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A Retrospective Analysis of Commercial Building Energy Codes: 1990-2008

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Prepared by Pacific Northwest National Laboratory
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A Retrospective Analysis of Commercial Building Energy Codes: 1990 – 2008

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October 2010

Prepared for
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under Contract DE-AC05-76RL01830

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Executive Summary

The Building Energy Codes Program (BECP) influences the energy efficiency of new buildings through a number of channels. These include the following:

- Support for development of more stringent national codes
- Technical assistance to states and localities
- Development of code-related materials
- Direct training assistance on updated codes and software tools.

These efforts are designed to result in increased stringency in national model energy codes, more rapid and broader adoption by states and localities of updated codes, and increased compliance and enforcement. This report estimates the historical impact of BECP in terms of energy savings achieved that are based upon various editions of *ANSI/ASHRAE/IESNA*[1] *Standard 90.1* (ASHRAE Standard 90.1). Such an analysis requires the development of counterfactual (alternate history) assumptions that essentially assume what would have happened (or not happened) in the absence of the program.

As of the 1992 EPAct legislation, the U.S. Department of Energy (DOE) has been tasked with providing a "determination" of whether the most recent edition of a national model code (e.g., ASHRAE Standard 90.1) will save energy compared to the prior edition. Pacific Northwest National Laboratory (PNNL) has performed several of these determinations which have compared, for various building types and climates, energy savings per building from the changes to the code. In some cases, these analyses are detailed enough to estimate savings by end use, allowing for further assumptions about savings by fuel source and hence impacts on emissions of CO_2 and other pollutants.

Unfortunately, there are no publicly available data sources that show annual new floor space of commercial buildings constructed by state—a key piece of data needed for this analysis. However, PNNL has been able to use data from the F.W. Dodge group of McGraw-Hill Construction to create a historical series from 1990 through 2008. PNNL has also been able to estimate renovations to existing floor space for the same time period.

Two final sets of key assumptions are required to complete the analysis: the accelerated adoption of building codes prompted by DOE activities and the impact that DOE has had on influencing compliance with the prevailing code. For adoption, this analysis defined five categories of states and assigns a discrete period of years, which represents our best judgment as to the impact DOE had in accelerating the adoption of a code. The analysis also contemplates "spill-over" effect, some of which is simply a result of market forces but also reflects the adoption of energy codes in other states.

The second group of assumptions deals with compliance to the provisions of the more stringent building code. 'Compliance' is defined here as the percentage of the potential energy savings caused by constructing to the level of the prevailing code, as compared to the prior code or "current practice." As there is little solid information on current compliance rates, the analysis must be constructed using a

[1] The American National Standards Institute; American Society of Heating, Refrigerating and Air-Conditioning Engineers; Illuminating Engineering Society of North America

series of assumptions about compliance, and changes thereto both in the absence and presence of the program.

We calculated energy savings for the period 1990-2008 attributable to BECP efforts. Total annual energy savings reach near one-third of a quad by 2008. These savings reduced commercial sector energy use in that year by over 1.5%. Applying national average commercial fuel prices for electricity and gas in each year, the estimated energy cost savings can also be calculated. By 2008, the cost savings are more than $2 billion per year (in 2008 dollars) and cumulative cost savings since 1990 total more than $12 billion. We performed a sensitivity analysis by varying key assumptions. This bounded the estimated cumulative savings by about 25% lower ($9.9 billion) and 13% higher ($14.9 billion) than the base case ($12 billion).

These base case cost savings can be compared to the budgetary cost of BECP over this same period, which is estimated to be around $40 million. Dividing the cumulative energy cost savings by the program cost results in a ratio of more than $300 in energy cost savings for each DOE Building Energy Codes Program dollar spent. However, this does not account for state implementation costs or for the additional cost of construction to meet these higher code levels. However, the simple return on investment appears to be both positive and quite substantial.

Acknowledgments

The authors would like to acknowledge the external review by Allen Lee of the Cadmus Group. His comments and insights improved this paper greatly. However, any remaining errors or omissions remain solely the responsibility of the authors.

Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BECP	Building Energy Codes Program
CABO	Council of American Building Officials
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EUI	energy use intensities
GPRA	Government Performance and Results Act
IESNA	Illuminating Engineering Society of North America
IECC	International Energy Conservation Code
ICC	International Code Council
LPD	lighting power density
MCEC	Model Code for Energy Conservation in New Building Construction
NEMS	National Energy Modeling System
NRC	National Research Council
NREC	nonresidential energy code
PNNL	Pacific Northwest National Laboratory
SPE/I	Special Plans Examiner/Inspector Program

Contents

Figures

Tables

1.0 Introduction

DOE, through the Building Energy Codes Program (BECP), influences the energy efficiency of new buildings through a number of channels. Specifically, the program seeks to do the following:

- Support the development of more stringent national codes and thus increase the energy savings potential of state and local building codes as they are adopted and updated
- Provide technical assistance to states and localities that demonstrates the energy and economic benefits of code adoption and thus promotes more rapid adoption
- Develop code-related materials and software to both enhance compliance and promote more rapid adoption
- Provide direct training assistance on updated codes and software tools to both enhance compliance and promote more rapid adoption

An evaluation of the impacts of U.S. Department of Energy (DOE) efforts to save energy through codes development, adoption, implementation, and enforcement is complex because of these varied aspects of the overall program. DOE influences the development of national model energy codes (*ANSI/ASHRAE/IESNA*[1] *Standard 90.1* and the *International Energy Conservation Code*), but the energy savings of these codes are only achieved to the extent that they are adopted and enforced at the state or local level. Thus, an evaluation of this effort is considerably more complicated than simple assessments of the technical potential for energy savings from individual technologies such as electronic ballasts and low-e windows. The analysis must explicitly deal with questions of attribution (which part of the program caused the energy savings) and additionally (how much energy is saved beyond what would have happened "normally") in determining program impacts.

Despite the complexity of this analysis, BECP staff at Pacific Northwest National Laboratory (PNNL) have undertaken an effort to quantify the impacts of building energy codes and standards for a number of years. The first serious attempt was made in 1995. This effort used a spreadsheet approach that estimated cumulative national-level energy savings, dollar savings, and emission reductions from changes to commercial building energy codes. The analysis made simplifying assumptions as it was not based on any state or regional information. A more comprehensive approach was initiated in 2001. The analysis (and assumptions) was disaggregated to individual states. In addition, a more careful identification and analysis of the various energy standards published by ASHRAE, and the impact on particular energy end-uses and fuel types, was employed. A detailed state-by-state, energy end-use approach is more challenging because of the lack of individual state compliance data.

While the analysis and results documented in this report are based whenever possible on known facts, assumptions are needed throughout that either make the analysis more tractable or substitute for unknowns. For instance, assumptions are made about how long a state would have taken to "otherwise" adopt a new code or standard without the influence of DOE. Assumptions also have to be made as to the current rate of code compliance (largely unknown) and how this rate is influenced by DOE. Whenever possible, these assumptions are backed by published studies. In other cases, the assumptions are based on

[1] The American National Standards Institute; American Society of Heating, Refrigerating and Air-Conditioning Engineers; Illuminating Engineering Society of North America

expert judgment of staff with a long history of supporting DOE's Building Energy Codes Program (BECP).

Analysis of code impacts requires the following:

1. Establishment of a baseline for energy-efficient construction practices
2. The impact of code-to-code changes so the affect can be traced over time
3. An understanding of how that code affects energy use in a particular state or region
4. The amount of new construction by state or region that is impacted by the code
5. Assumptions about rates of adoption and compliance; and the impact of the program on these as well as the level of code stringency with and without these efforts.

Each of these topics is discussed in subsequent sections. With this information in hand, the actual calculation of energy savings is rather straightforward, even as it deals with multiple states, several code changes, impacts on heating, cooling, and lighting, and differences in fuel types.

Included with this report is a discussion of the current understanding of compliance rates (Appendix A) and a sensitivity analysis (Appendix B) for the results of this analysis.

2.0 Standards, Codes, and Adoption

This report focuses on the energy savings achieved through the adoption of building energy codes that are based upon various editions of ASHRAE Standard 90.1 for commercial buildings (or, more explicitly, "buildings, except low-rise residential buildings," thus including residential structures with more than three floors). Beginning with the 1989 Standard, the Illuminating Energy Society of North America (IESNA) became formally involved in setting the lighting requirements in the standard. These standards have been developed under American National Standards Institute (ANSI) approved consensus standard procedures. Because all three organizations are involved in the development of the standard, the official name of the 2004 publication of the standard, for example, is the *ANSI/ASHRAE/IESNA Standard 90.1-2004*. For compactness in this paper, these standards will generally be called out as ASHRAE Standard 90.1-xxxx (where xxxx is a specific year) or simply an edition related to a specific year (e.g., 1999 edition).[1]

The publications developed by ASHRAE and IESNA are energy *standards*, that is rules and overall requirements for construction practices and building equipment that induce lower energy use in buildings. The earlier standards, particularly the 1980 and 1989 editions, are not designed to be directly adopted as building *codes* by states and jurisdictions. Newer versions of Standard 90.1 are written to be directly adopted as building codes, but most states currently adopt the model *International Energy Conservation Codes* (IECC) or make modifications to the language of Standard 90.1 in codification and adoption of that standard. Codes are written in language that can be readily used by governments to enforce compliance with the underlying standards. While there is a distinction between standards and codes, for convenience this report will often use the two terms interchangeably.

Moreover, only a few states have adopted ASHRAE Standard 90.1in a direct fashion. More recently, many states have adopted building energy codes based upon the International Code Council's (ICC) IECC. The IECC has historically placed more emphasis on residential building codes, but their published codes have also addressed small commercial buildings. The IECC has also generally included an alternative path for compliance by commercial buildings by reference to a particular version (year of publication) of the ASHRAE standard. For example, Chapter 5 of the 2006 IECC calls out Standard 90.1-2004 as an alternative compliance path for commercial buildings. In this study, an adoption of any specific edition of ASHRAE Standard 90.1includes both direct adoption of the standard as the building code and indirect adoption based upon the IECC.

[1] In some cases, we also drop an explicit mention of IESNA, as ASHRAE is the organization that actually publishes the standard.

3.0 Retrospective and Prospective Analysis

The BECP is involved with developing, promoting, and providing support for building energy codes and standards. Like all DOE programs, BECP is required to annually estimate the future impacts of its work to support budget requests and also as a requirement of the Government Performance and Results Act (GPRA). BECP periodically estimates the historical impact of the program as well. Such an analysis requires developing counterfactual (alternate history) assumptions that essentially assume what would have happened (or not happened) in the absence of the program. In the past, PNNL conducted these prospective and retrospective estimates independently. However, the current approach is to combine these analyses in a single (spreadsheet) model. The current approach allows for analysis at the state level and includes specific parameters that address the adoption and compliance of current, pending, and future commercial building energy codes. The spreadsheet was developed such that it could also make estimates of the separate impacts of more stringent future codes, accelerated adoption of codes, and improved compliance with codes. Because the GPRA process is largely forward-looking, the state-level spreadsheet was originally designed to begin in 2000. That year was convenient as it was the first year states could adopt the latest ASHRAE/IESNA Standard 90.1-1999 published in October of 1999.

The earliest national energy standard in the United States was ASHRAE Standard 90-75 *Energy Conservation in New Building Design.* This standard was codified and published in 1977 as a *Model Code for Energy Conservation in New Building Construction* (MCEC) by ASHRAE, and a number of code official organizations under the auspices of the Council of American Building Officials (CABO). Several states did in fact adopt the MCEC, and the MCEC eventually led to the development of the Model Energy Code. This standard was followed by *ANSI/ASHRAE/IES Standard 90A-1980 Energy Conservation in New Building Design* for commercial buildings, with ANSI and the Illuminating Engineering Society (IES) joining ASHRAE in this document. While a case can be made for utilizing either 1975 or 1980 as the baseline year for retrospective analysis of the commercial building energy codes impact, the limited adoption of energy codes at that time and the presumably even more limited enforcement of these codes dilutes the actual impact of these codes. Thus, PNNL selected 1990 as the baseline year for the retrospective approach.

4.0 Baseline for the Analysis

Although the choice of 1990 will, by construction, omit some of the historical impact DOE has had in the building codes arena, it has several practical advantages. First, 1990 provides a reasonable basis upon which to compare the first major update of the 90A-1980 standard, as it occurs immediately after the publication of Standard 90.1-1989. Using 1990 as a base period allows the use of 90A-1980 as the baseline standard from which impacts can be estimated. This assumption provides a reasonable bound on how low energy efficient construction practices might have been prior to 1990, because Standard 90A was used by many states at some point and it is assumed that construction practices required by that code were well known.

