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Evaluation of Building Energy Modeling Technology Research and Development Activities for Building Technologies Office

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Notice

Executive Summary

This report presents the findings from an evaluation of the Building Energy Modeling (BEM) program in the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Building Technologies Office (BTO). The project evaluated the quantifiable energy, environmental, and economic impacts associated with DOE-funded BEM research and software development, as it relates to the development of commercial building energy efficiency codes use case. A qualitative analysis was performed for the development of residential building energy efficiency codes and the development of energy efficiency incentive programs due to negligible evidence of BEM tools use in these instances.

The BEM program is located in the BTO's program office in DOE's EERE office. BTO develops, demonstrates, and accelerates the adoption of cost-effective technologies, techniques, tools, and services that enable high-performing, energy-efficient, and demand-flexible residential and commercial buildings in both the new and existing buildings markets, in support of an equitable transition to a decarbonized energy system by 2050, starting with a decarbonized power sector by 2035. BTO conducts work in three key areas to continually develop innovative, cost-effective, energy-saving solutions: research and development (R&D), market stimulation, and building codes and products.

BEM is a physics-based software simulation of building energy use given a description of the building's physical assets (envelope, lighting systems, heating, ventilation, and air-conditioning [HVAC] systems, and service water-heating systems), its operations (occupancy schedules, thermostat set points, lighting and plug-load schedules), and surrounding weather conditions. BEM supports energy efficiency via two types of use cases– use cases for specific buildings and also for prototypical buildings. BEM on specific buildings supports use cases like new construction and retrofit design, performance calculations for code-compliance, ratings, and energy efficiency incentives, as well as emerging operational use cases like performance monitoring, fault diagnosis, and model-predictive control. BEM on prototypical buildings is used to analyze entire building stocks and supports use cases like development of energy efficiency codes, guidelines, and energy efficiency incentive programs, and the development of energy-efficient products.

In 2020, BTO initiated an independent retrospective benefit-cost evaluation to understand the extent that DOE's investment in BEM projects and activities achieved energy, environmental, and economic benefits relative to the counterfactual without DOE involvement. The evaluation for the commercial energy efficiency codes use case compared the economic benefits of these projects and activities against the federal cost incurred in their support. The evaluation provides only lessons learned from review of the development practices and recommendations for the residential efficiency codes and the efficiency incentives use cases.

I. Portfolio Approach

This evaluation used a portfolio approach to quantify, analyze, and document three categories of impacts associated with DOE's investment in BEM tools and activities: energy, environmental, and economic. A portfolio approach means that only a portion of BEM's activities and use cases are included in the evaluation. The portfolio for this evaluation represented BEM projects and activities funded by DOE over a 20-year time horizon (2000–2020). These BEM projects and activities included the EnergyPlus BEM engine, OpenStudio Software Development Kit, and the ASHRAE Standard 140. BEM supports the development of energy efficiency codes and programs via its application to prototypical buildings. Prototypical buildings is the use case for which impacts are estimated. The prototypical buildings consist of 16 commercial and 16 residential stock-level buildings used as references. This evaluation focused on quantifying impacts resulting from DOE prototypical building BEM investments within two distinct use cases: 1) development of commercial and residential energy efficiency codes; and 2) development of energy efficiency incentive programs. The evaluation determined a quantitative analysis was not appropriate for the residential energy efficiency codes and energy efficiency incentive program use cases. This limited those use cases to qualitative case study findings exploring obstacles to BEM use, based on research and expert interviews. Examples of BTO activities not included are: empirical validation using instrumented test facilities, BuildStock, ASHRAE Standard 229P, Spawn, and URBANopt. Use cases not included are: customized buildings within the commercial and residential building sectors.

II. Methodology

To determine attributable benefits of DOE-funded BEM tools, the evaluation used a mixed-methods approach utilizing quantitative statistical methods, primary and secondary research, and qualitative description. Table ES-1 summarizes the evaluation methods used.

