | 0.4         |
| CT    | -9.5              | -18.5       | -15.1  | -0.1 | NM          | -13.6             | -20.0        | -20.0        | 0.5         |
| DE    | -10.4             | -15.0       | -16.0  | -0.2 | NV          | -14.5             | -20.7        | -18.8        | -0.1        |
| FL    | -16.6             | -17.7       | -17.8  | -0.3 | NY          | -9.2              | -17.5        | -13.8        | 0.0         |
| GA    | -14.3             | -17.7       | -18.8  | 0.4  | OH          | -9.6              | -16.0        | -17.1        | 0.5         |
| HI    | -20.4             | -20.4       | -20.4  | -1.7 | OK          | -27.2             | -35.1        | -40.8        | -1.3        |
| IA    | -9.8              | -15.8       | -16.8  | 0.5  | OR          | -10.0             | -15.0        | -15.4        | 1.1         |
| ID    | -10.2             | -14.8       | -14.9  | 0.8  | PA          | -9.5              | -14.9        | -16.0        | 0.6         |
| IL    | -9.4              | -17.1       | -17.1  | 0.3  | RI          | -9.2              | -15.5        | -15.1        | 0.2         |
| IN    | -10.1             | -16.0       | -17.1  | 0.6  | SC          | -18.0             | -22.6        | -23.2        | -0.1        |
| KS    | -24.9             | -35.3       | -39.1  | -1.6 | SD          | -21.2             | -34.1        | -35.9        | -1.7        |
| KY    | -11.5             | -15.6       | -17.9  | 0.7  | TN          | -16.1             | -20.5        | -21.3        | -0.1        |
| LA    | -15.4             | -17.6       | -18.3  | 0.5  | TX          | -15.0             | -18.6        | -18.6        | 0.0         |
| MA    | -9.1              | -16.8       | -14.8  | 0.1  | UT          | -10.7             | -17.6        | -15.7        | 0.7         |
| MD    | -10.9             | -17.1       | -16.4  | 0.2  | VA          | -12.6             | -17.0        | -18.1        | 0.5         |
| ME    | -19.9             | -32.9       | -31.9  | -2.6 | VT          | -9.5              | -15.5        | -14.6        | -0.2        |
| MI    | -8.5              | -15.2       | -16.3  | 0.4  | WA          | -8.8              | -12.8        | -14.0        | 1.2         |
| MN    | -13.8             | -18.0       | -18.6  | 0.2  | WI          | -9.5              | -15.9        | -16.4        | 0.4         |
| MO    | -25.4             | -33.3       | -38.6  | -1.0 | WV          | -25.3             | -29.8        | -38.9        | -0.8        |
| MS    | -35.7             | -42.4       | -42.6  | -3.3 | WY          | -22.7             | -36.6        | -36.4        | -1.4        |
|       |                   |             |        |      | <b>Avg.</b> | <b>-14.8</b>      | <b>-21.2</b> | <b>-21.6</b> | <b>-0.1</b> |

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

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

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

| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |             |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|-------------|
|       | Energy Use        | Energy Cost | Carbon | LCC  |             | Energy Use        | Energy Cost  | Carbon       | LCC         |
| AK    | -18.1             | -34.8       | -29.3  | -2.4 | MT          | -12.9             | -17.1        | -16.6        | -1.2        |
| AL    | -36.7             | -41.7       | -44.2  | -2.9 | NC          | -14.8             | -17.7        | -18.5        | -0.7        |
| AR    | -28.8             | -37.1       | -40.0  | -4.9 | ND          | -21.6             | -33.7        | -36.0        | 0.3         |
| AZ    | -29.1             | -32.1       | -32.9  | -1.6 | NE          | -11.7             | -17.2        | -17.9        | -0.2        |
| CA    | -18.2             | -22.3       | -20.6  | -1.3 | NH          | -12.2             | -17.0        | -16.2        | -1.7        |
| CO    | -24.9             | -36.6       | -37.9  | -4.2 | NJ          | -12.3             | -18.6        | -17.2        | -0.8        |
| CT    | -11.2             | -18.9       | -16.1  | -1.6 | NM          | -15.3             | -19.8        | -19.8        | -1.6        |
| DE    | -12.3             | -16.3       | -17.2  | -0.5 | NV          | -17.1             | -21.1        | -19.9        | -1.9        |
| FL    | -17.4             | -18.4       | -18.5  | -2.1 | NY          | -11.1             | -18.2        | -15.1        | -1.5        |
| GA    | -15.1             | -18.1       | -19.1  | -1.2 | OH          | -11.2             | -16.9        | -17.8        | -1.2        |
| HI    | -22.1             | -22.1       | -22.1  | -3.6 | OK          | -27.6             | -36.1        | -42.2        | 0.0         |
| IA    | -11.7             | -16.7       | -17.5  | -0.2 | OR          | -12.7             | -16.7        | -17.0        | -1.0        |
| ID    | -12.7             | -16.4       | -16.5  | -1.2 | PA          | -11.1             | -15.9        | -16.8        | -0.8        |
| IL    | -11.1             | -17.8       | -17.8  | -0.3 | RI          | -11.3             | -16.7        | -16.4        | -1.4        |
| IN    | -11.8             | -16.9       | -17.9  | -0.4 | SC          | -16.9             | -21.7        | -22.3        | -1.3        |
| KS    | -27.6             | -37.1       | -40.4  | 0.3  | SD          | -24.0             | -35.7        | -37.3        | -1.4        |
| KY    | -12.9             | -16.4       | -18.3  | -1.0 | TN          | -17.3             | -20.4        | -20.9        | -1.1        |
| LA    | -15.5             | -17.8       | -18.5  | -0.8 | TX          | -15.5             | -18.6        | -18.7        | -0.9        |
| MA    | -11.1             | -17.8       | -16.1  | -1.3 | UT          | -12.8             | -18.2        | -16.8        | -1.2        |
| MD    | -12.5             | -17.8       | -17.2  | -0.2 | VA          | -14.3             | -17.9        | -18.7        | -0.7        |
| ME    | -24.4             | -35.6       | -34.9  | -1.6 | VT          | -11.9             | -16.7        | -15.9        | -1.6        |
| MI    | -10.7             | -16.5       | -17.4  | -1.2 | WA          | -11.6             | -15.0        | -16.0        | -0.5        |
| MN    | -19.0             | -20.7       | -20.9  | -1.5 | WI          | -12.0             | -17.0        | -17.4        | -0.8        |
| MO    | -27.4             | -35.0       | -39.8  | 0.2  | WV          | -26.7             | -31.0        | -38.8        | -3.3        |
| MS    | -39.0             | -44.2       | -44.4  | -1.8 | WY          | -26.9             | -38.4        | -38.3        | -0.9        |
|       |                   |             |        |      | <b>Avg.</b> | <b>-16.9</b>      | <b>-22.2</b> | <b>-22.6</b> | <b>-1.2</b> |