A second advantage is that the year 1990 removes the need for considering an additional code level in the analysis (or building practices less stringent than 90A-1980). The spreadsheet currently attempts to separately measure the impact of each major code revision to ASHRAE Standard 90.1.[1] Because the entire spreadsheet is designed to analyze specific codes, any reduction in the number of code levels has a significant impact on the size and complexity of the overall spreadsheet model. This factor will be important if future work is devoted to extending this tool to perform prospective (future impacts of code changes) analysis as well.

We would also argue that most of the impact that DOE has had in buildings code area has in fact occurred since 1990. While there is little empirical evidence for this assertion, our judgment, based on discussions with participants in the development of Standard 90A-1980, is that 90A-1980 did not represent a large departure from existing current practice. A substantial portion of DOE's activities in the commercial codes arena in the 1980s was to support the technical foundation for ASHRAE Standard 90.1-1989, a standard much more stringent than 90A-1980. The adoption of the 1989 code by various states beginning in the early 1990s is captured in this framework.

[1] ASHRAE Standard 90.1-2001 is negligibly different from 90.1-1999. A substantially more stringent lighting code was part of the ASHRAE Standard published in 2004. A more modest update was made for ASHRAE Standard 90.1-2007, but very few states have adopted this code as of early 2009.

5.0 Code-to-Code Savings

The entire analysis is predicated on the fact that the energy savings can be reasonably measured from one code to another. As of the 1992 EPAct legislation, DOE has been tasked with providing a "determination" of whether the most recent edition of a national model code (e.g., ASHRAE Standard 90.1) will save energy compared to the prior edition. PNNL has performed several of these determinations, on both a qualitative and quantitative basis. The result is a comparison, for various building types and climates, of energy savings per building from the changes to the code. The energy savings are expressed in percentage savings which in turn can be translated into Btu/ft^2. In some cases, more detailed analysis of savings by end use (e.g., lighting), allows for further assumptions about savings by fuel source and hence impacts on emissions of CO_2 and other pollutants. These are foundational analyses which are in turn used in this report to estimate program impacts.

5.1 Comparison of ASHRAE Standard 90.1-1989 to ASHRAE Standard 90A-1980

The principal source for the energy savings to be derived from the adoption of Standard 90.1-1989 is the 1993 PNNL report prepared for DOE by Don Hadley and Mark Halverson (1993). The analysis described in that report utilized 10 commercial building prototypes in simulations that used, in turn, building characteristics based on Standard 90A-1980 and the Standard 90.1-1989. Overall, the report concluded that the average building constructed to the 1989 code would use 13% less energy (on a site or delivered basis) as compared to the 1980 code. The 13% figure appears, however, to be based upon a simple average across the building prototypes. In the current analysis, a very rough adjustment was applied to take account of the actual composition of construction across building types that occurred through the 1990s. With this adjustment, the overall percentage savings rises slightly to about 15%. The 15% reduction translates into about an 8,000 to 9,000 Btu per square foot (8 to 9 kBtu/ft^2) absolute difference across all building types and states.

5.2 Comparison of ASHRAE Standard 90.1-1999 to ASHRAE Standard 90.1-1989

The energy savings going from Standard 90.1-1989 to Standard 90.1-1999 were estimated by PNNL through a large number building energy simulations for seven building types and 12 locations across the U.S.[1] The simulations separately estimated the energy use intensities (EUI) in kBtu/ft^2 for Standard 90.1-1999for the envelope changes and the lighting changes. The energy use intensities, aggregated across building types and to census divisions are shown in Table 5.1. The building weights were derived from projections of future floor space construction from the National Energy Modeling System (NEMS), which in turn is used to project U.S. energy use as part of Annual Energy Outlook. In terms of site energy use, the 1999 standard resulted in an average national savings of approximately 4 %.[2] The electricity and gas savings by state were assumed to be similar for all states within a particular census division.

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[1] http://www.energycodes.gov/implement/determinations_90.1-1999.stm

[2] In some instances, the stringency of envelope requirements were relaxed between the 1989 and 1999 editions of the standards, leading to an increase in overall gas consumption shown in the middle panel of Table 1.

Table 5.1. Average Energy Use Intensities by Census Division for Standard 90.1-1989 and Standard 90.1-1999: Simulated Results

Standard 90.1-1989

No.	Census Division (augmented in West)	Weight	Electric EUI (kBtu/sf)	Gas EUI (kBtu/sf)	Site EUI (kBtu/sf)	Source EUI (kBtu/sf)
1	New England	0.040	39.83	15.83	55.65	144.42
2	Mid-Atlantic	0.098	39.74	14.53	54.26	142.69
3	East N. Central	0.166	37.91	18.45	56.36	141.23
4	West N. Central	0.064	42.55	19.88	62.43	157.60
5	South Atlantic	0.188	46.97	7.77	54.74	158.23
6	East S. Central	0.076	43.48	8.22	51.69	147.60
7	West S. Central	0.122	48.36	8.16	56.52	163.11
8	Mountain-North	0.074	40.80	17.21	58.02	149.08
9	Mountain-South	0.042	59.96	6.77	66.73	198.51
10	Oregon-Wash	0.024	38.04	11.79	49.83	134.24
11	California	0.108	41.27	7.40	48.68	139.69
	National Average		**43.36**	**12.09**	**55.44**	**151.52**

Standard 90.1-1999 - Envelope Change Only

No.	Census Division (augmented in West)	Weight	Electric EUI (kBtu/sf)	Gas EUI (kBtu/sf)	Site EUI (kBtu/sf)	Source EUI (kBtu/sf)
1	New England	0.040	39.77	16.58	56.35	145.07
2	Mid-Atlantic	0.098	39.70	15.16	54.86	143.28
3	East N. Central	0.166	38.01	20.03	58.04	143.31
4	West N. Central	0.064	42.42	22.08	64.49	159.61
5	South Atlantic	0.188	46.98	7.81	54.79	158.31
6	East S. Central	0.076	43.63	8.41	52.04	148.30
7	West S. Central	0.122	48.31	9.25	57.56	164.15
8	Mountain-North	0.074	41.06	17.46	58.52	150.15
9	Mountain-South	0.042	60.22	7.84	68.06	200.52
10	Oregon-Wash	0.024	37.41	12.69	50.10	133.25
11	California	0.108	42.04	7.63	49.67	142.39
	National Average		**43.46**	**12.85**	**56.31**	**152.70**

Standard 90.1-1999 - Lighting Change Only

No.	Census Division (augmented in West)	Weight	Electric EUI (kBtu/sf)	Gas EUI (kBtu/sf)	Site EUI (kBtu/sf)	Source EUI (kBtu/sf)
1	New England	0.040	36.29	17.18	53.47	134.66
2	Mid-Atlantic	0.098	36.16	16.03	52.19	132.98
3	East N. Central	0.166	36.28	19.95	56.23	137.72
4	West N. Central	0.064	38.25	21.10	59.35	145.25
5	South Atlantic	0.188	44.77	8.66	53.43	152.20
6	East S. Central	0.076	41.66	9.28	50.94	143.00
7	West S. Central	0.122	45.42	8.93	54.34	154.57
8	Mountain-North	0.074	38.36	18.02	56.39	142.20
9	Mountain-South	0.042	57.01	7.08	64.09	189.46
10	Oregon-Wash	0.024	35.90	12.62	48.52	128.36
11	California	0.108	38.86	7.82	46.69	132.47
	National Average		**40.80**	**13.09**	**53.89**	**144.48**

5.3 Comparison of ASHRAE Standard 90.1-2004 to ASHRAE Standard 90.1-1999

The DOE determination regarding Standard 90.1-2004 was published in the Federal Register at the end of December 2008. While the Energy Conservation and Production Act, as revised in 1992 (and, thus more commonly referred to as EPAct 1992) does not require a quantitative assessment of savings, such an assessment was included in the published determination. PNNL used a similar methodology for the 2004 determination as done previously for the 1999 assessment.[1] Thus, a large number of simulations were performed for seven major building types representing 11 locations across the U.S. In this work, however, separate simulations for lighting vs. envelope changes were not performed. As such, a single set of end-use intensities for the 1999 and 2004 were developed, with the 2004 set incorporating all of the revised requirements in the 2004 standard.

Table 5.2 shows the energy use intensities for the 1999 and 2004 standards by census division.[2] In terms of site energy use, the 2004 edition of the standard is estimated to generate national savings of 11.9% (1.0 - 43.75/49.64).

The 2004 ASHRAE Standard primarily affected only the lighting power density requirements for commercial buildings. The only other substantive change affected insulation requirements for buildings with mass walls in southern climates. Employing simulation results for locations not affected by the insulation changes, several simple regression models were developed with the aim of better representing the magnitude of savings for individual states. The first regression model examined the relationship between heating degree days (for the northern locations) and electricity savings. In general, a slight negative relationship was observed. This is because lighting changes in colder locations, which lost the heating "benefit" of the lighting, were not accompanied by the same level of savings in cooling electricity use, as demands for air conditioning are not as great. Electricity savings attributable to the changes in lighting requirements generally ranges between 6 and 7 $kBtu/ft^2$.

The second regression model was used to examine the interaction on the heating side between the change in electricity due to lighting (and cooling) and natural gas use. Figure 5.1 shows the estimated regression model based upon seven of the eleven locations used in the 2004 Determination.[3] The estimated model clearly shows that a greater fraction of the energy savings from lighting (and cooling) is offset by increased natural gas use in colder climates.[4]

[1] http://www.energycodes.gov/implement/determinations_90.1-2004.stm

[2] The tables were taken directly from the supporting spreadsheets for the 2004 determination, posted on the EERE/BTP website. Slight revisions in the simulation methodology produce small differences in the 1999 EUIs between the 1999 determination and the 2004 determination, yielding a lower overall average EUI for the later determination for the 1999 Standard.

[3] The locations employed in the regression model were: Providence, Detroit, Minneapolis, Denver, Phoenix, Tampa, and Seattle. The other locations in the 2004 Determination simulations were: Fresno, Shreveport, Knoxville, and Los Angeles.

[4] Strictly speaking, the coefficients cannot be interpreted solely as the energy offset to lighting resulting in greater heating, because change in electricity use includes both lighting and cooling. As a predictive device for the assigning savings to individual states, the approach is robust. An attempt to use the same approach for the 1989-1999 changes in the standard did not yield useful regression models, and thus the savings were assigned to states on the basis of census division averages from Table 5.1.

The two regression models were employed together, with average state-level heating degree days, to predict changes in electricity (decrease) and natural gas (increase) for 39 states. This framework could not be used for those southern states in which 2004 Standard altered the insulation requirements for some types of construction. For these states, the procedure essentially was reduced to assigning average state-level savings based upon the most representative location from the simulation work.[1]

Table 5.2. Average Energy Use Intensities by Census Division for Standard 90.1-1999 and Standard 90.1-2004: Simulated Results.

Standard 90.1-1999

No.	Census Division (augmented in West)	Weight	Electric EUI (kBtu/sf)	Gas EUI (kBtu/sf)	Site EUI (kBtu/sf)	Source EUI (kBtu/sf)
1	New England	0.042	36.34	12.27	48.61	128.46
2	Mid-Atlantic	0.069	36.07	12.12	48.19	127.44
3	East N. Central	0.137	36.95	16.24	53.19	134.81
4	West N. Central	0.070	37.94	17.50	55.44	139.32
5	South Atlantic	0.250	41.28	6.08	47.36	137.20
6	East S. Central	0.078	41.59	7.17	48.76	139.39
7	West S. Central	0.114	44.19	8.14	52.33	148.69
8	Mountain-North	0.058	39.10	14.53	53.62	139.69
9	Mountain-South	0.033	52.28	6.57	58.85	172.51
10	Oregon-Wash	0.027	34.50	9.74	44.24	119.84
11	California	0.123	36.86	6.24	43.10	123.41
	National Average		**39.75**	**9.89**	**49.64**	**136.59**

Standard 90.1-2004

No.	Census Division (augmented in West)	Weight	Electric EUI (kBtu/sf)	Gas EUI (kBtu/sf)	Site EUI (kBtu/sf)	Source EUI (kBtu/sf)
1	New England	0.042	31.05	13.41	44.46	113.02
2	Mid-Atlantic	0.069	30.75	13.09	43.84	111.70
3	East N. Central	0.137	31.60	17.65	49.25	119.46
4	West N. Central	0.070	32.55	19.00	51.56	123.98
5	South Atlantic	0.250	35.09	5.98	41.07	117.55
6	East S. Central	0.078	34.90	6.74	41.64	117.77
7	West S. Central	0.114	36.41	6.38	42.79	122.16
8	Mountain-North	0.058	33.40	15.97	49.37	123.29
9	Mountain-South	0.033	45.57	6.87	52.43	151.63
10	Oregon-Wash	0.027	29.24	10.73	39.97	104.31
11	California	0.123	30.90	5.50	36.39	103.74
	National Average		**33.67**	**10.07**	**43.75**	**117.60**

[1] The states that were affected by insulation requirements, and thus could not employ the straightforward regression approach, were: Alabama, Arkansas, Georgia, Louisiana, Mississippi, New Mexico, North Carolina, South Carolina, and Texas.