Table ES-1. Evaluation Methods

Method	Description
Primary interviews to focus the study	Eight BEM and building scientists were interviewed to determine the scope for the evaluation strategy, as well as input for the design of the logic models for each use case.
Delphi panel and survey to determine attribution of energy savings to BEM	The panel was provided a list of addenda by technology and code version and considered the role of the BEM program versus rival factors and alternative scenarios in the absence of DOE-funded BEM tools in advancing energy efficiency efforts. The panel included seven experts with substantial ASHRAE Standard 90.1 involvement.
Approach to energy impacts	The evaluation determined the estimates of the energy impacts due to DOE-funded BEM tools' influence on ASHRAE 90.1 by first calculating the total gross energy savings generated by the code, then estimating the influence of DOE-funded BEM tools through a Delphi panel survey of code committee decision-makers. From these two estimates, evaluators calculated the net energy savings attributable to DOE-funded BEM tools and the ensuing energy benefits from net energy savings and corresponding energy price data from EIA.
Approach to emissions and environmental health impacts	The evaluation calculated emissions of NO_x, $PM_{2.5}$, SO_2, VOC, and NH_3 by multiplying net DOE-funded BEM energy savings by various emissions factors from the U.S. Environmental Protection Agency's (EPA) AVoided Emissions and geneRation Tool (AVERT) tool (electricity) and EPA's AP-42 Compilation of Air Emissions Factors database (natural gas). The evaluation calculated CO_2e emissions using emissions factors from the Emissions & Generation Resource Integrated Database (eGRID) for electricity and EPA's Greenhouse Gas (GHG) Emission Factors Hub for natural gas. Next, the evaluation converted the emissions related to ambient air quality into avoided health endpoints and healthcare benefits using EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA) tool. COBRA results were population-adjusted using U.S. Census Data to reflect the changing U.S. population during each year of the study period.

Method	Description
Approach to economic performance estimation	The evaluation determined the monetary value of the energy savings and avoided environmental health incidents and expressed the economic benefits in constant (2020) dollars using the GDP Implicit Price Deflators. Evaluators conducted a benefit-cost analysis that included calculating the following six economic metrics: present value of BEM investment, gross benefits, present value of benefits, net present value, benefit-to-cost ratio, and return on investment. The evaluation applied sensitivities around attributions (evaluating the 25th and 75th percentile around the median or base case) and the economic performance discount rate (evaluating a 3% rate alongside the default 7% rate), creating a range of values for the metrics.

III. Findings

III.I Findings for Commercial Energy Efficiency Codes

Overall, the findings demonstrate that the investment into DOE-funded BEM tools is cost-effective, with a benefit-to-cost ratio of 3.78 from only the energy benefits of the commercial code use case. The influence from DOE-funded BEM tools on the commercial building code's improved efficiency was estimated to be moderate at roughly 10%, but it resulted in large energy savings due to impacting the vast amount of commercial new construction affected by energy-saving updates to ASHRAE 90.1. These energy savings generated large economic benefits and a favorable return on DOE's investment in these tools, especially when considering the combined energy and environmental health benefits.

III.I.I Delphi Panel Results

Participants in the Delphi panel unanimously agreed that DOE-funded BEM tools impacted ASHRAE 90.1 code development for all evaluated building technology categories. Relative to the other five factors influencing code development, DOE-funded BEM tools received the second-highest median influence score in four of the five technology categories and the third-highest median influence score for one (refer to Section 4.1.1). Collectively, panelists believed that the absence of DOE-funded BEM would have led to less energy efficiency across all alternative scenarios presented. From the Delphi panel results, the evaluation calculated the percentage of the gross ASHRAE energy savings attributable to DOE-funded BEM tools for each technology category (Table ES-2). The base case is defined as the median of the panel results, while the low-end and high-end cases are their 25th and 75th percentile, following the rationale of the sensitivity analysis in Section 4.4.