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

| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |             |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|-------------|
|       | Energy Use        | Energy Cost | Carbon | LCC  |             | Energy Use        | Energy Cost  | Carbon       | LCC         |
| AK    | -11.1             | -30.0       | -23.7  | -2.2 | MT          | -8.6              | -13.6        | -12.9        | 0.3         |
| AL    | -37.9             | -43.7       | -46.7  | -4.9 | NC          | -14.7             | -19.1        | -20.4        | -0.1        |
| AR    | -30.8             | -39.1       | -42.1  | -2.9 | ND          | -16.6             | -28.8        | -31.2        | -1.6        |
| AZ    | -28.3             | -33.6       | -35.1  | -2.4 | NE          | -10.9             | -18.8        | -19.8        | 0.3         |
| CA    | -17.9             | -26.3       | -22.7  | -0.4 | NH          | -8.4              | -13.8        | -12.9        | -0.5        |
| CO    | -20.7             | -36.0       | -37.9  | -1.8 | NJ          | -11.4             | -20.4        | -18.3        | -0.2        |
| CT    | -10.4             | -21.2       | -17.2  | -0.7 | NM          | -15.2             | -22.8        | -22.9        | -0.1        |
| DE    | -11.3             | -16.9       | -18.0  | -0.8 | NV          | -14.1             | -22.1        | -19.6        | -0.4        |
| FL    | -18.4             | -20.0       | -20.1  | -0.9 | NY          | -9.1              | -18.3        | -14.3        | -0.4        |
| GA    | -15.5             | -19.7       | -21.2  | -0.1 | OH          | -10.3             | -17.9        | -19.2        | 0.1         |
| HI    | -23.0             | -23.0       | -23.0  | -2.5 | OK          | -29.9             | -38.5        | -44.8        | -2.6        |
| IA    | -10.0             | -16.4       | -17.4  | 0.2  | OR          | -10.6             | -16.7        | -17.1        | 0.7         |
| ID    | -10.6             | -15.6       | -15.7  | 0.5  | PA          | -10.3             | -16.8        | -18.0        | 0.2         |
| IL    | -10.3             | -19.4       | -19.4  | -0.2 | RI          | -9.7              | -17.2        | -16.7        | -0.3        |
| IN    | -11.0             | -18.1       | -19.4  | 0.2  | SC          | -20.2             | -26.0        | -26.8        | -0.7        |
| KS    | -24.8             | -36.3       | -40.4  | -2.6 | SD          | -17.3             | -30.6        | -32.5        | -2.0        |
| KY    | -12.9             | -17.9       | -20.6  | 0.2  | TN          | -16.1             | -21.9        | -22.9        | -0.5        |
| LA    | -16.7             | -19.6       | -20.6  | 0.0  | TX          | -16.3             | -20.9        | -20.9        | -0.6        |
| MA    | -9.5              | -18.7       | -16.4  | -0.3 | UT          | -12.0             | -20.1        | -18.0        | 0.3         |
| MD    | -12.0             | -19.7       | -18.8  | -0.4 | VA          | -14.2             | -19.6        | -20.8        | 0.0         |
| ME    | -18.0             | -30.6       | -29.7  | -3.1 | VT          | -8.2              | -13.4        | -12.6        | -0.3        |
| MI    | -8.5              | -15.9       | -17.1  | 0.1  | WA          | -9.2              | -14.1        | -15.5        | 0.9         |
| MN    | -11.3             | -15.2       | -15.7  | 0.2  | WI          | -8.2              | -13.7        | -14.2        | 0.2         |
| MO    | -26.0             | -34.9       | -40.6  | -1.9 | WV          | -24.4             | -29.6        | -39.1        | -1.4        |
| MS    | -38.2             | -45.6       | -45.9  | -4.7 | WY          | -19.1             | -33.4        | -33.2        | -1.8        |
|       |                   |             |        |      | <b>Avg.</b> | <b>-15.2</b>      | <b>-22.4</b> | <b>-22.8</b> | <b>-0.6</b> |

**Table B-5 15-Story Hotel Building Summary Table for LEC and 10-Year Study Period**

| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |             |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|-------------|
|       | Energy Use        | Energy Cost | Carbon | LCC  |             | Energy Use        | Energy Cost  | Carbon       | LCC         |
| AK    | -6.9              | -23.5       | -18.0  | -1.8 | MT          | -9.4              | -11.5        | -11.3        | 0.4         |
| AL    | -30.3             | -36.2       | -39.2  | -3.0 | NC          | -14.9             | -18.4        | -19.4        | 0.3         |
| AR    | -21.5             | -32.1       | -36.0  | -1.6 | ND          | -10.0             | -20.8        | -22.8        | -1.1        |
| AZ    | -23.1             | -26.4       | -27.3  | -1.0 | NE          | -12.7             | -18.9        | -19.7        | 0.6         |
| CA    | -18.2             | -24.5       | -21.8  | 0.0  | NH          | -8.9              | -11.2        | -10.8        | -0.2        |
| CO    | -16.0             | -28.8       | -30.3  | -1.1 | NJ          | -13.1             | -20.2        | -18.6        | 0.1         |
| CT    | -12.7             | -21.6       | -18.3  | -0.5 | NM          | -15.7             | -21.1        | -21.1        | 0.4         |
| DE    | -13.1             | -17.6       | -18.5  | -0.6 | NV          | -8.8              | -14.7        | -13.0        | 0.7         |
| FL    | -16.7             | -18.8       | -19.0  | -0.1 | NY          | -11.2             | -18.0        | -15.0        | -0.2        |
| GA    | -14.5             | -18.5       | -19.9  | 0.4  | OH          | -11.8             | -18.1        | -19.2        | 0.4         |
| HI    | -18.0             | -18.1       | -18.1  | -0.6 | OK          | -19.7             | -29.9        | -37.5        | -1.2        |
| IA    | -11.0             | -15.3       | -16.0  | 0.5  | OR          | -13.8             | -18.4        | -18.8        | 0.9         |
| ID    | -12.3             | -15.9       | -15.9  | 0.7  | PA          | -11.8             | -17.1        | -18.2        | 0.4         |
| IL    | -11.8             | -19.2       | -19.2  | 0.2  | RI          | -12.1             | -18.1        | -17.7        | -0.1        |
| IN    | -12.3             | -18.1       | -19.2  | 0.5  | SC          | -8.5              | -14.6        | -15.4        | 0.9         |
| KS    | -19.7             | -29.4       | -32.9  | -1.5 | SD          | -11.8             | -21.8        | -23.2        | -1.3        |
| KY    | -13.7             | -17.6       | -19.8  | 0.6  | TN          | -9.6              | -13.6        | -14.3        | 0.8         |
| LA    | -14.5             | -18.1       | -19.3  | 0.6  | TX          | -14.9             | -19.6        | -19.6        | 0.0         |
| MA    | -11.8             | -19.3       | -17.4  | -0.1 | UT          | -14.2             | -20.2        | -18.6        | 0.6         |
| MD    | -13.4             | -19.4       | -18.7  | -0.1 | VA          | -14.9             | -18.8        | -19.8        | 0.4         |
| ME    | -14.0             | -23.1       | -22.5  | -2.3 | VT          | -9.0              | -11.3        | -11.0        | -0.1        |
| MI    | -10.1             | -15.5       | -16.4  | 0.2  | WA          | -12.3             | -16.2        | -17.2        | 1.1         |
| MN    | -6.8              | -6.8        | -6.8   | 0.9  | WI          | -8.9              | -11.2        | -11.4        | 0.4         |
| MO    | -19.8             | -27.5       | -32.6  | -0.9 | WV          | -18.9             | -23.4        | -32.3        | -0.6        |
| MS    | -34.4             | -37.0       | -37.1  | -2.8 | WY          | -13.8             | -24.7        | -24.6        | -1.3        |
|       |                   |             |        |      | <b>Avg.</b> | <b>-13.9</b>      | <b>-19.6</b> | <b>-20.0</b> | <b>-0.1</b> |