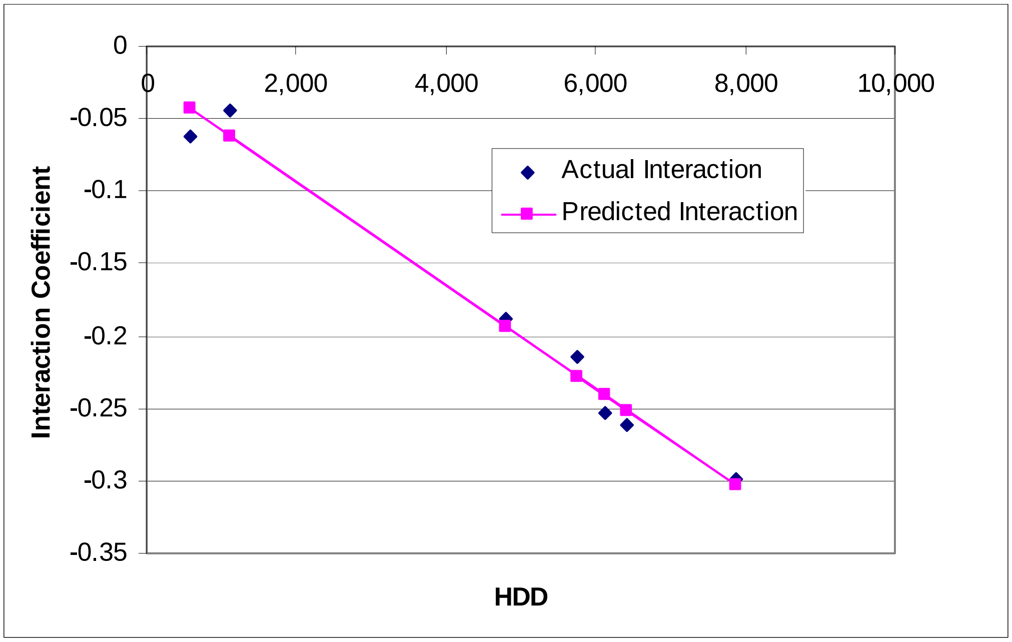

Figure 5.1. Electricity-Natural Gas Interaction Regression Model

6.0 Annual Floor Space Subject to Building Energy Codes

Unfortunately, there are no publicly available data sources that show annual new floor space of commercial buildings constructed by state. However, PNNL has recently purchased recent building project-level data from the F.W. Dodge group of McGraw-Hill Construction, a division of the McGraw-Hill Companies of New York.[1] These data cover nonresidential building projects collected by MHC-Dodge over the period 2003 through 2009. After aggregation of the floor space and valuation data to the state level, this information forms a benchmark for the historical series from 1990 through 2008.

Table 6.1 presents a comparison of the published national data from Table 931 in the 2010 *Statistical Abstract* with the aggregated data based upon the project-level (micro) data obtained by PNNL. Both values relate to total nonresidential construction, but exclude manufacturing buildings. The top panel of Table 6.1 indicates that the correspondence for floor space is very good, with the maximum deviation of less than 1.5% over the six years in which the published values and an aggregation of the micro data overlap.

Table 6.1. Comparison of Published and Aggregated Micro Data from MHC-Dodge, New Commercial Floor Space, 2003-2009.

Total Square Feet (millions)			
	Published	Micro	Micro/Pub.
2003	1,329.0	1,313.0	0.988
2004	1,371.0	1,355.5	0.989
2005	1,448.0	1,428.7	0.987
2006	1,554.0	1,535.5	0.988
2007	1,578.0	1,557.4	0.987
2008	1,303.0	1,293.9	0.993
2009	NA	725.9	NA

Value of Construction (billion dollars)					
	Published	Micro (Total)	Micro (New + Additions)	Micro (Major Alterations)	Alterations/ (New + Additions)
2003	149.2	147.5	120.1	27.4	0.228
2004	156.5	154.9	125.7	29.2	0.232
2005	172.3	170.5	139.7	30.8	0.220
2006	203.7	202.1	168.0	34.1	0.203
2007	218.3	216.6	177.0	39.6	0.224
2008	213.3	209.7	168.2	41.5	0.246
2009	NA	155.8	116.3	39.5	0.339

Notes:
(1) U.S Nonresidential construction, excl. manufacturing
(2) Published value includes major alterations, not included micro data
Source: Published data from Table 931 in *Statistical Abstract of the U.S: 2009*

[1] As a shorthand naming convention, the term "MHC-Dodge" will be used to refer to this data source.

The differences in the lower part of the table stem from the treatment of projects that entailed only major alterations. The published valuation data in the *Statistical Abstract* include the value of major alterations, while the project-level data exclude these projects. Major alterations do not create any additional floor space; thus the floor space values match very closely while the valuation values do not. PNNL acquired the MHC-Dodge project data for both new construction (including additions to existing buildings) as well as for major alterations[1]. The U.S. totals from the micro data are shown in the "Micro (New + Additions)" and "Micro (Major Alterations)" columns of Table 6.1. The value of alterations was sustained in 2008 and 2009, in spite of a slowdown in new construction contracts. Accordingly, the ratio of the value of alterations to new construction increased in both 2008 and 2009, particularly during 2009 with the dramatic decline in new construction.

The value of the micro data, acquired by PNNL, is that it provides an accurate measure of construction activity by state over much of the last decade. For new construction, this data set provides a physical measure of construction in terms of square footage. The assumptions used to convert the value of alterations to a measure of floor space that will be subject to energy codes is explained below.

While MHC-Dodge is an extremely valuable source for measuring the amount of new floor space additions, this source does not cover all new commercial building projects in the U.S. MHC-Dodge does not cover smaller projects, typically only those costing less than $100,000. Moreover, some projects may not be captured, simply because they are not put out for bid by building contractors. Thus, some means must be applied to account for this under-coverage.

For some years now, PNNL has undertaken analyses of growth in commercial floor space. For that work, the published national square footage data by year from MHC-Dodge have been applied in a PNNL spreadsheet model to estimate annual total floor space of existing U.S. commercial buildings. Using a floor space survival function, the model is calibrated to yield similar growth rates in total U.S. commercial building floor space as reported in various editions of EIA's *Commercial Building Energy Consumption Survey* (e.g., EIA 2006). As part of this calibration, the MHC-Dodge figures for total construction are factored upward by 20%, to account for underreporting (esp., small building projects).[2] While it is likely that the underreporting is not the same across states, there are no data to support differential adjustment factors by state. Thus, the 20% factor is applied uniformly across all states. Simply put, after this adjustment, the sum of the state-level square footage estimates would be 20% higher than those shown in the top portion of Table 6.1 to account for this under-coverage.

The data acquired by PNNL does not cover the earlier period from 1990-2002 included in this analysis. For this earlier time period, values of all types of construction projects (from MHC-Dodge) by state from the *Statistical Abstract of the U.S.* were used. Unfortunately, these total values include both alterations and manufacturing construction, but nevertheless can be used to provide a reasonable approximation to the distribution of new commercial building construction across states.

[1] Below it is implied that "new" construction includes both new buildings and additions.

[2] This adjustment is similar to that used by the Census Bureau to develop estimates of private nonresidential construction in the U.S. The data from McGraw-Hill Construction (F.W. Dodge) is adjusted upward by 25% to account for undercoverage of projects collected by McGraw-Hill. (See the methodology description on http://www.census.gov/const/www/methodpage.html) The smaller adjustment factor in PNNL's work provides a better calibration with the published floor space data in the CBECS.

The first step in the development of state-level estimates for the years prior to 2003 was to generate a set of allocation factors based upon the project-level data available from MHC-Dodge. An allocation factor for each state was developed, creating the average new floor space *per dollar of total* construction activity over the period 2003-2007. Based upon Table 5.2, these years were selected as a benchmark period, under the assumption that this period may provide a reasonable representation of the composition of construction activity in prior years. For each state, the allocation factor was then multiplied by the value of total construction projects in that state (as published in the *Statistical Abstract*) for the years 1990 through 2002. Of course, under the assumption that the ratio of alteration and manufacturing activity to new construction remained constant in these previous years (and that the overall cost of construction remained constant), the product of these two factors would yield a completely accurate estimate of the amount of new floor space in these previous years. While this assumption cannot be assumed to be strictly true, the judgment is that the composition of construction in each state was sufficiently similar in the previous decade as to lead to a reasonable first approximation for new construction activity.

The sum of the estimated new floor space across states from this first step was then compared to the national estimate of total new floor space published in the *Statistical Abstract*. In general, the calculated sum was less than the known amount of total floor space, owing to the lower cost of construction (per square foot) in these earlier years as compared to the 2003-2007 benchmark period. The second step of the estimation process was then to scale all of the preliminary state-level estimates uniformly so as to yield a final total matching the published national (control) total. In essence, this procedure is valid under a plausible assumption that the cost per square foot increased in all states by roughly the same in percentage terms. The overall procedure thus maintains the observed differences across states in both the composition of construction activity and relative construction cost differences (e.g., New York costs are greater than those in South Carolina), as evidenced by the 2003-2007 data period. Because nearly 80% of the total value of all construction activity is for new construction at a national level, using the state-level data that includes alterations can still provide a reasonably accurate distribution of new floor space by state.[1]

The estimation of alteration construction activity was performed in a related manner. The average ratio of the value of alterations to the value of new construction is computed using data from 2003 through 2007. Unfortunately, no data is collected that links the value of alterations to the amount of floor space affected by the alteration. At this point, two simplifying assumptions were made. The first assumption is that when the alteration (renovation) covers a major building system involving the envelope, lighting, or HVAC, the per square foot cost of such an upgrade is roughly comparable to that in a new building. The second assumption is that about *half* of all alterations cover these energy-using subsystems, and the remaining half cover cosmetic and other upgrades. Thus, to estimate the effective amount of state-level floor space from alterations that would have been subject to a building energy code, the alteration/new ratios from 2003 through 2007 described were first multiplied by the estimated amount of new floor space for each year between 1990 and 2002 (from the procedure described above). These values were then multiplied by 0.5 to reflect the assessment that not all the described alterations will have an energy impact.

[1] The contamination of the value data with manufacturing construction is also judged not to be highly significant. In the period 1990-2002, the percentage of new national nonresidential floor space typically ranged between 4 and 10%.

The range of alteration activity shows some considerable variance across states. Using the benchmark 2003-2007 years, the largest ratios of the value of major alterations to new construction were in Hawaii (63%), New York (59%), and Washington, D.C. (43%). In the western and more rural states the ratios were generally between 12% and 25%. (e.g., Colorado (14%), Texas (20%), and Utah (15%). The smallest ratio was in Nevada, with 8.5%, resulting from the very rapid population growth during this period combined with few constraints on buildable land.

7.0 Adoption and Compliance Assumptions

In addition to the estimates of the code-to-code changes, two groups of key assumptions are required to complete the analysis. The first group relates to the accelerated adoption of building codes prompted by DOE activities. The second group deals with the impact that DOE has had on influencing compliance with the prevailing code.

7.1 Accelerated Adoption

From 1990 to 2000, the impact of the BECP program was primarily attributable to efforts to accelerate the adoption of the ASHRAE 90.1-1989 standard and to provide materials to improve the compliance with that version of the code. After 2000, energy savings are also attributable to DOE efforts to increase the stringency of the code, as states update to both the Standard 90.1-1999 and 90.1-2004.

Consistent with the methodology suggested by the National Research Council (NRC 2000) to evaluate DOE's energy efficiency programs, this analysis only assumes that DOE efforts will *accelerate* the adoption of the most recent national building code (or equivalent).[1] That is, with a favorable political and fiscal climate, some states could have been expected to adopt a code within a few years without federal assistance.