Table ES-2. Delphi Panel Results by Technology Category

Technology Category	Base Case Attribution	Low-End Attribution	High-End Attribution
Envelope	12.3%	6.7%	21.8%
HVAC	10.5%	4.4%	16.5%
Service Hot Water	3.5%	2.2%	8.2%
Power	5.3%	2.2%	16.5%

Technology Category	Base Case Attribution	Low-End Attribution	High-End Attribution
Lighting	7.0%	4.4%	12.4%

III.I.II Energy Results

Net energy savings which are attributed to DOE-funded BEM tools is estimated at 40 MMBtu, on average, making up about 10% of the gross energy savings. Refer to Table ES-3 for the gross and net savings.

Table ES-3. Gross ASHRAE and Net DOE-Funded BEM Energy Savings (2000-2020)

Fuel Type	Gross ASHRAE Energy Savings	Net DOE-Funded BEM Energy Savings
Total Site Electricity Savings (GWh)	64,283	6,416
Total Site Natural Gas Savings (Million Therms)	1,606	179
Total Site Energy Savings - all fuels (Million MMBtu)	380	40

The net DOE-funded BEM energy savings presented in Table ES-3 result in energy cost benefits (Table ES-4). Attributed DOE BEM energy costs savings is estimated to be $820 million (undiscounted) 2020$ inflation-adjusted, which is $227 million and $466 Million at 7% and 3% discount rates, respectively.

Table ES-4. Energy Impacts and Energy Cost Benefits (2000-2020)

Metric	Base Case	Low Case	High Case
Total site energy savings - all fuels (Million MMBtu)	40	19	66
Total electricity site savings (Million kWh)	6,416	3,054	10,608
Total natural gas site savings (Million therms)	179	85	297
Monetary value of energy savings @ 7% real discount rate (Million 2020$)	$227	$107	$670
Monetary value of energy savings @ 3% real discount rate* (Million 2020$)	$466	$222	$952
Monetary value of energy savings, undiscounted (Million 2020$)	$820	$390	$1,356
Notes: * The 7% rate is the primary discount rate for this evaluation. The 3% discount rate is presented as an alternative to 7% as recommended in OMB Circular A-94.			

III.I.III Emissions and Human Health Results

In total, the avoided carbon dioxide equivalent emissions was 4,527,627 metric tons CO_2e, with a monetary value of avoided adverse health events of $144 million.

Table ES-5. Emissions and Human Health Benefits (2000-2020)

Metric	Units	Impacts and Benefits
Avoided carbon dioxide equivalent (CO_2e) emissions	Metric Tons (MTCO2e)	4,527,627
Avoided particulate matter ($PM_{2.5}$) emissions	Short Tons	356
Avoided sulfur dioxide (SO_2) emissions	Short Tons	3,544
Avoided nitrogen oxide (NO_x) emissions	Short Tons	3,784
Avoided ammonia (NH_3) emissions	Short Tons	93
Avoided volatile organic compound (VOC) emissions	Short Tons	132
Monetary value of avoided adverse health events due to reduced air emissions @ 7% real discount rate	Million 2020$	$144
Monetary value of avoided adverse health events due to reduced air emissions @ 3% real discount rate	Million 2020$	$293

III.I.IV Economic Performance Results

The economic performance of DOE-funded BEM tools is presented in Table ES-6. The 20-year portfolio investment cost of $107 million produced net economic benefits (combined energy and environmental health) of $1,224 million. This resulted in a benefit-to-cost ratio of 3.78 and an internal rate of return of 20% when considering energy benefits alone.