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

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

**Table B-7 8-Story Office Building Summary Table for LEC and 10-Year Study Period**

| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |             |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|-------------|
|       | Energy Use        | Energy Cost | Carbon | LCC  |             | Energy Use        | Energy Cost  | Carbon       | LCC         |
| AK    | -21.3             | -25.8       | -24.6  | 0.0  | MT          | -16.9             | -18.1        | -18.0        | -1.5        |
| AL    | -31.7             | -32.2       | -32.4  | -0.7 | NC          | -20.2             | -20.9        | -21.1        | -1.9        |
| AR    | -30.0             | -31.4       | -31.9  | -5.2 | ND          | -26.0             | -28.1        | -28.4        | 1.3         |
| AZ    | -28.1             | -28.0       | -28.0  | -2.3 | NE          | -18.5             | -21.2        | -21.5        | -2.2        |
| CA    | -21.4             | -21.9       | -21.8  | -2.8 | NH          | -16.9             | -18.2        | -18.1        | -2.2        |
| CO    | -28.3             | -29.7       | -29.9  | -5.1 | NJ          | -19.5             | -21.4        | -21.1        | -2.5        |
| CT    | -18.3             | -21.3       | -20.5  | -2.7 | NM          | -21.4             | -22.5        | -22.5        | -2.8        |
| DE    | -19.7             | -21.1       | -21.3  | -3.2 | NV          | -23.0             | -23.4        | -23.3        | -3.6        |
| FL    | -20.1             | -20.2       | -20.2  | -2.6 | NY          | -17.0             | -20.1        | -19.0        | -2.5        |
| GA    | -19.5             | -20.2       | -20.4  | -1.7 | OH          | -17.9             | -20.6        | -20.9        | -2.2        |
| HI    | -21.3             | -21.3       | -21.3  | -3.6 | OK          | -31.2             | -32.9        | -34.0        | 0.9         |
| IA    | -17.3             | -19.6       | -19.8  | -1.5 | OR          | -20.9             | -22.0        | -22.0        | -3.0        |
| ID    | -19.3             | -20.4       | -20.4  | -2.4 | PA          | -18.0             | -20.3        | -20.6        | -2.4        |
| IL    | -17.8             | -21.0       | -21.0  | -2.2 | RI          | -18.9             | -21.0        | -20.9        | -2.4        |
| IN    | -18.5             | -20.8       | -21.1  | -2.0 | SC          | -21.7             | -21.9        | -22.0        | -2.2        |
| KS    | -32.5             | -33.1       | -33.3  | 0.3  | SD          | -26.8             | -28.4        | -28.6        | -0.5        |
| KY    | -19.5             | -20.8       | -21.4  | -2.4 | TN          | -23.4             | -22.7        | -22.6        | -3.0        |
| LA    | -19.9             | -20.2       | -20.3  | -1.8 | TX          | -19.9             | -20.5        | -20.5        | -2.6        |
| MA    | -18.3             | -21.1       | -20.6  | -2.5 | UT          | -20.7             | -22.5        | -22.1        | -2.6        |
| MD    | -19.7             | -21.4       | -21.2  | -2.9 | VA          | -20.8             | -21.7        | -21.9        | -2.2        |
| ME    | -28.1             | -29.2       | -29.1  | 0.0  | VT          | -16.5             | -18.0        | -17.8        | -2.0        |
| MI    | -16.7             | -19.6       | -19.8  | -2.2 | WA          | -20.0             | -21.1        | -21.3        | -2.3        |
| MN    | -21.4             | -19.8       | -19.6  | -1.3 | WI          | -16.4             | -18.0        | -18.1        | -1.2        |
| MO    | -32.3             | -32.5       | -32.6  | 0.4  | WV          | -30.1             | -30.4        | -30.3        | -4.8        |
| MS    | -32.4             | -32.0       | -31.9  | 1.1  | WY          | -29.2             | -30.1        | -30.0        | 0.7         |
|       |                   |             |        |      | <b>Avg.</b> | <b>-21.5</b>      | <b>-22.8</b> | <b>-22.8</b> | <b>-2.1</b> |

**Table B-8 16-Story Office Building Summary Table for LEC and 10-Year Study Period**

| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |            |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|------------|
|       | Energy Use        | Energy Cost | Carbon | LCC  |             | Energy Use        | Energy Cost  | Carbon       | LCC        |
| AK    | -8.1              | -14.9       | -12.9  | -0.2 | MT          | -11.7             | -12.5        | -12.5        | 0.4        |
| AL    | -23.3             | -25.1       | -26.0  | -1.0 | NC          | -17.2             | -19.1        | -19.6        | 0.4        |
| AR    | -18.2             | -23.8       | -25.7  | 0.0  | ND          | -9.9              | -13.5        | -14.1        | 0.4        |
| AZ    | -19.6             | -20.5       | -20.8  | 0.0  | NE          | -15.2             | -20.2        | -20.7        | 0.8        |
| CA    | -19.8             | -21.8       | -21.0  | -0.1 | NH          | -11.3             | -12.3        | -12.2        | -0.6       |
| CO    | -15.7             | -21.2       | -21.7  | 0.1  | NJ          | -16.0             | -21.0        | -20.1        | -0.1       |
| CT    | -15.2             | -21.6       | -19.6  | -0.9 | NM          | -18.9             | -21.7        | -21.7        | 0.3        |
| DE    | -16.0             | -19.4       | -19.9  | -1.0 | NV          | -12.5             | -16.0        | -15.1        | 0.7        |
| FL    | -17.6             | -18.5       | -18.5  | -0.2 | NY          | -13.9             | -18.7        | -16.9        | -0.6       |
| GA    | -16.5             | -18.4       | -19.1  | 0.5  | OH          | -14.4             | -19.5        | -20.2        | 0.5        |
| HI    | -16.4             | -16.4       | -16.4  | -0.6 | OK          | -17.3             | -23.0        | -26.9        | 0.3        |
| IA    | -13.0             | -16.2       | -16.6  | 0.6  | OR          | -17.8             | -20.9        | -21.1        | 1.0        |
| ID    | -15.3             | -17.7       | -17.8  | 0.9  | PA          | -14.4             | -18.9        | -19.6        | 0.4        |
| IL    | -13.9             | -19.8       | -19.8  | 0.2  | RI          | -15.3             | -20.0        | -19.7        | -0.3       |
| IN    | -15.0             | -19.7       | -20.4  | 0.6  | SC          | -12.1             | -15.5        | -15.9        | 1.0        |
| KS    | -17.1             | -21.6       | -23.1  | 0.3  | SD          | -10.1             | -13.2        | -13.6        | 0.2        |
| KY    | -16.2             | -19.3       | -20.7  | 0.7  | TN          | -12.3             | -15.0        | -15.4        | 0.8        |
| LA    | -16.6             | -18.3       | -18.8  | 0.7  | TX          | -16.8             | -19.1        | -19.1        | -0.1       |
| MA    | -14.4             | -20.2       | -19.0  | -0.3 | UT          | -17.5             | -21.7        | -20.8        | 0.6        |
| MD    | -16.0             | -20.1       | -19.7  | -0.3 | VA          | -18.0             | -20.6        | -21.1        | 0.4        |
| ME    | -13.9             | -15.9       | -15.8  | -0.7 | VT          | -11.3             | -12.3        | -12.2        | -0.4       |
| MI    | -12.6             | -16.9       | -17.5  | 0.2  | WA          | -16.2             | -19.1        | -19.8        | 1.4        |
| MN    | -8.7              | -7.8        | -7.7   | 1.0  | WI          | -10.9             | -11.9        | -12.0        | 0.3        |
| MO    | -16.3             | -20.0       | -22.2  | 0.9  | WV          | -16.9             | -19.1        | -23.0        | 0.9        |
| MS    | -27.3             | -24.8       | -24.7  | -0.5 | WY          | -12.8             | -16.2        | -16.1        | 0.1        |
|       |                   |             |        |      | <b>Avg.</b> | <b>-15.3</b>      | <b>-18.3</b> | <b>-18.5</b> | <b>0.3</b> |



**Table B-9 1-Story Retail Store Summary Table for LEC and 10-Year Study Period**

| State | Percentage Change |             |        |      | State       | Percentage Change |              |              |             |
|-------|-------------------|-------------|--------|------|-------------|-------------------|--------------|--------------|-------------|
|       | Energy Use        | Energy Cost | Carbon | LCC  |             | Energy Use        | Energy Cost  | Carbon       | LCC         |
| AK    | -26.3             | -27.3       | -26.8  | -0.2 | MT          | -16.0             | -17.7        | -17.5        | 0.1         |
| AL    | -35.1             | -35.6       | -35.9  | -0.9 | NC          | -15.8             | -17.2        | -17.6        | 0.1         |
| AR    | -29.8             | -31.8       | -32.5  | -1.7 | ND          | -31.8             | -33.4        | -33.7        | 0.6         |
| AZ    | -31.6             | -32.4       | -32.6  | -1.8 | NE          | -12.5             | -16.8        | -17.2        | 0.8         |
| CA    | -16.1             | -17.8       | -17.1  | 0.0  | NH          | -15.9             | -17.8        | -17.5        | -0.9        |
| CO    | -28.4             | -32.0       | -32.4  | -2.0 | NJ          | -13.9             | -17.4        | -16.7        | 0.1         |
| CT    | -12.3             | -16.9       | -15.5  | -1.7 | NM          | -15.6             | -18.9        | -18.9        | 0.1         |
| DE    | -14.2             | -16.7       | -17.1  | -0.8 | NV          | -21.0             | -21.9        | -21.7        | -0.6        |
| FL    | -17.9             | -18.2       | -18.2  | -0.7 | NY          | -12.4             | -16.4        | -14.9        | -0.6        |
| GA    | -15.5             | -16.5       | -16.8  | 0.5  | OH          | -12.5             | -16.1        | -16.6        | -0.5        |
| HI    | -22.3             | -22.3       | -22.3  | -3.1 | OK          | -30.5             | -32.6        | -34.0        | 1.9         |
| IA    | -14.3             | -17.2       | -17.6  | 0.6  | OR          | -13.2             | -15.3        | -15.4        | 0.8         |
| ID    | -14.2             | -16.3       | -16.3  | 1.2  | PA          | -12.3             | -15.4        | -15.9        | 0.1         |
| IL    | -12.5             | -16.9       | -16.9  | -0.4 | RI          | -12.4             | -15.8        | -15.6        | -1.5        |
| IN    | -13.5             | -16.8       | -17.4  | 0.5  | SC          | -20.2             | -20.5        | -20.5        | 0.2         |
| KS    | -30.6             | -33.9       | -35.1  | 1.0  | SD          | -29.9             | -33.5        | -34.0        | -0.9        |
| KY    | -14.9             | -17.2       | -18.3  | 0.5  | TN          | -23.1             | -22.6        | -22.5        | -0.4        |
| LA    | -15.0             | -15.5       | -15.7  | 0.7  | TX          | -15.3             | -16.5        | -16.5        | 0.0         |
| MA    | -11.8             | -16.1       | -15.2  | 0.1  | UT          | -13.0             | -17.3        | -16.3        | 1.2         |
| MD    | -14.3             | -17.3       | -17.0  | -0.1 | VA          | -16.1             | -18.2        | -18.7        | 0.5         |
| ME    | -31.7             | -33.2       | -33.1  | -1.2 | VT          | -15.7             | -17.5        | -17.3        | -0.8        |
| MI    | -12.6             | -16.0       | -16.4  | -0.3 | WA          | -12.3             | -13.9        | -14.3        | 1.1         |
| MN    | -27.3             | -23.9       | -23.5  | -0.8 | WI          | -15.9             | -18.0        | -18.1        | -1.1        |
| MO    | -31.3             | -33.5       | -34.8  | 1.7  | WV          | -30.7             | -31.6        | -32.9        | -1.8        |
| MS    | -40.6             | -38.8       | -38.8  | -0.3 | WY          | -30.5             | -34.0        | -34.0        | 0.4         |
|       |                   |             |        |      | <b>Avg.</b> | <b>-18.9</b>      | <b>-20.9</b> | <b>-21.0</b> | <b>-0.1</b> |