Unfortunately, there is no empirical evidence upon which we can rely to ascertain how much longer it may have taken a specific state to adopt the code in question. The proposed approach in this analysis is to define five categories of states and assign a discrete period of years that represents our best judgment as to the impact DOE had in accelerating the adoption of a code. The five categories of states are:

1. State Codes Exceeding ASHRAE 90.1
2. Rapid Adoption Rate
3. Medium Adoption Rate
4. Slower Adoption Rate
5. States Without State-Wide Energy Code

7.1.1 State Codes Exceeding ASHRAE 90.1

This category of states have historically developed their own codes; in terms of stringency, these codes have generally exceeded the most recent ASHRAE standard. For this analysis, the states assumed to have fallen into this category were: California, Oregon, Washington, and Florida.

[1]The concept of an acceleration is presented in " Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000," (2001), National Research Council, National Academy Press, Washington, D.C. In the case of the codes activities, it is argued that the availability of compliance software, training assistance, and, in some cases direct technical support to show the benefits of adoption in a particular state, all lead to adoption more rapidly than would otherwise be the case.

7.1.2 Rapid Adoption Rate

By state law, Maine was required to adopt the most recent ASHRAE code. Maine state law has now been changed to require adoption of the latest version of the IECC, but is still treated as a rapid adopter. Other states, such as Massachusetts, were very early adopters of the most recent ASHRAE commercial standard. No accelerated adoption is assumed for these states.

7.1.3 Medium Adoption Rate

Specifically, for this analysis, these states have shown a willingness to adopt a state-level building code with minimal federal support. This willingness is demonstrated by the adoption of the 90A-1980 on similar code during the 1980s. We assume that these states would have adopted the 1989 code within five years of the actual adoption date, had BECP not existed during the 1990s.

7.1.4 Slower Adoption Rate

These states are judged to have taken little action to update or adopt a commercial building code without substantial DOE support. We assume that these states would have adopted the 1989 code within eight years of the actual adoption date, had BECP not existed during the 1990s.

7.1.5 States Without State-Wide Energy Code

At least in terms of commercial building energy codes, there are still a number of states that have not yet adopted a mandatory state-level code, even with stringency equivalent to Standard 90.1-1989. Missouri, Alabama, North Dakota, and Wyoming are all examples of this lack of adoption. In terms of the analytical approach, these states reflect no direct impact from BECP.

7.2 Spillovers and Implicit Adoption

While some states have not yet adopted any state-wide commercial energy code, it is unreasonable to believe that common building practice remains at the level of Standard 90A-1980 in these states. Building efficiency has improved nationwide due the presence of more cost-effective technologies (e.g., electronic ballasts and T-8 lamps) as well as the transfer of knowledge of efficient construction practices from states with building energy codes. The use of national or regional architect-engineering firms in these states undoubtedly influences the level of common practice. This entire process is often characterized as a “spill-over” effect, some of which is simply due to market forces but is also impacted by the adoption of energy codes in other states. It can be argued that the existence of BECP has indirectly influenced new building efficiency in these states, even if it is difficult to quantify.

To recognize that building practices in all states will likely eventually meet a given historical code level, the approach in this analysis incorporates the notion of an “implicit” adoption. As regards to the 90.1-1989 standard, it is assumed that by 2004 building construction practices and technologies reach the efficiency levels implied by that standard, even in states and jurisdictions without a formal energy code. For the 1999 and later ASHRAE Standards, this time lag is assumed to be ten years.[1]

In reality, this process of knowledge spillovers related to energy codes is a gradual one, with some practices and technologies likely being employed in non-code states soon after a code has been adopted in a neighboring state. This spillover process would accelerate as more states adopt and regional design and construction firms carry over efficiency measures in projects in states without codes (or without the most recent national model code). The spreadsheet model does not incorporate the gradual nature of this process but instead assumes a sudden, one-year transition to the newer, more energy-efficient practices (code level).

A more difficult issue is how to attribute any benefits to the DOE's codes programs from this process. Because the analysis assumes that adoption occurs all at once in a state in a single year the calculation methodology implicitly assumes that there are no spillover effects from other states, for the state undergoing adoption in that year. However, we can still speak of an acceleration even of these implicit adoptions that is a result of national codes development and deployment activities. Without the DOE activities in a large number of states, even the implicit adoptions would have occurred later than in actuality. For purposes of attributing some benefits in such (non-code) states, we assume, albeit without a particular basis, a five-year acceleration, and thus all the energy savings from the buildings built during this time period are attributed to BECP.

Table 7.1 shows our current assumptions that relate to the acceleration of code adoption resulting from BECP activities for three specific editions of ASHRAE Standard 90.1 (1989, 1999, and 2004). The (gray) highlighted years are cases in which the code is assumed to have been adopted implicitly. Table 7.1 incorporates an additional assumption that the acceleration prompted by BECP is likely to be smaller with respect to more recent codes. As states gain more experience in the process of evaluating and adopting the latest national code, we expect that they would have been more willing to adopt these later standards (90.1-1999 and 90.1-2004). This assumption is reflected in the acceleration time periods declining by one year in each of the subsequent editions of the code. Thus, in states where it is assumed that BECP advanced the adoption of 90.1-1989 by eight years, the acceleration period is reduced to seven years for 90.1-1999 and to six years for the 2004 code.

7.3 Improved Compliance

The second group of assumptions deals with compliance to the provisions of the more stringent building code. As there is little solid information on current compliance rates, the analysis must be constructed using a series of assumptions about compliance, and changes thereto both in the absence and presence of the program. For an overview of the current understanding of compliance rates, see Appendix A.

[1] The assumption that a "baseline" construction practice is at least equivalent to ASHRAE Standard 90.1-1999, even in states without a state-wide code, is being used in a current (2009) PNNL study to estimate to estimate the potential energy savings from bringing all states up to the current 90.1-2007 code.

Table 7.1. Adoption Dates and Acceleration Assumptions by State.

State	90.1-1989 Year Adopted	90.1-1989 Delay w/o program (years)	90.1-1999 Year Adopted	90.1-1999 Delay w/o program (years)	90.1-2004 Year Adopted	90.1-2004 Delay w/o program (years)
Alabama	2004	0	2009	0	2015	0
Alaska	2004	0	2009	0	2015	0
Arizona	2004	0	2009	0	2015	0
Arkansas	1995	0	2005	0	2010	0
California	NA		NA		NA	
Colorado	2004	0	2009	0	2015	0
Connecticutt	1994	5	2005	4	2010	3
Delaware	1996	5	2004	4	2010	3
District of Columbia	2000	8	2009	0	2009	6
Florida	NA		NA		NA	
Georgia	1996	5	2003	4	2007	3
Hawaii	1995	5	2004	4	2010	3
Idaho	2004	0	2005	7	2008	6
Illinois	2004	0	2006	7	2010	6
Indiana	2004	0	2009	0	2015	0
Iowa	1993	5	2007	4	2007	3
Kansas	1997	5	2003	4	2007	3
Kentucky	2004	0	2005	7	2007	6
Louisiana	1999	8	2005	7	2007	6
Maine	1990	5	2000	4	2005	3
Maryland	1997	5	2005	4	2007	3
Massachusetts	1992	5	2001	4	2008	3
Michigan	2003	8	2003	7	2008	6
Minnesota	1992	5	2009	0	2009	0
Mississippi	2004	0	2009	0	2015	0
Missouri	2004	0	2009	0	2015	0
Montana	1996	5	2005	4	2008	3
Nebraska	2004	0	2005	7	2010	6
Nevada	2004	0	2005	7	2011	6
New Hampshire	1993	5	2002	4	2007	3
New Jersey	1997	5	2002	4	2007	3
New Mexico	2004	8	2004	7	2008	6
New York	1991	5	2002	4	2008	3
North Carolina	1995	5	2002	4	2006	3
North Dakota	2004	0	2009	0	2015	0
Ohio	1995	5	2002	4	2007	3
Oklahoma	2004	0	2009	0	2015	0
Oregon	NA		NA		NA	
Pennsylvania	2004	8	2004	7	2007	6
Rhode Island	1997	5	2004	4	2007	3
South Carolina	1997	8	2005	7	2008	6
South Dakota	2004	0	2004	0	2015	0
Tennessee	2004	0	2004	0	2015	0
Texas	2001	8	2001	7	2008	6
Utah	1995	5	2002	4	2007	3
Vermont	1996	5	2001	4	2007	3
Virginia	1997	8	2008	7	2008	6
Washington	1994	5	2002	4	2005	3
West Virginia	2003	8	2003	7	2010	6
Wisconsin	1997	5	2008	4	2008	3
Wyoming	2004	0	2004	0	2015	0

There are many definitions of compliance, but for our purposes, the definitions can be condensed to define the percentage of the potential energy savings caused by constructing to the level of the prevailing code as compared to the prior code or "current practice." The spreadsheet actually recognizes a definition of legal compliance in which all of the provisions of the code are met, but then must also account for energy savings in buildings that only partially meet the requirements of the new code.

The impact of training and the availability of software compliance tools is deemed to have a notification and educational aspect. Without training, it is reasonable to assume that most builders and code officials would not change behavior and thus the training serves a critical information dissemination function. However, it could be expected that the more progressive municipalities and builders would attempt to meet at least some of the more well-publicized requirements of the new code, e.g., lighting, solely from the knowledge that a new code is in effect. Another potential reason for some dissemination of requirements from new codes is professional liability. Registered professional designers may be held to the "most current" design standards even if their state or local jurisdiction is using an outdated energy code.

For purposes of the analysis, we assume that the percentage of potential energy savings would be between 20% and 30% of the total potential even if no specific training and software materials were supplied to support compliance with the revised code. This particular range applies to the first major national standard considered in the analysis, ASHRAE Standard 90.1-1989. It is reasonable to expect that as states become more experienced with building energy codes, the percentage of energy savings would increase for subsequent editions of the code, even without DOE involvement for deployment.

Even with training, it also not plausible to expect that all provisions of the new code would be complied with, at least in the first year or two of the new code. As a rough range across all states, we assume that the initial fraction of potential energy savings for the Standard 90.1-1989 would increase to between 60% and 70% (of the potential savings) even if training were offered.

In addition, the percentage of compliance is expected to increase over time for a given code, even without formal training, as more experience is gained by the building community. In our analytical framework, this effect is modeled as a reduction in the non-compliance with the code. Generally, we assume that without training materials and software compliance tools, compliance would increase very slowly. In the spreadsheet model, we project a likely compliance rate after 10 years. With training and software compliance tools, we assume that the increase in compliance will be more rapid.

The specific assumptions related to compliance are shown in Table 7.2 (for envelope requirements) and Table 7.3 (for lighting requirements). The compliance rates for lighting, without the DOE activities, are assumed to be somewhat greater than for envelope. The rationale for this assumption is that implementation and compliance with lighting codes is more straightforward and observable while envelope codes are less so.

Taking a more detailed look, Table 7.2 provides the compliance assumptions for three editions of the ASHRAE 90.1 standard related to envelope. In the first row, assuming no DOE deployment activities had been undertaken, the compliance rate (in legal terms) is assumed to be 10% of newly constructed buildings. These buildings achieve 100% of the savings potential prompted by the code (as compared to the previous code based upon Standard 90A-1980). For non-compliant buildings, only a fraction (0.1%) of the potential energy savings is assumed to be achieved. Combining these two assumptions, an estimated 19% of the potential energy savings is achieved in the initial year of the code [column (d), Table 7.2]. After 10 years, the legal compliance rate is assumed to increase to 40% and the percentage of savings rises to 46%.

Table 7.2. Code Compliance Assumptions for Envelope Requirements.

	(a) Initial Compliance (%)	(b) Compliance after 10 Years (%)	(c) Fraction of Savings for Non-Compliant Units	(d) Initial Compliance (Energy terms) %	(e) 10-Year Compliance (Energy Terms) %
90.1-1989					
Without BECP	20%	50%	0.2	36.0%	60.0%
With BECP	40%	80%	0.5	70.0%	90.0%
90.1-1999					
Without BECP	20%	50%	0.2	36.0%	60.0%
With BECP	40%	80%	0.5	70.0%	90.0%
90.1-2004					
Without BECP	30%	60%	0.2	44.0%	68.0%
With BECP	50%	80%	0.5	75.0%	90.0%

Notes:
(a), (b) Compliance in legal terms, defined as percentage of new building floor space fully meeting provisions of code change
(c) Fraction of potential energy savings from previous code in units not fully (legally) compliance
(d),(e) Fraction of potential savings for both legally compliant and not legally compliant buildings

Table 7.3. Code Compliance Assumptions for Lighting Requirements.

	(a) Initial Compliance (%)	(b) Compliance after 10 Years (%)	(c) Fraction of Savings for Non-Compliant Units	(d) Initial Compliance (Energy terms) %	(e) 10-Year Compliance (Energy Terms) %
90.1-1989					
Without BECP	20%	40%	0.2	36.0%	52.0%
With BECP	40%	60%	0.4	64.0%	76.0%
90.1-1999					
Without BECP	30%	50%	0.3	51.0%	65.0%
With BECP	50%	68%	0.5	75.0%	84.0%
90.1-2004					
Without BECP	30%	60%	0.4	58.0%	76.0%
With BECP	50%	68%	0.5	75.0%	84.0%

Notes:
(a), (b) Compliance in legal terms, defined as percentage of new building floor space fully meeting provisions of code change
(c) Fraction of potential energy savings from previous code in units not fully (legally) compliance
(d),(e) Fraction of potential savings for both legally compliant and not legally compliant buildings

More formally, the logic in the previous paragraph can stated in terms of a straightforward formula. Let P(C) be the amount of floor space that is legally compliant (i.e., 100% of the potential savings from the most recent code) and P(NC) be percentage of floor space that is non-compliant. However, we recognize that there is some fraction of the potential (code-to-code) energy savings (FES) even in the floor space represented by these non-compliant buildings. Thus, compliance in terms of energy savings (CE) can be expressed as:

$$CE = P(C) + P(NC) * FES \qquad (7.1)$$

Taking our numerical examples in terms of Table 7.2 and substituting into Equation (7.1), we have initially:

$$CE = 0.20 + 0.8 * 0.2 = 0.36$$

And after 10 years,

$$CE = 0.50 + 0.5 * 0.2 = 0.60$$

Given the outreach, training, information dissemination activities, and code compliance tools developed under DOE's program at the time, initial (legal) compliance is assumed to have initially been 40%. With these activities also leading to a greater fraction of savings (0.5) for non-compliant buildings, energy savings is calculated [based on Equation (7.1)] to be 70% of potential (based on a code-to-code comparison). After 10 years, the percentage of energy potential savings, as implied by the two standards, is assumed to increase to 90%. Generally, these assumptions imply that the DOE programmatic activities were responsible for achieving about half of the code-to-code savings implied by full compliance (i.e., in the first year 70% - 36% = 34%). Figure 7.1 compares the compliance rates, with and without BECP, over time.

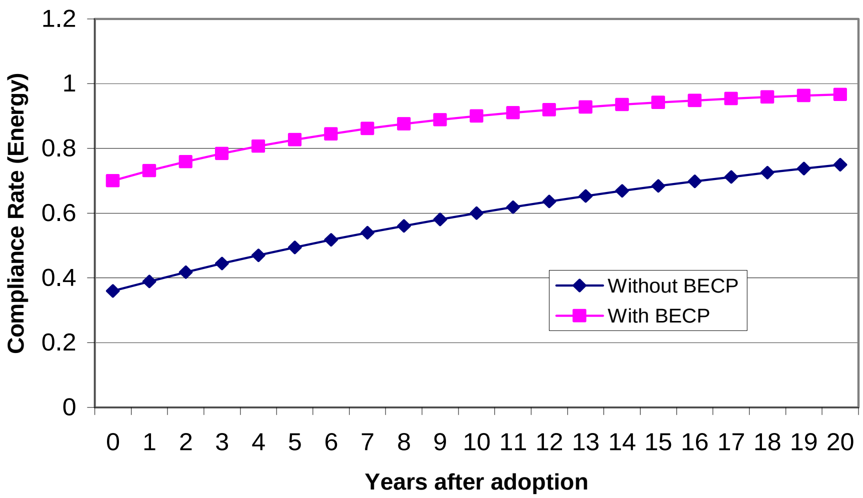

Figure 7.1. Assumed Paths of Compliance Rates for 90.1-1989 Envelope, With and Without BECP

Unfortunately, there are a limited number of empirical studies that have addressed the issue of compliance with respect to energy codes for commercial buildings. Three extant studies were conducted in Washington, Vermont, and Hawaii, all during the late 1990s. Two of the studies develop estimates of the potential energy savings captured by the code (Washington and Hawaii) and both fall in the range of 80 to 90%. Both studies were performed several years after a new code had gone into effect. No quantitative estimates of energy savings were developed for the New Hampshire, but the relatively high rate of legal compliance for seventeen specific aspects of the code suggests that savings would also be in the neighborhood of 80% to 90%. Appendix A provides brief summaries of each of these studies.

The analysis assumes that even without DOE activities, the compliance rates for later codes (based upon 90.1-1999 and 90.1-2004) would increase. Thus, for example, the table shows that the percentage of potential energy savings from the 2004 standard (as compared to the previous 90.1-1999 standard) would be 44%. The effectiveness of the DOE activities is also assumed to increase slightly such that 75% of the savings in the initial year is achieved. Thus, by the 2004 standard the incremental impact of BECP is reduced from about 50% of the code-to-code savings to about 30% of such savings.

Table 7.3 shows the compliance rate assumptions for lighting. The compliance rates for lighting are largely based on a recent national survey conducted by ZING communications. This survey covered U.S. architects, electrical engineers, lighting designers to examine compliance with the lighting provisions in the 1999 and subsequent editions of ASHRAE Standard 90.1.[1] The quantitative results of the survey were based upon 431 responses. The survey results were assumed to reflect compliance after 10 years with regard to Standard 90.1-1999 (as a conservative assumption). The compliance rates for the 1989 edition of the standard were then set to be slightly lower than those for 1999 Standard under the assumption that the initial experience would have resulted in lower compliance. More detailed discussion of the ZING survey and how it was used to develop the quantitative assumptions in Table 7.3 is presented in Appendix A.

The numerical assumptions related to compliance are also applied uniformly across all states. In some states, there has been greater support of training and software using state resources, and as such, would not be as affected if DOE support were not available. As yet, these enhancements have not been included in this analysis.

[1] The final report was issued in January 2007. The full report can be accessed on the energycodes.gov website: http://www.energycodes.gov/implement/code_compliance.stm. Click on the entry for Lighting Controls Association, "Energy Code Survey Suggests 80% Compliance Rate."

8.0 Mathematical Framework for Calculating Savings

The formal framework for calculating the savings from the building codes can be laid out as follows. First, let (k) be an index of relevant editions of the code (i.e., k = 0 for 90A-1980, k = 1 for 90.1-1989, k = 2 for 90.1-1999, and so forth). We then define key variables:

ECTC(k) = "code-to-code" energy savings per square foot between code edition k and code edition (k-1)

T(k) = year in which code k is adopted
$A_k(t)$ = adoption status of code k in year t.
$A_k(t) = 0$ if $t < T(k)$
$A_k(t) = 1$ if $t >= T(k)$

CE(t – T(k)) = compliance (in energy terms) t – T(k) years after adoption of code k. See Equation (7.1).

NFS(t) = additions to floor space in year t (i.e., new floor space)

The savings for the floor space additions in any year t is the sum of the adoption status of compliance rates for all editions of the code up to that point in time. Thus, we have for energy savings (ES) in year t

$$ES(t) = \sum A_k(t) \times CE(t - T(k)) \times ECTC(k) \times NFS(t). \quad (8.1)$$

Note that equation (8.1) is generic in the sense that it applies to the situation with or without the BECP activities. As described in the previous two subsections, BECP has primarily been involved in accelerating the adoption and increasing the compliance with various versions of the code. Formally, we can consider these influences to affect the first two terms of Equation (8.1), Denoting these modified functions with an "*", we can then rewrite (8.1) as[1]

$$ES^*(t) = \sum A_k^*(t) \times CE^*(t - T(k)) \times ECTC(k) \times NFS(t) \quad (8.2)$$

If we take Equation (8.1) as representing the "counterfactual" situation with no BECP, then the savings attributable to BECP in year t is simply

$$ES^*(t) - ES(t). \quad (8.3)$$

In terms of historical analysis, we have assumed that the stringency (represented by the code-to-code savings) and the timing of the various editions of Standard 90.1-1989 to be independent of DOE influence. In fact, DOE has devoted considerable resources, beginning with Standard 90.1-1989, to assist ASHRAE in its code development activities. One could argue that DOE activities have helped to make the 1999 and 2004 editions of 90.1 standard more stringent than previous standards. However, in this analysis, we have ignored this third method through which DOE activities may have yielded additional energy savings.[2]

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[1] To be more rigorous, the values for the adoption year, T(k), without and with BECP, are assumed to be different. These alternative values thus affect the adoption status function, $A_k(t)$.

[2] This omission stems largely from the any credible method of developing a counterfactual stringency that would have been achieved without DOE participation in the ASHRAE process. For the prospective analysis described in Appendix C, we do account for a DOE impact on future stringency.

9.0 National Energy and Economic Benefits

Based upon the above assumptions and an allocation of national level new floor space to the various states, we have calculated energy savings for the period 1990-2008 attributable to BECP efforts. Table 9.1 shows the results of this analysis, in terms of source (or primary) energy.[1] The first column shows the estimated savings from the baseline assumptions. By the end of the decade, some states are assumed to have adopted a code equivalent to Standard 90.1-1989, even without the activities of the BECP. As shown in Table 7.2 and Table 7.3, the program is assumed to have accelerated the adoption and increased compliance of the 1989 code in a number of states. By 2000, the cumulative effect of these activities results in energy savings of over 60 trillion Btu—this represents the total savings, as compared with no states adopting Standard 90.1-1989 and where compliance with the older 90A-1980 was unchanged. The program impact is the difference between these two scenarios; by the end of 2000 the program impact is estimated to have been 53 trillion Btu of energy savings.

Table 9.1. Estimated Impact of BECP Program to the Commercial Buildings Sector, 1990-2008

Year	Baseline (Trillion Btu, Source)	Total Savings, w/BECP (Trillion Btu, Source)	Program Impact (Trillion Btu, Source)	Energy Cost Savings (Million 2008$)	Cumulative Cost Savings (Million 2008$)
1990	0.0	0.0	0.0	0.1	0.1
1991	0.1	0.6	0.5	5.8	5.2
1992	0.1	1.6	1.5	15.9	19.3
1993	0.1	2.7	2.6	28.1	44.2
1994	0.2	4.5	4.3	45.2	84.3
1995	0.2	8.2	8.0	81.7	156.8
1996	0.6	13.3	12.7	127.6	269.9
1997	1.5	20.9	19.4	191.6	439.7
1998	2.8	32.6	29.7	283.1	690.6
1999	4.9	46.7	41.8	383.9	1,030.9
2000	9.0	62.3	53.3	497.5	1,471.8
2001	14.3	83.1	68.8	681.2	2,075.6
2002	20.4	103.9	83.5	795.7	2,780.8
2003	26.2	124.0	97.8	941.1	3,614.9
2004	32.1	152.3	120.2	1,150.9	4,634.9
2005	39.3	182.9	143.6	1,429.3	5,901.7
2006	48.5	216.7	168.2	1,820.6	7,515.3
2007	58.7	257.1	198.4	2,185.5	9,452.3
2008	70.3	305.3	234.9	2,783.3	11,919.1

The savings in more recent years include the impacts of accelerated adoption and increased compliance with the later 1999 and 2004 editions of the 90.1 standard. However, the impact of the more recent codes is as yet significantly lower than that of the 1989 edition, as the (code-to-code) energy savings of the 1999 edition was relatively small and the adoption of the 2004 code has only recently

[1] Electricity is converted to primary Btu with a conversion factor of 10,800 Btu/kWh, equivalent to a ratio of primary to delivered energy of 3.165.

occurred in a few states. Figure 5.1 shows the attribution of savings from the 1989 standard and from the two more recent standards, as well as showing the relative importance of accelerated adoption versus increased compliance. As Figure 5.1 indicates, the accelerated adoption and increased compliance with the 1989 edition of the standard is responsible for the major proportion of benefits in the latter years of the analysis.

From Figure 9.1 (and Table 9.1), total annual energy savings reach near one-third of a quad by 2008. These savings reduced commercial sector energy use in that year by over 1.5%. Applying national average commercial fuel prices for electricity and gas in each year, the estimated energy cost savings can be calculated. By 2008, the cost savings are more than $2.5 billion per year (in 2008 dollars). Cumulative cost savings since 1990 total nearly $12 billion.