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

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

## C Total Changes from Nationwide Adoption of the LEC Design

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

| State | Code | Average Annual New Floor Area<br>1000 m <sup>2</sup> (1000 ft <sup>2</sup> ) | Energy Use<br>(GWh) | Energy Costs<br>(\$million) | Carbon<br>(1000 tCO <sub>2</sub> e) | LCC<br>(\$million) |
|-------|------|------------------------------------------------------------------------------|---------------------|-----------------------------|-------------------------------------|--------------------|
| FL    | 2007 | 16 542 (178 061)                                                             | 3790.5              | 333.0                       | 3230.0                              | 151.3              |
| TX    | 2007 | 14 446 (155 495)                                                             | 2831.6              | 235.0                       | 2630.0                              | 106.8              |
| CA    | 2007 | 14 492 (155 996)                                                             | 2543.2              | 306.0                       | 1146.0                              | 124.9              |
| AZ    | 1999 | 4758 (51 214)                                                                | 1857.5              | 136.0                       | 1255.0                              | 79.1               |
| GA    | 2007 | 7240 (77 934)                                                                | 1348.0              | 103.0                       | 1018.0                              | 28.5               |
| IL    | 2007 | 6929 (74 579)                                                                | 1212.7              | 124.0                       | 1344.0                              | 31.4               |
| CO    | 2001 | 3292 (35 437)                                                                | 1112.9              | 72.7                        | 1126.0                              | 59.7               |
| AL    | 1999 | 2254 (24 266)                                                                | 1050.6              | 84.9                        | 908.8                               | 37.0               |
| NY    | 2007 | 6071 (65 346)                                                                | 1037.6              | 133.0                       | 560.8                               | 37.1               |
| MO    | None | 2358 (25 383)                                                                | 984.7               | 56.9                        | 1001.0                              | 2.7                |
| VA    | 2007 | 4499 (48 426)                                                                | 871.3               | 60.5                        | 695.0                               | 14.0               |
| NC    | 2007 | 4437 (47 758)                                                                | 827.9               | 56.2                        | 585.0                               | 20.3               |
| OH    | 2007 | 4907 (52 814)                                                                | 826.8               | 74.1                        | 837.6                               | 33.9               |
| MN    | 2004 | 2329 (25 068)                                                                | 816.7               | 33.5                        | 443.8                               | 12.4               |
| TN    | 2004 | 3272 (35 219)                                                                | 807.8               | 58.7                        | 626.8                               | 28.1               |
| PA    | 2007 | 4661 (50 170)                                                                | 764.9               | 63.9                        | 628.9                               | 18.2               |
| NV    | 2004 | 3516 (37 844)                                                                | 709.0               | 59.7                        | 327.2                               | 17.9               |
| MS    | 1999 | 1251 (13 465)                                                                | 689.6               | 46.3                        | 465.2                               | 14.8               |
| IN    | 2007 | 3663 (39 425)                                                                | 656.9               | 49.8                        | 652.7                               | 13.3               |
| MD    | 2007 | 3385 (36 433)                                                                | 622.2               | 62.4                        | 448.9                               | 28.8               |
| 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               |
| NJ    | 2007 | 3476 (37 421)                                                                | 581.6               | 72.7                        | 436.8                               | 20.8               |
| WA    | 2007 | 3710 (39 937)                                                                | 525.0               | 32.3                        | 266.7                               | -11.5              |
| MI    | 2007 | 2964 (31 905)                                                                | 511.9               | 40.4                        | 490.9                               | 17.0               |
| WI    | 2007 | 2386 (25 679)                                                                | 491.0               | 33.2                        | 383.7                               | 14.8               |
| KS    | None | 1077 (11 590)                                                                | 438.6               | 28.6                        | 436.0                               | 2.3                |
| AR    | 2001 | 1186 (12 762)                                                                | 426.1               | 28.6                        | 372.7                               | 20.4               |
| MA    | 2007 | 2579 (27 760)                                                                | 403.8               | 56.0                        | 277.4                               | 12.8               |
| 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                |
| UT    | 2007 | 1718 (18 492)                                                                | 286.6               | 18.8                        | 144.3                               | 5.4                |
| IA    | 2007 | 1447 (15 573)                                                                | 283.7               | 17.6                        | 256.4                               | 4.0                |
| OR    | 2007 | 1745 (18 788)                                                                | 261.4               | 17.4                        | 146.1                               | -0.4               |
| CT    | 2007 | 1445 (15 549)                                                                | 232.0               | 35.1                        | 160.6                               | 19.7               |
| ME    | None | 497 (5349)                                                                   | 216.6               | 18.0                        | 113.3                               | 6.4                |
| WV    | 2001 | 479 (5159)                                                                   | 177.2               | 9.7                         | 161.3                               | 7.1                |
| NE    | 2007 | 920 (9900)                                                                   | 170.8               | 11.1                        | 166.6                               | 1.4                |
| NM    | 2007 | 817 (8790)                                                                   | 153.7               | 11.7                        | 146.0                               | 5.5                |
| ID    | 2007 | 802 (8629)                                                                   | 139.9               | 7.6                         | 69.9                                | 1.5                |
| HI    | 2004 | 536 (5773)                                                                   | 138.4               | 23.9                        | 123.8                               | 13.9               |
| SD    | None | 303 (3262)                                                                   | 122.3               | 6.5                         | 98.2                                | 2.4                |
| NH    | 2007 | 553 (5948)                                                                   | 108.0               | 10.9                        | 59.2                                | 5.8                |
| ND    | None | 229 (2464)                                                                   | 104.5               | 4.8                         | 75.8                                | 0.0                |
| AK    | 1999 | 290 (3116)                                                                   | 99.4                | 9.8                         | 58.4                                | 2.4                |
| WY    | 1999 | 230 (2477)                                                                   | 76.6                | 5.3                         | 45.3                                | 0.7                |
| DE    | 2007 | 344 (3700)                                                                   | 60.1                | 6.5                         | 45.1                                | 4.5                |
| RI    | 2007 | 335 (3604)                                                                   | 55.3                | 6.6                         | 37.5                                | 3.1                |
| MT    | 2007 | 238 (2562)                                                                   | 52.5                | 2.9                         | 24.1                                | 0.5                |
| VT    | 2007 | 200 (2147)                                                                   | 37.3                | 3.4                         | 20.7                                | 1.4                |

**Table C-2 Energy Use Reduction per Unit of Floor Area from Adoption of the LEC Design, 10-Year**

| State | Code | Average Annual New Floor Area<br>1000 m <sup>2</sup> (1000 ft <sup>2</sup> ) | Energy Savings<br>(GWh) | kWh/m <sup>2</sup> | kWh/ft <sup>2</sup> |
|-------|------|------------------------------------------------------------------------------|-------------------------|--------------------|---------------------|
| MS    | None | 1251 (13 465)                                                                | 689.6                   | 551                | 51                  |
| AL    | None | 2254 (24 266)                                                                | 1050.6                  | 466                | 43                  |
| ND    | None | 229 (2464)                                                                   | 104.5                   | 456                | 42                  |
| ME    | None | 497 (5349)                                                                   | 216.6                   | 436                | 40                  |
| MO    | None | 2358 (25 383)                                                                | 984.7                   | 418                | 39                  |
| KS    | None | 1077 (11 590)                                                                | 438.6                   | 407                | 38                  |
| SD    | None | 303 (3262)                                                                   | 122.3                   | 404                | 37                  |
| AZ    | None | 4758 (51 214)                                                                | 1857.5                  | 390                | 36                  |
| OK    | None | 1590 (17 115)                                                                | 598.1                   | 376                | 35                  |
| WV    | 2001 | 479 (5159)                                                                   | 177.2                   | 370                | 34                  |
| AR    | 2001 | 1186 (12 762)                                                                | 426.1                   | 359                | 33                  |
| MN    | 2004 | 2329 (25 068)                                                                | 816.7                   | 351                | 33                  |
| AK    | None | 290 (3116)                                                                   | 99.4                    | 343                | 32                  |
| CO    | 2001 | 3292 (35 437)                                                                | 1112.9                  | 338                | 31                  |
| WY    | None | 230 (2477)                                                                   | 76.6                    | 333                | 31                  |
| HI    | 2004 | 536 (5773)                                                                   | 138.4                   | 258                | 24                  |
| TN    | 2004 | 3272 (35 219)                                                                | 807.8                   | 247                | 23                  |
| FL    | 2007 | 16 542 (178 061)                                                             | 3790.5                  | 229                | 21                  |
| MT    | 2007 | 238 (2562)                                                                   | 52.5                    | 221                | 20                  |
| SC    | 2004 | 2718 (29 257)                                                                | 594.5                   | 219                | 20                  |
| NV    | 2004 | 3516 (37 844)                                                                | 709                     | 202                | 19                  |
| WI    | 2007 | 2386 (25 679)                                                                | 491                     | 206                | 19                  |
| IA    | 2007 | 1447 (15 573)                                                                | 283.7                   | 196                | 18                  |
| KY    | 2007 | 1956 (21 050)                                                                | 378                     | 193                | 18                  |
| LA    | 2007 | 1700 (18 294)                                                                | 324.6                   | 191                | 18                  |
| NH    | 2007 | 553 (5948)                                                                   | 108                     | 195                | 18                  |
| TX    | 2007 | 14 446 (155 495)                                                             | 2831.6                  | 196                | 18                  |
| VA    | 2007 | 4499 (48 426)                                                                | 871.3                   | 194                | 18                  |
| GA    | 2007 | 7240 (77 934)                                                                | 1348                    | 186                | 17                  |
| IN    | 2007 | 3663 (39 425)                                                                | 656.9                   | 179                | 17                  |
| MD    | 2007 | 3385 (36 433)                                                                | 622.2                   | 184                | 17                  |
| NC    | 2007 | 4437 (47 758)                                                                | 827.9                   | 187                | 17                  |
| NE    | 2007 | 920 (9900)                                                                   | 170.8                   | 186                | 17                  |
| NM    | 2007 | 817 (8790)                                                                   | 153.7                   | 188                | 17                  |
| VT    | 2007 | 200 (2147)                                                                   | 37.3                    | 187                | 17                  |
| CA    | 2007 | 14 492 (155 996)                                                             | 2543.2                  | 175                | 16                  |
| DE    | 2007 | 344 (3700)                                                                   | 60.1                    | 175                | 16                  |
| ID    | 2007 | 802 (8629)                                                                   | 139.9                   | 174                | 16                  |
| IL    | 2007 | 6929 (74 579)                                                                | 1212.7                  | 175                | 16                  |
| MI    | 2007 | 2964 (31 905)                                                                | 511.9                   | 173                | 16                  |
| NJ    | 2007 | 3476 (37 421)                                                                | 581.6                   | 167                | 16                  |
| NY    | 2007 | 6071 (65 346)                                                                | 1037.6                  | 171                | 16                  |
| OH    | 2007 | 4907 (52 814)                                                                | 826.8                   | 168                | 16                  |
| MA    | 2007 | 2579 (27 760)                                                                | 403.8                   | 157                | 15                  |
| PA    | 2007 | 4661 (50 170)                                                                | 764.9                   | 164                | 15                  |
| RI    | 2007 | 335 (3604)                                                                   | 55.3                    | 165                | 15                  |
| UT    | 2007 | 1718 (18 492)                                                                | 286.6                   | 167                | 15                  |
| CT    | 2007 | 1445 (15 549)                                                                | 232                     | 161                | 15                  |
| OR    | 2007 | 1745 (18 788)                                                                | 261.4                   | 150                | 14                  |
| WA    | 2007 | 3710 (39 937)                                                                | 525                     | 142                | 13                  |

**Table C-3 Life-Cycle Cost Reductions per Unit of New Floor Area from Adoption of the LEC Design, 10-Year**

| State | Code | kWh/m <sup>2</sup> | LCC Savings (\$million) | LCC Savings (\$/m <sup>2</sup> ) | LCC Savings (\$/ft <sup>2</sup> ) |
|-------|------|--------------------|-------------------------|----------------------------------|-----------------------------------|
| HI    | 2004 | 258                | 13.9                    | 25.93                            | 2.41                              |
| CO    | 2001 | 338                | 59.7                    | 18.13                            | 1.68                              |
| AR    | 2001 | 359                | 20.4                    | 17.20                            | 1.60                              |
| AZ    | 1999 | 390                | 79.1                    | 16.62                            | 1.54                              |
| AL    | 1999 | 466                | 37.0                    | 16.42                            | 1.53                              |
| WV    | 2001 | 370                | 7.1                     | 14.82                            | 1.38                              |
| CT    | 2007 | 161                | 19.7                    | 13.63                            | 1.27                              |
| DE    | 2007 | 175                | 4.5                     | 13.08                            | 1.22                              |
| ME    | None | 436                | 6.4                     | 12.88                            | 1.20                              |
| MS    | 1999 | 551                | 14.8                    | 11.83                            | 1.10                              |
| NH    | 2007 | 195                | 5.8                     | 10.49                            | 0.97                              |
| RI    | 2007 | 165                | 3.1                     | 9.25                             | 0.86                              |
| FL    | 2007 | 229                | 151.3                   | 9.15                             | 0.85                              |
| CA    | 2007 | 175                | 124.9                   | 8.62                             | 0.80                              |
| TN    | 2004 | 247                | 28.1                    | 8.59                             | 0.80                              |
| MD    | 2007 | 184                | 28.8                    | 8.51                             | 0.79                              |
| AK    | 1999 | 343                | 2.4                     | 8.28                             | 0.77                              |
| SD    | None | 404                | 2.4                     | 7.92                             | 0.74                              |
| TX    | 2007 | 196                | 106.8                   | 7.39                             | 0.69                              |
| VT    | 2007 | 187                | 1.4                     | 7.00                             | 0.65                              |
| OH    | 2007 | 168                | 33.9                    | 6.91                             | 0.64                              |
| NM    | 2007 | 188                | 5.5                     | 6.73                             | 0.63                              |
| WI    | 2007 | 206                | 14.8                    | 6.20                             | 0.58                              |
| NY    | 2007 | 171                | 37.1                    | 6.11                             | 0.57                              |
| NJ    | 2007 | 167                | 20.8                    | 5.98                             | 0.56                              |
| MI    | 2007 | 173                | 17.0                    | 5.74                             | 0.53                              |
| MN    | 2004 | 351                | 12.4                    | 5.32                             | 0.49                              |
| NV    | 2004 | 202                | 17.9                    | 5.09                             | 0.47                              |
| KY    | 2007 | 193                | 9.8                     | 5.01                             | 0.47                              |
| MA    | 2007 | 157                | 12.8                    | 4.96                             | 0.46                              |
| NC    | 2007 | 187                | 20.3                    | 4.58                             | 0.43                              |
| IL    | 2007 | 175                | 31.4                    | 4.53                             | 0.42                              |
| SC    | 2004 | 219                | 12.2                    | 4.49                             | 0.42                              |
| GA    | 2007 | 186                | 28.5                    | 3.94                             | 0.37                              |
| PA    | 2007 | 164                | 18.2                    | 3.90                             | 0.36                              |
| IN    | 2007 | 179                | 13.3                    | 3.63                             | 0.34                              |
| UT    | 2007 | 167                | 5.4                     | 3.14                             | 0.29                              |
| VA    | 2007 | 194                | 14.0                    | 3.11                             | 0.29                              |
| WY    | 1999 | 333                | 0.7                     | 3.04                             | 0.28                              |
| IA    | 2007 | 196                | 4.0                     | 2.76                             | 0.26                              |
| KS    | None | 407                | 2.3                     | 2.14                             | 0.20                              |
| MT    | 2007 | 221                | 0.5                     | 2.10                             | 0.20                              |
| LA    | 2007 | 191                | 3.2                     | 1.88                             | 0.17                              |
| ID    | 2007 | 174                | 1.5                     | 1.87                             | 0.17                              |
| NE    | 2007 | 186                | 1.4                     | 1.52                             | 0.14                              |
| MO    | None | 418                | 2.7                     | 1.15                             | 0.11                              |
| OK    | 1999 | 376                | 0.7                     | 0.44                             | 0.04                              |
| ND    | None | 456                | 0.0                     | 0.00                             | 0.00                              |
| OR    | 2007 | 150                | -0.4                    | -0.23                            | -0.02                             |
| WA    | 2007 | 142                | -11.5                   | -3.10                            | -0.29                             |