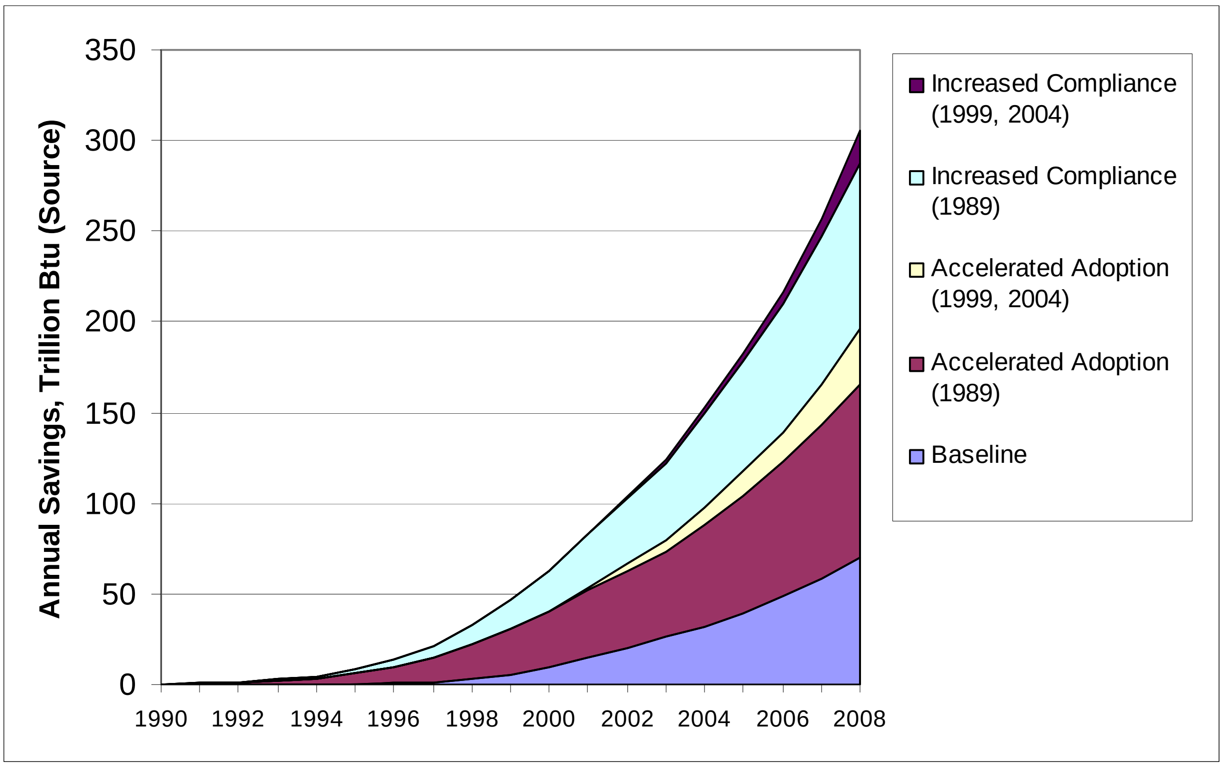

Figure 9.1. Attribution of Key Components to Total Energy Savings

These cost savings can be compared in a simplistic fashion to the budgetary cost of BECP over this same period (1990-2008), estimated to be around $40 million. Dividing these two figures, we would obtain a ratio of more than $300 in energy cost savings for each DOE program dollar spent. This does not account for state implementation costs or for the additional cost of construction to meet these higher code levels. However, the DOE program cost is also overstated as some portion of these EERE expenditures have been devoted to improving residential building codes. In any case, the simple return on investment appears to be positive, as well as large.[1]

Given the uncertainty behind many of the assumptions employed in the methodology, the historical energy savings can only be considered as approximate.[2] Several caveats should be noted with regard to the specific assumptions and data behind these estimates:

1. Assumed compliance rates were uniformly used across all states that adopted the 90.1-1989, 90.1-1999, and 90.1-2004 codes. A method of using the historical data on training and use of the COM*check* software to differentially adjust these rates might be developed.
2. Some additional study of the reports comparing the 90A-1980 and 90.1-1989 standards is warranted. The two studies cited above use dissimilar prototypical buildings to compare these standards as compared to the later determination work for the 1999 and 2004 editions of the standard. In addition, if the absolute, rather than percentage, changes in energy use from the Hadley-Halverson report were applied, the energy and cost impacts would be somewhat greater than those shown here.

Finally, as discussed briefly earlier, one further significant limitation of the study relates to the dollar values of program benefits. We have not included the incremental cost, per square foot, of building to the higher code levels. As a consequence, our monetized energy savings are not "net" of these costs. We recognize that for consistency with the method recommended in 2001 by the National Research Council, this aspect would more accurately refine the measures.

Even with recognition of these caveats, this analysis shows that DOE's activities to support the implementation of energy codes for commercial buildings have provided significant benefits to the nation. Through 2008, program impacts are approximately 0.3 quads of annual energy savings, with an annual energy expenditure savings of over $2.5 billion. Continuing efforts to support adoption and compliance of more stringent building codes in the future is clearly a major strategy that the nation can pursue in its efforts to increase energy security and reduce greenhouse gas emissions.

[1] The earlier 1995-2000 national-level analysis also showed that the savings from residential code adoption and compliance to be about 12% of the total impacts of the program through 2001. If we assume this same proportion in the present approach, the estimate of the total cumulative cost savings in 2001 would rise to about $2.6 billion, or about $55 in energy savings per dollar of program cost.

[2] To better understand how the estimates of program benefits might change in response to alternative adoption and compliance scenarios, a brief sensitivity analysis is described in Appendix B.

10.0 References

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Appendix A

Summary of Key Compliance Studies for Commercial Buildings

Appendix A

Summary of Key Compliance Studies for Commercial Buildings

Only a limited number of studies have addressed compliance for new commercial buildings. Key findings from these studies are presented below

1. Compliance Study related to Washington State Nonresidential Code (1997)

An informal report was prepared by the Washington Department of Energy to examine the relevance of the 1994 Washington State Nonresidential Energy Code (NREC)[1]. The 1994 NREC was deemed to be equivalent to ASHRAE Standard 90.1-1989. A primary source of the estimates prepared in this summary report was a more extensive report, *Energy Consequences of Non-Compliance with the 1994 Washington Nonresidential Code* (Kennedy et al 1997)[2].

The more detailed background study by Kennedy et al. indicated that the code and implementation process resulted in average annual electrical energy savings of 10.2 megawatts and an average annual increase in gas use of 640,000 to 740, 000 therms.

Full compliance with the code would result in additional energy savings of 1.93 average megawatts of electricity and some small savings in natural gas (about 9,500 therms). These detailed results, suggest that about 80% of the potential energy savings from the 1994 code were achieved.

Another measure of non-compliance is the percentage of buildings in a given sample that are determined to be compliant. As indicated in the summary report, the Kennedy et al. report determined a (legal) code compliance fraction of about 0.6 in a sample of 88 non-residential structures. This estimate implies that for non-complying buildings that about 60% of the potential energy savings were achieved (0.6 x 100% + 0.4 * 50% = 80%)

The compliance study found major areas of non-compliance:

- Semi-heated space heating system capacity limitations
- Lighting power allowances for retail spaces, and
- Insulation requirements for on-grade slabs.

The compliance study was conducted roughly two years after the adoption of the 1994 code. The report describes a number of implementation activities conducted by the state to promote compliance with

[1] "Non-Compliance with the Washington State Non-residential Energy Code: Causes and Consequences, prepared by John Devine, Washington State Energy Office. Available from DOE website: http://www.energycodes.gov/implement/pdfs/wa_compliance_1997.pdf.

[2] Kennedy, M et al. 1997. *Energy Consequences of Non-Compliance with the 1994 Washington Nonresidential Energy Code.* For Washington State University, Pullman, Washington.

the code, including inspector certification, training (including "Circuit Rider" trainers), published materials, and a technical assistance hotline.

Of particular note was the formation of the program termed the Special Plans Examiner/Inspector Program (SPE/I). A local jurisdiction could require a permit applicant to hire a third party SPE/I, whose fees could be partially reimbursed by local utilities. When buildings were inspected via this program, the compliance rate was estimated to be 90%, as compared to the overall average of 60%. This finding lends support to the notion that more qualified inspectors can significantly improve the level of code compliance.

2. Survey of Commercial Construction in New Hampshire (2000)

In 1999, GDS Associates and ENTECH Engineering (2000) undertook a study of new commercial activities for the New Hampshire Commercial Construction Study Group, a group made up by the state-level energy office and two major utilities. GDS and ENTECH examined plans and performed on-site inspections of 30 recently constructed commercial and industrial buildings in the State. At the time, the commercial energy code in New Hampshire was based upon the ASHRAE 90.1-1989 building standard.

The key finding of the study respect to code compliance was summarized by the authors in the following manner:

> Plan and print reviews and site visits also showed that nearly half (47%) of the facilities reviewed met or exceeded the code in all seventeen of the major categories for which this study quantified compliance. Of the remaining facilities, roughly half failed to meet the code in just two major code categories. None of the facilities reviewed failed more than two of the seventeen major categories.

According the executive summary, the study found two areas in which the likelihood of not meeting the code was the greatest. First, the cooling efficiency of packaged cooling equipment in approximately 20% of the facilities failed to meet the requirements of the code (EER of 8.5 in units where the code called for a minimum of an 8.9 EER). Second, code insulation requirements for service water systems were not met in about a quarter of buildings examined.

For lighting, the GDS team looked at watts/ft^2 in both the plan and specification review documents, as well as conducting some site inspections. Given that improvements in fluorescent lamps (both linear and CFLs) had been significant since the publication of the 1989 standard, the study found that majority of buildings meet or exceeded standard efficiency. According to Figure 1 at the end of Appendix A, 76% (of the buildings) exceeded the standard, 16% met the standard, and 8% were below the standard.

The discussion in the study of building envelope compliance is not clear. The following two points were made in order in the report's summary of findings:

- Roof and wall insulation was identified as often being specified incorrectly or misapplied during field installation.
- Commercial roofs, walls, doors, and foundations were seen as typically specified and installed at standard rating levels and limited in their levels of efficiency due to design and economic constraints.

The graphics at the end of the report indicated that 13% of buildings failed with respect to fenestration requirements and 30% failed with respect to "Other criteria" (e.g., mainly opaque constructions). However, the text of the report does not provide any discussion of how these percentages were obtained.

3. Energy Code Compliance Study for Hawaii

In 1998, the state of Hawaii tasked Eley Associates of San Francisco to perform a study of energy compliance in Honolulu and Hawaii counties (State of Hawaii 1999). A revised energy code was adopted in late 1994 and in Oahu (Honolulu County) in early 1995. Eley Associates examined 32 building plans for projects that received permits after the new building codes were adopted.

The Eley study defined the level of compliance using five qualitative levels as defined below:

- **Exceeds**. Performance level is significantly better than that required by the code. For example, lighting power is 25% lower than required.
- **Meets**. Performance level equal to or better than required.
- **Minor Non-Compliance**. Within roughly 10% of required performance, or a small element of a system is not in compliance or is not documented in the plans. This category includes the case when a few spaces within a large project do not meet lighting control requirements.
- **Moderate Non-Compliance**. This category includes cases when non-compliance is significant but not complete. For example, lighting power is 10% to 50% higher than allowed, or a significant fraction of spaces do not have complying lighting controls, or envelope insulation is not adequate.
- **Major Non-Compliance**. This category includes problems such as no roof insulation and installed lighting power 50% to 100% greater than allowed. These cases may have significant energy impacts.

Based upon these definitions, the study categorized compliance among major building sub-systems as shown in Table A.1.

Table A.1. Percentage of Plans at Each Compliance Level (Oahu and Hawaii)

Code Requirement	Exceeds	Meets	Minor Non-Compliance	Moderate Non-Compliance	Minor Non-Compliance
Lighting controls	0%	45%	39%	16%	0%
Lighting power	10%	61%	10%	10%	10%
Roof	6%	72%	6%	6%	11%
Wall	6%	76%	6%	12%	0%
Window	6%	76%	12%	6%	0%
HVAC controls	0%	65%	35%	0%	0%
Cooling equipment	0%	70%	30%	0%	0%
HVAC insulation	0%	67%	25%	8%	0%
SWH equipment	0%	90%	10%	0%	0%
SWH insulation	0%	54%	32%	0%	0%
Heat Recovery	0%	40%	20%	40%	0%

Eley Associates also provided some estimates of energy savings under the assumption that all non-complying buildings were brought up to minimum code levels. For lighting, the power density for non-complying buildings (was about 0.6 W/sf higher on average than the maximum code level. Based upon the amount of floor space in non-complying buildings, the study estimated that the average power density would fall by about 0.08 W/sf if this space met the standard. Most of the non-complying buildings were high-end retail and restaurants. These savings represent about 5% of the total lighting power in new buildings and renovations.