**Table C-4 Energy Cost Reduction per kWh of Energy Use Reduction from Adoption of the LEC Design, 10-Year**

| State | Code | Offset* (%) | Electricity Rate (\$/kWh) | Natural Gas Rate (\$/kWh) | Energy Cost Reduction (\$/kWh) |
|-------|------|-------------|---------------------------|---------------------------|--------------------------------|
| HI    | 2004 | 0.0%        | 0.22                      | 0.09                      | \$0.17                         |
| CT    | 2007 | 18.5%       | 0.17                      | 0.03                      | \$0.15                         |
| MA    | 2007 | 18.0%       | 0.15                      | 0.04                      | \$0.14                         |
| NJ    | 2007 | 17.4%       | 0.14                      | 0.03                      | \$0.13                         |
| NY    | 2007 | 7.6%        | 0.16                      | 0.03                      | \$0.13                         |
| CA    | 2007 | 13.0%       | 0.13                      | 0.02                      | \$0.12                         |
| RI    | 2007 | 16.8%       | 0.14                      | 0.04                      | \$0.12                         |
| DE    | 2007 | 17.4%       | 0.12                      | 0.05                      | \$0.11                         |
| AK    | 1999 | -24.9%      | 0.14                      | 0.03                      | \$0.10                         |
| IL    | 2007 | 11.6%       | 0.11                      | 0.03                      | \$0.10                         |
| MD    | 2007 | 13.3%       | 0.12                      | 0.03                      | \$0.10                         |
| NH    | 2007 | -20.4%      | 0.15                      | 0.04                      | \$0.10                         |
| FL    | 2007 | 4.0%        | 0.11                      | 0.03                      | \$0.09                         |
| OH    | 2007 | 15.3%       | 0.10                      | 0.03                      | \$0.09                         |
| VT    | 2007 | -18.6%      | 0.13                      | 0.04                      | \$0.09                         |
| AL    | 1999 | 1.8%        | 0.10                      | 0.04                      | \$0.08                         |
| GA    | 2007 | 10.4%       | 0.09                      | 0.03                      | \$0.08                         |
| IN    | 2007 | 13.6%       | 0.08                      | 0.03                      | \$0.08                         |
| ME    | None | -27.5%      | 0.13                      | 0.04                      | \$0.08                         |
| MI    | 2007 | 3.7%        | 0.09                      | 0.03                      | \$0.08                         |
| NM    | 2007 | 16.0%       | 0.08                      | 0.02                      | \$0.08                         |
| NV    | 2004 | 1.1%        | 0.11                      | 0.03                      | \$0.08                         |
| PA    | 2007 | 17.2%       | 0.10                      | 0.03                      | \$0.08                         |
| TX    | 2007 | 9.2%        | 0.10                      | 0.02                      | \$0.08                         |
| AR    | 2001 | 17.2%       | 0.08                      | 0.03                      | \$0.07                         |
| AZ    | 1999 | 2.2%        | 0.09                      | 0.04                      | \$0.07                         |
| CO    | 2001 | 8.6%        | 0.08                      | 0.02                      | \$0.07                         |
| KS    | None | 2.6%        | 0.08                      | 0.03                      | \$0.07                         |
| KY    | 2007 | 11.1%       | 0.08                      | 0.03                      | \$0.07                         |
| MS    | 1999 | -20.7%      | 0.10                      | 0.03                      | \$0.07                         |
| NC    | 2007 | 11.3%       | 0.08                      | 0.03                      | \$0.07                         |
| OR    | 2007 | 18.8%       | 0.07                      | 0.03                      | \$0.07                         |
| SC    | 2004 | 9.1%        | 0.09                      | 0.03                      | \$0.07                         |
| TN    | 2004 | -9.4%       | 0.10                      | 0.03                      | \$0.07                         |
| UT    | 2007 | 21.7%       | 0.07                      | 0.02                      | \$0.07                         |
| VA    | 2007 | 12.4%       | 0.08                      | 0.03                      | \$0.07                         |
| WI    | 2007 | -25.9%      | 0.10                      | 0.03                      | \$0.07                         |
| WY    | 1999 | 6.9%        | 0.07                      | 0.02                      | \$0.07                         |
| IA    | 2007 | -1.0%       | 0.08                      | 0.02                      | \$0.06                         |
| LA    | 2007 | 7.7%        | 0.08                      | 0.03                      | \$0.06                         |
| MO    | None | 3.0%        | 0.07                      | 0.03                      | \$0.06                         |
| MT    | 2007 | -38.9%      | 0.08                      | 0.03                      | \$0.06                         |
| NE    | 2007 | 9.6%        | 0.07                      | 0.02                      | \$0.06                         |
| OK    | 1999 | 17.2%       | 0.07                      | 0.03                      | \$0.06                         |
| WA    | 2007 | 19.4%       | 0.07                      | 0.04                      | \$0.06                         |
| ID    | 2007 | 8.4%        | 0.06                      | 0.03                      | \$0.05                         |
| ND    | None | -33.0%      | 0.07                      | 0.02                      | \$0.05                         |
| SD    | None | -14.6%      | 0.07                      | 0.02                      | \$0.05                         |
| WV    | 2001 | 3.9%        | 0.07                      | 0.04                      | \$0.05                         |
| MN    | 2004 | -121.2%     | 0.08                      | 0.02                      | \$0.04                         |

**Table C-5 Carbon Reduction per GWh of Energy Use Reduction from Adoption of the LEC Design, 10-Year**

| State | Code | Offset* (%) | CO <sub>2</sub> e Emissions Rate for Electricity (t/GWh) | CO <sub>2</sub> e Emissions Rate for Natural Gas (t/GWh) | CO <sub>2</sub> e Reduction (t/GWh) |
|-------|------|-------------|----------------------------------------------------------|----------------------------------------------------------|-------------------------------------|
| OK    | 1999 | 17.2%       | 970.1                                                    | 241                                                      | 1135                                |
| IL    | 2007 | 11.6%       | 992.9                                                    | 241                                                      | 1108                                |
| MO    | None | 3.0%        | 984.2                                                    | 241                                                      | 1016                                |
| OH    | 2007 | 15.3%       | 874.8                                                    | 241                                                      | 1013                                |
| CO    | 2001 | 8.6%        | 993.6                                                    | 241                                                      | 1012                                |
| IN    | 2007 | 13.6%       | 874.8                                                    | 241                                                      | 994                                 |
| KS    | None | 2.6%        | 971.1                                                    | 241                                                      | 994                                 |
| NE    | 2007 | 9.6%        | 891.8                                                    | 241                                                      | 975                                 |
| MI    | 2007 | 3.7%        | 908.8                                                    | 241                                                      | 959                                 |
| NM    | 2007 | 16.0%       | 835.1                                                    | 241                                                      | 950                                 |
| TX    | 2007 | 9.2%        | 858.4                                                    | 241                                                      | 929                                 |
| WV    | 2001 | 3.9%        | 874.8                                                    | 241                                                      | 910                                 |
| IA    | 2007 | -1.0%       | 891.8                                                    | 241                                                      | 904                                 |
| KY    | 2007 | 11.1%       | 819.0                                                    | 241                                                      | 903                                 |
| HI    | 2004 | 0.0%        | 835.2                                                    | 241                                                      | 895                                 |
| AR    | 2001 | 17.2%       | 756.1                                                    | 241                                                      | 875                                 |
| AL    | 1999 | 1.8%        | 847.4                                                    | 241                                                      | 865                                 |
| FL    | 2007 | 4.0%        | 826.1                                                    | 241                                                      | 852                                 |
| LA    | 2007 | 7.7%        | 780.0                                                    | 241                                                      | 831                                 |
| PA    | 2007 | 17.2%       | 708.0                                                    | 241                                                      | 822                                 |
| SD    | None | -14.6%      | 891.8                                                    | 241                                                      | 803                                 |
| VA    | 2007 | 12.4%       | 723.1                                                    | 241                                                      | 798                                 |
| WI    | 2007 | -25.9%      | 905.1                                                    | 241                                                      | 781                                 |
| TN    | 2004 | -9.4%       | 819.0                                                    | 241                                                      | 776                                 |
| GA    | 2007 | 10.4%       | 847.4                                                    | 241                                                      | 755                                 |
| NJ    | 2007 | 17.4%       | 652.5                                                    | 241                                                      | 751                                 |
| DE    | 2007 | 17.4%       | 652.5                                                    | 241                                                      | 750                                 |
| ND    | None | -33.0%      | 891.8                                                    | 241                                                      | 725                                 |
| MD    | 2007 | 13.3%       | 652.5                                                    | 241                                                      | 721                                 |
| NC    | 2007 | 11.3%       | 647.3                                                    | 241                                                      | 707                                 |
| SC    | 2004 | 9.1%        | 647.3                                                    | 241                                                      | 694                                 |
| CT    | 2007 | 18.5%       | 598.8                                                    | 241                                                      | 692                                 |
| MA    | 2007 | 18.0%       | 598.8                                                    | 241                                                      | 687                                 |
| RI    | 2007 | 16.8%       | 598.8                                                    | 241                                                      | 678                                 |
| AZ    | 1999 | 2.2%        | 801.4                                                    | 241                                                      | 675                                 |
| MS    | 1999 | -20.7%      | 759.1                                                    | 241                                                      | 675                                 |
| WY    | 1999 | 6.9%        | 660.7                                                    | 241                                                      | 591                                 |
| AK    | 1999 | -24.9%      | 663.3                                                    | 241                                                      | 588                                 |
| OR    | 2007 | 18.8%       | 493.6                                                    | 241                                                      | 559                                 |
| VT    | 2007 | -18.6%      | 598.8                                                    | 241                                                      | 555                                 |
| NH    | 2007 | -20.4%      | 598.8                                                    | 241                                                      | 548                                 |
| MN    | 2004 | -121.2%     | 891.8                                                    | 241                                                      | 543                                 |
| NY    | 2007 | 7.6%        | 513.7                                                    | 241                                                      | 540                                 |
| ME    | None | -27.5%      | 598.8                                                    | 241                                                      | 523                                 |
| WA    | 2007 | 19.4%       | 493.6                                                    | 241                                                      | 508                                 |
| UT    | 2007 | 21.7%       | 493.6                                                    | 241                                                      | 503                                 |
| ID    | 2007 | 8.4%        | 493.6                                                    | 241                                                      | 500                                 |
| NV    | 2004 | 1.1%        | 493.6                                                    | 241                                                      | 461                                 |
| MT    | 2007 | -38.9%      | 573.3                                                    | 241                                                      | 459                                 |
| CA    | 2007 | 13.0%       | 497.3                                                    | 241                                                      | 450                                 |





## D Percentage Changes by Building Type for the Nationwide Adoption of the *ASHRAE 90.1-2007* Design

**Table D-1 4-Story Apartment Building Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period**

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

**Table D-2 6-Story Apartment Building Summary Table for *ASHRAE 90.1-2007* and 10-Year Study Period**

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

**Table D-3 4-Story Dormitory Summary Table for ASHRAE 90.1-2007 and 10-Year Study Period**

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

**Table D-4 6-Story Dormitory Summary Table for ASHRAE 90.1-2007 and 10-Year Study Period**

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

**Table D-5 15-Story Hotel Building Summary Table for ASHRAE 90.1-2007 and 10-Year Study Period**

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

**Table D-6 2-Story High School Summary Table for ASHRAE 90.1-2007 and 10-Year Study Period**

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

**Table D-7 8-Story Office Building Summary Table for ASHRAE 90.1-2007 and 10-Year Study Period**

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

**Table D-8 16-Story Office Building Summary Table for ASHRAE 90.1-2007 and 10-Year Study Period**

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

**Table D-9 1-Story Retail Store Summary Table for ASHRAE 90.1-2007 and 10-Year Study Period**

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

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

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

## E Total Changes from Nationwide Adoption of the *ASHRAE 90.1-2007* Design

**Table E-1 Total Reductions by State for Adoption of the *ASHRAE 90.1-2007* Design, 10-Year**

| State | Code | Average Annual New Floor Area<br>1000 m <sup>2</sup> (1000 ft <sup>2</sup> ) | Energy Use<br>(GWh) | Energy Costs<br>(\$million) | Carbon<br>(1000 tCO <sub>2</sub> e) | LCC<br>(\$million) |
|-------|------|------------------------------------------------------------------------------|---------------------|-----------------------------|-------------------------------------|--------------------|
| AZ    | None | 4758 (51 214)                                                                | 946.3               | 62.2                        | 561.7                               | 30.8               |
| NV    | 2004 | 3516 (37 844)                                                                | 117.3               | 2.9                         | 24.6                                | 6.3                |
| CO    | 2001 | 3292 (35 437)                                                                | 543.0               | 35.0                        | 541.4                               | 53.9               |
| TN    | 2004 | 3272 (35 219)                                                                | 172.6               | 6.5                         | 66.1                                | 7.5                |
| SC    | 2004 | 2718 (29 257)                                                                | 92.2                | 6.5                         | 60.7                                | 2.9                |
| MO    | None | 2358 (25 383)                                                                | 524.1               | 29.1                        | 502.3                               | 1.9                |
| MN    | 2004 | 2329 (25 068)                                                                | 282.7               | 6.0                         | 70.8                                | 7.3                |
| AL    | None | 2254 (24 266)                                                                | 631.6               | 49.8                        | 527.8                               | 25.7               |
| OK    | None | 1590 (17 115)                                                                | 300.5               | 29.1                        | 502.3                               | -5.7               |
| MS    | None | 1251 (13 465)                                                                | 470.6               | 28.1                        | 281.2                               | 12.3               |
| AR    | 2001 | 1186 (12 762)                                                                | 204.3               | 14.4                        | 190.3                               | 17.5               |
| KS    | None | 1077 (11 590)                                                                | 229.5               | 13.9                        | 208.4                               | -2.9               |
| HI    | 2004 | 536 (5773)                                                                   | 12.1                | 2.1                         | 10.8                                | 2.0                |
| ME    | None | 497 (5349)                                                                   | 105.5               | 9.4                         | 58.8                                | 3.3                |
| WV    | 2001 | 479 (5159)                                                                   | 96.4                | 5.0                         | 78.8                                | 7.2                |
| SD    | None | 303 (3262)                                                                   | 57.5                | 3.1                         | 47.9                                | 1.4                |
| AK    | None | 290 (3116)                                                                   | 14.0                | 4.3                         | 22.0                                | 1.4                |
| WY    | None | 230 (2477)                                                                   | 34.9                | 2.6                         | 22.9                                | 0.5                |
| ND    | None | 229 (2464)                                                                   | 45.7                | 2.4                         | 37.7                                | 0.0                |