The study made estimates of the energy consequences of non-compliance with the lighting controls provisions in the code (primarily required multi-level switching or occupancy sensors). Using a somewhat rougher calculation, the study estimated the cost savings to be in the range of 1.4% to 2.8% of lighting energy for all new projects.

As shown in Table A.1, the compliance for envelope requirements was somewhat good (for roofs, walls, and windows, all in the range of 80% at or above the code level.) The study concluded that “the energy impact of the envelope non-compliance cases is not large because most of the significant problems were in buildings without air conditioning.”

The overall cost impact of the “lost” savings due to non-compliance was estimated to be about $630,000 per year by the end of 1998. For the four years ending in 1998, the study estimated a total non-compliance impact of about $1.6 million. These potential savings are around 2% of the to the total annual energy used by the new buildings analyzed.

One additional comparison is particularly relevant in assessing the non-compliance with regard to the previous energy code in Hawaii. Prior to the adoption of the code in 1994/1995, an “Impact Analysis” was conducted (1993). This earlier analysis predicted energy cost savings of around $12 million through the first four years after the adoption of the proposed code. Thus, based upon the Eley estimates, the new code captured about 87% of the benefits that were likely predicted on the assumption of full compliance.

4. ZING Communications Survey of Lighting Compliance

In late 2006, ZING Communications conducted a survey of U.S. architects, electrical engineers, lighting designers and building contractors to examine compliance with the lighting provisions in ASHRAE Standard 90.1.[1] The study was jointly sponsored by the Architectural Products Magazine and the Lighting Controls Association. The report was designed to gain insights into a number of issues: to what extent are energy codes enforced, who enforces them, which participants in a construction has the most influence for compliance, and what is the current rate of compliance.

The research method for the study involved developing a list of some 11,000 commercial architects, engineers, and building contractors. An additional group of about 1,000 lighting designers was also included in the survey. After facing issues related to out-of-date addresses and overlaps, the survey instrument was distributed to approximately 10,000 professionals. The total number of responses was 431.

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[1] The final report was issued in January 2007. The full report can be accessed on the energycodes.gov website: http://www.energycodes.gov/implement/code_compliance.stm. Click on the entry for Lighting Controls Association, “Energy Code Survey Suggests 80% Compliance Rate.”

The focus of the compliance in the study was in regard to Standard 90.1-1999 and subsequent standards. As of August 2006, the Building Codes Assistance Project indicated that 17 states had adopted a code at least as stringent as Standard 90.1-2004.

Nineteen states had adopted a code that met the provisions of either the 1999 or 2001 standards (equivalent in terms of stringency). The remaining states had either no code or a code less stringent than the 1999 standard (likely, the 1989 edition of Standard 90.1).

Three questions in the survey focused on a quantitative measure of compliance. The respondents were first asked to estimate the percentage of their firm's projects that fully met the requirements of the lighting section of the code. Subsequently, they were asked to estimate the percentage of projects that met 1) the Lighting Power Density (LPD) requirements and 2) the lighting control (automatic shutoff) requirements. Results were tabulated only for those respondents whose primary work was in one of the 36 states where the code met or exceeded Standard 90.1-1999.

A.1 Key Findings

With respect to the first question involving overall compliance, the weighted average response across all groups of respondents indicated that 85.7% of new projects met all the requirements of the applicable code. Some irregular results, however, were uncovered for the more detailed questions. Respondents reported 86.5% of their projects met the LPD requirements of the code, but only 80% of the projects complied with the automatic lighting shutoff requirement. The report speculated as to the reason for the lower level of compliance for the automatic shut off as follows, "1) respondents are not aware of these requirements for compliance, or 2) attempt at compliance is made but automatic lighting controls are more sensitive to market barriers such as value engineering."

The report displayed concern about the magnitude of non-response for the questions related to compliance. Nearly 40% of the respondents did not know, or refused to answer, the question about the percentage of projects that met the overall lighting requirements of the code. The study authors recognized that some respondents would not have sufficient information to answer this question, perhaps reflecting a more limited role in the process to show compliance with the code. However, a desire to not admit non-compliance may also be at work, "… the high rate of non-response may also suggest non-compliance."

The report also provided some information on responses by subgroups. With regard to overall compliance, architects reported the highest compliance (87.4%), following by lighting designers (81.0%), and engineers (79.6%). The report considers that engineers are likely to have highest level of awareness of compliance, given that engineers are often assigned the role of assuring compliance and that they are most likely to be involved in the latter stages of the actual construction process.

Compliance rates were estimated to be slightly higher in the west coast states (California, Oregon, and Washington). In these states, a weighted average of 86.7% of new construction projects were estimated to fully comply with the code, as compared to 84.9% in other states. The biggest difference pertained to the compliance related to automatic shut off. In the west coast states, 85.8% of the projects were estimated to comply with this requirement, in contrast to 76.3% in other states. (The LPD results were 88.6% and 84.9% in the west coast and other states, respectively.) The influence of the likely more aggressive enforcement in the west coast states is also reflected in the non-response rates. With regard to overall energy code (lighting section) compliance rate, only 32% of respondents in the west coast states didn't know, or refused to answer, as compared to 43% of respondents in the other states (i.e., the other 33 starts with an applicable energy code).

A.2 Implications for Compliance Assumptions in the Current Study

The ZING Communications reports provides a reasonable benchmark from which to develop the compliance assumptions in this report. Unfortunately, the definition of compliance runs along a legal perspective, rather than an energy perspective, that is required in this analysis. Moreover, the high rates of compliance suggested in the report are likely to be biased on the high side, if the report's assessment of non-response rates is correct (i.e., non-response reflecting higher levels of non-compliance). Thus, it is still necessary to make several key assumptions in order to apply these results.

As a benchmark, it is first assumed that the ZING survey results apply to the compliance rates after 10 years, as discussed in the section on improved compliance in the report. This is a conservative assumption, as less than 10 years had passed between the earliest adoption of Standard 90.1-1999 and the compliance survey.

As part of The ZING report's "Key Findings," a conservative assumption is made that "lighting requirements of the code" are met in 80% of new construction projects. This value corresponds to the results for automatic shutoff question, the results of which were to show somewhat lower compliance rates than the response to the overall lighting requirements question (86.5% compliance). The authors of the ZING report chose to use the lower of these two values as being a more accurate reflection of overall compliance. Thus, in the retrospective analysis here, the 80% value is considered an initial national estimate.

The ZING report, however, examines the west coast states separately from other states. In the retrospective analysis here, two of those states, California and Oregon, have been specifically excluded from the benefits analysis. (It is arguable, as well, that Washington should also be excluded). Thus, following the same approach as the ZING report, an estimate that may more accurately reflect overall compliance for all other states is the compliance rate for shutoff requirements for these states. As stated earlier, this rate was found to 76%.

Moreover, the ZING report also suggested that that the high level of non-response may also suggest non-compliance. Obviously, there is no way to accurately measure this impact if it exists. For the purpose of the study here, it is assumed that the level of compliance for these projects was 25% lower than for the projects of the responding professionals. Using an overall non-response rate of 40%, one then derives a (legal) compliance rate of

$$0.6 \text{ x } 0.76 + 0.4 * 0.57 = 0.684 \sim 68\%.$$

The legal-based compliance rates in the ZING survey of course relate to the percentage of projects (buildings) that fully meet the lighting requirements. However, as discussed in methodology used in the present study, the focus is on energy compliance. As shown in relation to Equation (7.1) of the main text, an assumption about the partial (energy) compliance from legally non-complying buildings must be made. In this case, it is assumed that 50% of the potential savings will have been achieved. With this assumption, the overall energy compliance can be calculated along the lines of Equation (7.1) in the main text:

Compliance (Energy), CE = 0.68 + (1 – 0.68) * 0.5 = 0.84 = 84%.

Table A.2 shows the compliance assumptions in terms of both legal and energy compliance for Standard 90.1-1999. All of the discussion above relates to the "With BECP" case in which BECP played a role in a large number of states by supporting training and compliance tools. Without the deployment portion of the federal program, one is confronted by a situation that may not have actually occurred in any state; i.e., a code being adopted but where no significant activity was subsequently undertaken to see its widespread implementation. As shown in the table, it is assumed in the counterfactual ("Without BECP") case that only about half of the potential energy savings might have been initially achieved; later increasing to just about two-thirds of the potential savings after ten years.

Table A.2. Compliance Assumptions for Standard 90.1-1999

90.1-1999	Initial Compliance (%)	Compliance after 10 Years (%)	Fraction of Savings for Non-Compliant Units	Initial Compliance (Energy terms) %	10-Year Compliance (Energy Terms) %
Without BECP	30%	50%	0.3	51.0%	65.0%
With BECP	50%	68%	0.5	75.0%	84.0%

The assumptions in Table A.2 influenced the lighting compliance rates with regard to the 1989 and 2004 standards. As shown in Table 7.3 in the main report, the percentage of potential energy savings for the 1989 standard (both with and without BECP) were assumed to be lower than that for the 1999 standard. This assumption reflects the view that compliance would be (have been) lower in states with limited experience with comprehensive energy codes. Compliance rates for the codes based upon the 2004 standard were assumed to be the same as for the 1999 standard. The 2004 standard substantially increased the stringency of the LPD requirements as compared to the 1999 standard. Thus, while in some states the adoption of the 2004-based code represents additional experience with code enforcement (assuming prior adoption of the 1999 standard), greater effort to meet the increased stringency, leading to somewhat lower compliance, may tend to offset increased experience by the builder and code enforcement community. Unfortunately, the ZING survey did not attempt to distinguish compliance rates on the basis of the applicable code edition.

A.3 References

GDS Associates and ENTECH Engineering. 2000. *Survey of Commercial New Construction Activities in New Hampshire.* Provided to: The New Hampshire Commercial Construction Study Group. May.

State of Hawaii. 1999. *Energy Code Compliance Study: Honolulu and Hawaii Counties.* Prepared for the Department of Business, Economic Development, and Tourism; Energy, Resources, and Technology Division by Eley Associates, San Francisco, CA.

Appendix B

Sensitivity Analysis

Appendix B

Sensitivity Analysis

Appendix B describes a modest sensitivity analysis related to the accelerated adoption and compliance assumptions with the purpose of providing some bounding estimates to those presented in the main report. A "low" case was developed by reducing the acceleration time periods by two years and by increasing the compliance rates that are assumed would have occurred without BECP. A "high" case was constructed in a similar manner by increasing the acceleration period by several years and adjusting compliance rates. The estimates presented in the main report are referred to below as the "base" case.

B.1 Acceleration Assumptions

As shown in Table 7.1 in the main report, most states were categorized into two groups. In the first group, the program was assumed to have accelerated the adoption of Standard 90.1- 1989 by five years. In the second group, the program was assumed to accelerated adoption by 8 years. The acceleration periods were reduced by one year in the subsequent 90.1-1999 standard and by two years for the 2004 edition of the standard.

For the sensitivity analysis, the low (savings) case is generated by assuming that states would have adopted somewhat more quickly on their own. To reflect this notion, the acceleration periods for the two groups were shortened by two years, thus yielding a 3- year and 6-year acceleration for these groups. In addition, the low case assumes that the program had no impact on states without codes through spillover effects discussed in the main report. Finally the base case assumed a 5-year acceleration of the "implicit" adoption of the 1989 edition of the standard by 2004 while the low case assumes no acceleration.

The high case is generated analogously by lengthening the acceleration period for Standard 90.1-1989 by two years; that is, the efforts of BECP were assumed to accelerate adoption by two years earlier. In this case, a 10-year acceleration was assumed for those states that implicitly adopted Standard 90.1-1989 by 2004. However, because the analysis period ends with 2008, only half of the benefits are realized by this year under this assumption.

Table B.1 displays the assumptions for the acceleration periods by state for each of the three cases.[1] The actual (historical) adoption dates are the same for each case. For each case, the acceleration period is added to the actual adoption year to develop the (hypothetical) year that the state would have adopted, or will adopt, the relevant standard had DOE's BECP not been in existence.

[1] All tables and figures are shown at the end of the appendix.

Table B.1. Acceleration Periods by State and Case

	Low		Base		High	
State	Year Adopted	Delay w/o program (years)	Year Adopted	Delay w/o program (years)	Year Adopted	Delay w/o program (years)
Alabama	2004	0	2004	5	2004	10
Alaska	2004	0	2004	5	2004	10
Arizona	2004	0	2004	5	2004	10
Arkansas	1995	6	1995	8	1995	10
California	NA		NA		NA	
Colorado	2004	0	2004	5	2004	10
Connecticutt	1994	3	1994	5	1994	7
Delaware	1996	3	1996	5	1996	7
District of Columbi	2000	6	2000	8	2000	10
Florida	NA		NA		NA	
Georgia	1996	3	1996	5	1996	7
Hawaii	1995	3	1995	5	1995	7
Idaho	2004	0	2004	5	2004	10
Illinois	2004	0	2004	5	2004	10
Indiana	2004	0	2004	5	2004	10
Iowa	1993	3	1993	5	1993	7
Kansas	1997	3	1997	5	1997	7
Kentucky	2004	0	2004	5	2004	10
Louisiana	1999	6	1999	8	1999	10
Maine	1990	3	1990	5	1990	7
Maryland	1997	3	1997	5	1997	7
Massachusetts	1992	3	1992	5	1992	7
Michigan	2003	6	2003	8	2003	10
Minnesota	1992	3	1992	5	1992	7
Mississippi	2004	0	2004	5	2004	10
Missouri	2004	0	2004	5	2004	10
Montana	1996	3	1996	5	1996	7
Nebraska	2004	0	2004	5	2004	10
Nevada	2004	0	2004	5	2004	10
New Hampshire	1993	3	1993	5	1993	7
New Jersey	1997	3	1997	5	1997	7
New Mexico	2004	6	2004	8	2004	10
New York	1991	3	1991	5	1991	7
North Carolina	1995	3	1995	5	1995	7
North Dakota	2004	0	2004	5	2004	10
Ohio	1995	3	1995	5	1995	7
Oklahoma	2004	0	2004	5	2004	10
Oregon	NA		NA		NA	
Pennsylvania	2004	6	2004	8	2004	10
Rhode Island	1997	3	1997	5	1997	7
South Carolina	1997	6	1997	8	1997	10
South Dakota	2004	0	2004	5	2004	10
Tennessee	2004	0	2004	5	2004	10
Texas	2001	6	2001	8	2001	10
Utah	1995	3	1995	5	1995	7
Vermont	1996	3	1996	5	1996	7
Virginia	1997	6	1997	8	1997	10
Washington	1994	3	1994	5	1994	7
West Virginia	2003	6	2003	8	2003	10
Wisconsin	1997	3	1997	5	1997	7
Wyoming	2004	0	2004	5	2004	10

B.2 Compliance Assumptions

The base case compliance assumptions were shown in Table 7.2 and Table 7.3 in the main report. For the sensitivity analysis, only the compliance rates for the cases *without* the BECP program were modified. For the "low" case, the initial and 10-year compliance rates were increased by 20 percentage points. This has the effect of reducing the difference in compliance rates between the "without BECP" case and the "with BECP" case, and thus is aimed toward providing a (judgmentally determined) lower bound on the savings. No change was made to the fraction of savings for the non-compliant new floor space. In a similar manner, the "high" case was developed by reducing the initial and 10-year compliance rates by 20 percentage points.

Table B.2 and Table B.3 show the alternative compliance rates for envelope and lighting, respectively, for the low case. Tables B.4 and B.5 show the compliance rates for the high case.

B.3 Results

Table B.6 shows the estimated impacts of the BECP program in terms of energy expenditure savings impacts in 2008. A number of spreadsheet model runs were performed to analyze the separate effects of the assumptions for adoption and compliance. The top three lines shows the impacts of three alternative acceleration cases, while holding the compliance rates at their base values. The 2008 savings range from a low of $11.2 billion to $14.9 billion (2005 dollars).

In the second panel of the table, the compliance rates are varied, while holding the accelerated adoption assumptions at their base values. Here, the range of savings is somewhat smaller, from $12.4 billion to $13.9 billion. In part, the smaller range is related to the interaction of the two sets of assumptions. In the "low" case for compliance, the "without" program compliance rates are higher than with the program. Thus, the impact of any accelerated adoption (including the base case) is *greater* than it would be otherwise, leading to offset some of the savings yielded by the smaller difference in compliance rates.

The last panel of the table shows the cases where the assumption sets are matched. In the low case, the shortened acceleration periods are matched up with higher compliance rates without the program. Moreover, no attribution of savings is made for those states that are assumed to have implicitly adopted Standard 90.1-1989 by 2004. In this case, the expenditure savings in 2008 are about 25% lower than the base case ($9.9 billion). In the high case, the expenditure savings are about 13 higher than the base case, at $14.9 billion.

Figure B.1 shows the timeline of estimated national annual energy savings in Trillion Btu from 1990 through 2008. The scenarios are very similar through most of the 1990s, as under all cases some accelerated adoption is assumed. In the low case, many states would have adopted Standard 90.1-1989 without DOE, and thus the increase in savings for such states become much smaller. By 2008, the relative differences between the cases are very similar to the expenditure savings impacts, with the low case about 25% less than the base case and the high case about 14 greater than the base case.

Table B.2. Code Compliance Assumptions for Envelope – Low Case

	(a) Initial Compliance (%)	(b) Compliance after 10 Years (%)	(c) Fraction of Savings for Non-Compliant Units	(d) Initial Compliance (Energy terms) %	(e) 10-Year Compliance (Energy Terms) %
90.1-1989					
Without BECP	40%	70%	0.2	52.0%	76.0%
With BECP	40%	80%	0.5	70.0%	90.0%
90.1-1999					
Without BECP	40%	70%	0.2	52.0%	76.0%
With BECP	40%	80%	0.5	70.0%	90.0%
90.1-2004					
Without BECP	50%	80%	0.2	60.0%	84.0%
With BECP	50%	80%	0.5	75.0%	90.0%

Notes:
(a), (b) Compliance in legal terms, defined as percentage of new building floor space fully meeting provisions of code change
(c) Fraction of potential energy savings from previous code in units not fully (legally) compliance
(d),(e) Fraction of potential savings for both legally compliant and not legally compliant buildings

Table B.3. Code Compliance Assumptions for Lighting – Low Case

	(a) Initial Compliance (%)	(b) Compliance after 10 Years (%)	(c) Fraction of Savings for Non-Compliant Units	(d) Initial Compliance (Energy terms) %	(e) 10-Year Compliance (Energy Terms) %
90.1-1989					
Without BECP	40%	70%	0.3	58.0%	79.0%
With BECP	50%	80%	0.6	80.0%	92.0%
90.1-1999					
Without BECP	50%	70%	0.3	65.0%	79.0%
With BECP	50%	80%	0.6	80.0%	92.0%
90.1-2004					
Without BECP	60%	80%	0.4	76.0%	88.0%
With BECP	75%	85%	0.7	92.5%	95.5%

Notes:
(a), (b) Compliance in legal terms, defined as percentage of new building floor space fully meeting provisions of code change
(c) Fraction of potential energy savings from previous code in units not fully (legally) compliance
(d),(e) Fraction of potential savings for both legally compliant and not legally compliant buildings

Table B.4. Code Compliance Assumptions for Envelope – High Case

	(a) Initial Compliance (%)	(b) Compliance after 10 Years (%)	(c) Fraction of Savings for Non-Compliant Units	(d) Initial Compliance (Energy terms) %	(e) 10-Year Compliance (Energy Terms) %
90.1-1989					
Without BECP	0%	30%	0.2	20.0%	44.0%
With BECP	40%	80%	0.5	70.0%	90.0%
90.1-1999					
Without BECP	0%	30%	0.2	20.0%	44.0%
With BECP	40%	80%	0.5	70.0%	90.0%
90.1-2004					
Without BECP	10%	40%	0.2	28.0%	52.0%
With BECP	50%	80%	0.5	75.0%	90.0%

Notes:
(a), (b) Compliance in legal terms, defined as percentage of new building floor space fully meeting provisions of code change
(c) Fraction of potential energy savings from previous code in units not fully (legally) compliance
(d),(e) Fraction of potential savings for both legally compliant and not legally compliant buildings

Table B.5. Code Compliance Assumptions for Lighting – High Case

	(a) Initial Compliance (%)	(b) Compliance after 10 Years (%)	(c) Fraction of Savings for Non-Compliant Units	(d) Initial Compliance (Energy terms) %	(e) 10-Year Compliance (Energy Terms) %
90.1-1989					
Without BECP	0%	30%	0.3	30.0%	51.0%
With BECP	50%	80%	0.6	80.0%	92.0%
90.1-1999					
Without BECP	10%	30%	0.3	37.0%	51.0%
With BECP	50%	80%	0.6	80.0%	92.0%
90.1-2004					
Without BECP	20%	40%	0.4	52.0%	64.0%
With BECP	75%	85%	0.7	92.5%	95.5%

Notes:
(a), (b) Compliance in legal terms, defined as percentage of new building floor space fully meeting provisions of code change
(c) Fraction of potential energy savings from previous code in units not fully (legally) compliance
(d),(e) Fraction of potential savings for both legally compliant and not legally compliant buildings

Table B.6. 2008 Expenditure Impacts Under Various Assumption Sets

Model Run	Adoption	Compliance	Expenditure Impact - 2008 (billion 2005$)
1	Base	Base	13.2
2	Low	Base	11.2
3	High	Base	14.5
1	Base	Base	13.2
4	Base	Low	12.4
5	Base	High	13.9
1	Base	Base	13.2
6	Low	Low	9.9
7	High	High	14.9

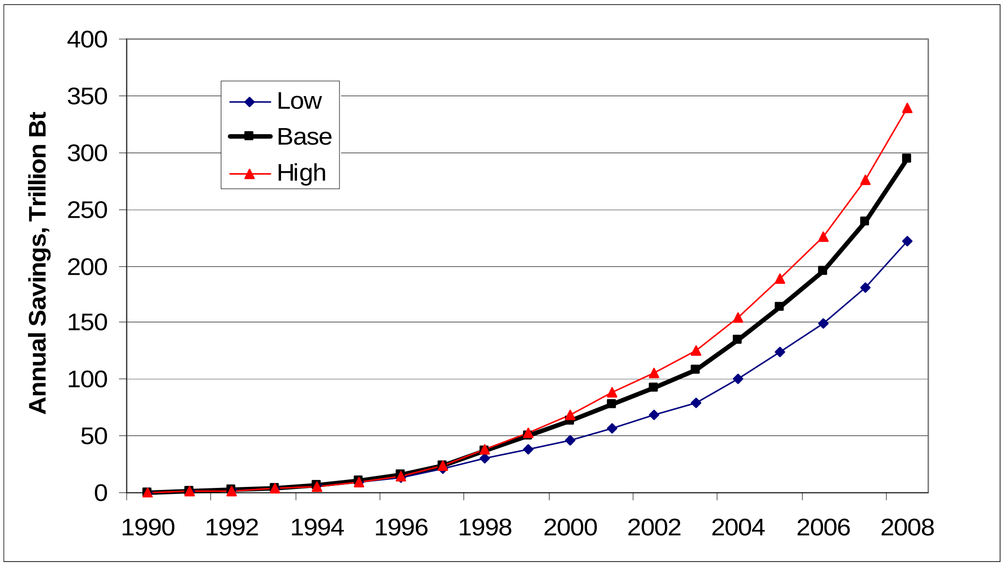

Figure B.1. National Energy Savings Impacts by Year

Unfortunately, the scenario type of analysis presented here does not lend itself to statistical measures of uncertainty. Nevertheless, our collective judgment is that the low and high cases would fall into a 90% confidence range. As a result, we suggest that the energy and economic benefits estimates developed in the study would fall into uncertainty range of plus 15% or minus 25% of the base case point estimates at a 90% level of confidence. A more sophisticated analysis might employ Monte Carlo techniques to explore the uncertainty ramifications of the various assumptions, but such analysis was beyond the scope of this study.

The U.S. Department of Energy's Building Energy Codes Program is an information resource on national model energy codes. We work with other government agencies, state and local jurisdictions, national code organizations, and industry to promote stronger building energy codes and help states adopt, implement, and enforce those codes.

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