**Table E-2 Energy Use Reduction per Unit of Floor Area from Adoption of the ASHRAE 90.1-2007 Design, 10-Year**

| State | Code | Average Annual New<br>Floor Area<br>1000 m <sup>2</sup> (1000 ft <sup>2</sup> ) | Energy Savings<br>(GWh) | kWh/m <sup>2</sup> | kWh/ft <sup>2</sup> |
|-------|------|---------------------------------------------------------------------------------|-------------------------|--------------------|---------------------|
| MS    | None | 1251 (13 465)                                                                   | 470.6                   | 376                | 35                  |
| AL    | None | 2254 (24 266)                                                                   | 631.6                   | 280                | 26                  |
| MO    | None | 2358 (25 383)                                                                   | 524.1                   | 222                | 21                  |
| KS    | None | 1077 (11 590)                                                                   | 229.5                   | 213                | 20                  |
| ME    | None | 497 (5349)                                                                      | 105.5                   | 212                | 20                  |
| WV    | 2001 | 479 (5159)                                                                      | 96.4                    | 201                | 19                  |
| ND    | None | 229 (2464)                                                                      | 45.7                    | 200                | 19                  |
| AZ    | None | 4758 (51 214)                                                                   | 946.3                   | 199                | 18                  |
| SD    | None | 303 (3262)                                                                      | 57.5                    | 190                | 18                  |
| OK    | None | 1590 (17 115)                                                                   | 300.5                   | 189                | 18                  |
| AR    | 2001 | 1186 (12 762)                                                                   | 204.3                   | 172                | 16                  |
| CO    | 2001 | 3292 (35 437)                                                                   | 543.0                   | 165                | 15                  |
| WY    | None | 230 (2477)                                                                      | 34.9                    | 152                | 14                  |
| MN    | 2004 | 2329 (25 068)                                                                   | 282.7                   | 121                | 11                  |
| TN    | 2004 | 3272 (35 219)                                                                   | 172.6                   | 53                 | 5                   |
| AK    | None | 290 (3116)                                                                      | 14.0                    | 48                 | 4                   |
| SC    | 2004 | 2718 (29 257)                                                                   | 92.2                    | 34                 | 3                   |
| NV    | 2004 | 3516 (37 844)                                                                   | 117.3                   | 33                 | 3                   |
| HI    | 2004 | 536 (5773)                                                                      | 12.1                    | 23                 | 2                   |

**Table E-3 Life-Cycle Cost Reductions per Unit of New Floor Area from Adoption of the ASHRAE 90.1-2007 Design, 10-Year**

| State | Code | Energy Use Savings (kWh/m <sup>2</sup> ) | Electricity Rate (\$/kWh) | LCC Savings (\$million) | LCC Savings (\$/m <sup>2</sup> ) | LCC Savings (\$/ft <sup>2</sup> ) |
|-------|------|------------------------------------------|---------------------------|-------------------------|----------------------------------|-----------------------------------|
| CO    | 2001 | 165                                      | 0.08                      | 53.9                    | 16.37                            | 1.52                              |
| WV    | 2001 | 201                                      | 0.07                      | 7.2                     | 15.03                            | 1.40                              |
| AR    | 2001 | 172                                      | 0.08                      | 17.5                    | 14.76                            | 1.37                              |
| AL    | None | 280                                      | 0.10                      | 25.7                    | 11.40                            | 1.06                              |
| MS    | None | 376                                      | 0.10                      | 12.3                    | 9.83                             | 0.91                              |
| ME    | None | 212                                      | 0.13                      | 3.3                     | 6.64                             | 0.62                              |
| AZ    | None | 199                                      | 0.09                      | 30.8                    | 6.47                             | 0.60                              |
| AK    | None | 48                                       | 0.14                      | 1.4                     | 4.83                             | 0.45                              |
| SD    | None | 190                                      | 0.07                      | 1.4                     | 4.62                             | 0.43                              |
| HI    | 2004 | 12                                       | 0.22                      | 2.0                     | 3.73                             | 0.35                              |
| MN    | 2004 | 121                                      | 0.08                      | 7.3                     | 3.13                             | 0.29                              |
| TN    | 2004 | 53                                       | 0.10                      | 7.5                     | 2.29                             | 0.21                              |
| WY    | None | 152                                      | 0.07                      | 0.5                     | 2.17                             | 0.20                              |
| NV    | 2004 | 33                                       | 0.11                      | 6.3                     | 1.79                             | 0.17                              |
| SC    | 2004 | 34                                       | 0.09                      | 2.9                     | 1.07                             | 0.10                              |
| MO    | None | 222                                      | 0.07                      | 1.9                     | 0.81                             | 0.07                              |
| ND    | None | 200                                      | 0.07                      | 0.0                     | 0.00                             | 0.00                              |
| KS    | None | 213                                      | 0.08                      | -2.9                    | -2.69                            | -0.25                             |
| OK    | None | 189                                      | 0.07                      | -5.7                    | -3.58                            | -0.33                             |

**Table E-4 Energy Cost Reduction per kWh of Energy Use Reduction from Adoption of the ASHRAE 90.1-2007 Design, 10-Year**

| State | Code | Weighted Offset (%) | Electricity Rate* (\$/kWh) | Electricity Rate* (\$/kWh) | Energy Cost Reduction (\$/MWh) |
|-------|------|---------------------|----------------------------|----------------------------|--------------------------------|
| AK    | None | 66.2 %              | 0.14                       | 0.03                       | 307                            |
| HI    | 2004 | 0.0 %               | 0.22                       | 0.09                       | 174                            |
| OK    | None | 24.4 %              | 0.07                       | 0.03                       | 97                             |
| ME    | None | -14.7 %             | 0.13                       | 0.04                       | 89                             |
| AL    | None | -3.5 %              | 0.10                       | 0.04                       | 79                             |
| WY    | None | 17.2 %              | 0.07                       | 0.02                       | 74                             |
| SC    | 2004 | 5.0 %               | 0.09                       | 0.03                       | 70                             |
| AR    | 2001 | 24.1 %              | 0.08                       | 0.03                       | 70                             |
| AZ    | None | -7.3 %              | 0.09                       | 0.04                       | 66                             |
| CO    | 2001 | 6.6 %               | 0.08                       | 0.02                       | 64                             |
| KS    | None | -7.6 %              | 0.08                       | 0.03                       | 61                             |
| MS    | None | -59.4 %             | 0.10                       | 0.03                       | 60                             |
| MO    | None | -4.6 %              | 0.07                       | 0.03                       | 56                             |
| SD    | None | -4.1 %              | 0.07                       | 0.02                       | 54                             |
| ND    | None | -8.8 %              | 0.07                       | 0.02                       | 53                             |
| WV    | 2001 | -10.1 %             | 0.07                       | 0.04                       | 52                             |
| TN    | 2004 | -282.3 %            | 0.10                       | 0.03                       | 38                             |
| NV    | 2004 | -230.6 %            | 0.11                       | 0.03                       | 25                             |
| MN    | 2004 | -3113.8 %           | 0.08                       | 0.02                       | 21                             |

**Table E-5 Carbon Reduction per GWh of Energy Use Reduction from Adoption of the ASHRAE 90.1-2007 Design, 10-Year**

| State | Code | Weighted Offset (%) | CO2e Emissions Rate for Electricity* (\$/kWh) | CO2e Emissions Rate for Natural Gas* (\$/kWh) | Carbon Emissions Reduction (tCO <sub>2</sub> e/GWh) |
|-------|------|---------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------------|
| OK    | None | 24.4 %              | 970                                           | 241                                           | 1672                                                |
| AK    | None | 66.2 %              | 663                                           | 241                                           | 1571                                                |
| CO    | 2001 | 6.6 %               | 994                                           | 241                                           | 997                                                 |
| MO    | None | -4.6 %              | 984                                           | 241                                           | 958                                                 |
| AR    | 2001 | 24.1 %              | 756                                           | 241                                           | 931                                                 |
| KS    | None | -7.6 %              | 971                                           | 241                                           | 908                                                 |
| HI    | 2004 | 0.0 %               | 835                                           | 241                                           | 893                                                 |
| AL    | None | -3.5 %              | 847                                           | 241                                           | 836                                                 |
| SD    | None | -4.1 %              | 892                                           | 241                                           | 833                                                 |
| ND    | None | -8.8 %              | 892                                           | 241                                           | 825                                                 |
| WV    | 2001 | -10.1 %             | 875                                           | 241                                           | 817                                                 |
| SC    | 2004 | 5.0 %               | 647                                           | 241                                           | 658                                                 |
| WY    | None | 17.2 %              | 661                                           | 241                                           | 656                                                 |
| MS    | None | -59.4 %             | 759                                           | 241                                           | 598                                                 |
| AZ    | None | -7.3 %              | 801                                           | 241                                           | 594                                                 |
| ME    | None | -14.7 %             | 599                                           | 241                                           | 557                                                 |
| TN    | 2004 | -282.3 %            | 819                                           | 241                                           | 383                                                 |
| MN    | 2004 | -3113.8 %           | 892                                           | 241                                           | 250                                                 |
| NV    | 2004 | -230.6 %            | 494                                           | 241                                           | 210                                                 |