Table ES-6. Economic Performance Metrics (2000-2020)

Metric	Units	Energy Benefits*	Combined Energy and Environmental Health Benefits*
Portfolio Investment Cost - undiscounted	Million, 2020$	$107	$107
Gross Economic Benefits - undiscounted	Million, 2020$	$820	$1,331
Net Economic Benefits - undiscounted	Million, 2020$	$713	$1,224
Net Present Value at 7% real discount rate	Million, 2020$	$167	$310
Net Present Value at 3% real discount rate*	Million, 2020$	$385	$678
Benefit-to-Cost Ratio (BCR) at 7% real discount rate	Ratio	3.78	6.18

Metric	Units	Energy Benefits*	Combined Energy and Environmental Health Benefits*
Benefit-to-Cost Ratio (BCR) at 3% real discount rate	Ratio	5.75	9.36
Internal Rate of Return	Percent	20%	21%
Notes: * While the benefits for the selected use case began to accrue in 2012, the program costs and activities associated with bringing the use case to market go back to 2000.			

III.II Findings for Residential Energy Efficiency Codes and Energy Efficiency Incentive Programs

Due to negligible findings of BEM use in residential energy code development and energy efficiency incentive program development, the evaluation only focused on a qualitative analysis based on primary interviews with residential code and incentive program subject matter experts. Those findings are presented in Sections 4.5.1 and 4.5.2.

IV. Recommendations

Based on the findings of this evaluation, the following are recommendations to improve DOE-funded BEM technologies:

- Maintain the existing rigor of modeling proposed ASHRAE Standard 90.1 amendments using DOE-funded BEM tools to determine their cost-effectiveness, along with all other engagements that encourage the ASHRAE committees to base a significant attribution of their decision-making on DOE-funded BEM tools.
- Increase engagement with the International Codes Council (ICC) regarding the International Energy Conservation Code in light of the new American National Standards Institute (ANSI) code development process. Encourage ICC to prioritize compulsory, BEM-based cost-effectiveness tests where they provide benefits
- Expand upon the existing functionality and user-friendliness of EnergyPlus and prototypical models according to the needs of code and energy efficiency incentive program stakeholders.

V. Limitations

The evaluation encountered the following limitations:

- The evaluation team was limited to surveying a maximum of nine commercial energy efficiency code experts. This resulted in a less statistically robust data set for the attribution analysis.
- The evaluation team may have introduced unintended bias to the panelists in its formulation of the alternative scenarios used in the counterfactual analysis.
- Research found that several of the possible and anticipated pathways of the original logic models did not occur in practice. As a result, the evaluation was unable to use the quantitative Delphi method for the residential energy efficiency codes and energy efficiency incentive program use cases. This limited those use cases to qualitative findings based on research and expert interviews (refer to Section 4.5).
- In the development of the rival factors, the evaluation team only considered a static definition for each factor, and did not ask panelists to evaluate how factors may have differed or changed in attribution across the entire time period of the study.

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List of Acronyms

Acronym	Description
ACEEE	American Council for an Energy-Efficient Economy
AEDG	Advanced Energy Design Guide
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AVERT	AVoided Emissions and geneRation Tool
BCR	Benefit-to-Cost Ratio
BEA	Bureau of Economic Analysis
BEM	Building Energy Modeling
BLAST	Building Loads And System Thermodynamics Program
BTO	Building Technologies Office
CALMAC	California Measurement Advisory Council
CBECS	Commercial Building Energy Consumption Survey
CEC	California Energy Commission
C&I	Commercial and Industrial
COBRA	CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool
DOD	Department of Defense
DOE	Department of Energy
DSIRE	Database of State Incentives for Renewables & Efficiency
ECMs	Energy Conservation Measures
EERE	Energy Efficiency and Renewable Energy
eGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPACT	Energy Policy Act
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration

Acronym	Description
ET	Emerging Technologies Program
EUIs	Energy Use Intensities
EUL	Effective Useful Life
FEA	Federal Energy Administration
GB	Gross Economic Benefits
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emissions
HVAC	Heating, Ventilation, and Air Conditioning
ICC	International Codes Council
IECC	International Energy Conservation Code
IEQ	Indoor Environmental Quality
IRR	Internal Rate of Return
IT	Information Technology
LCC	Lifecycle Cost
NB	Net Economic Benefits
NECAP	NASA Energy-Cost Analysis Program
NGO	Non-Governmental Organizations
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
OMB	Office of Management and Budget
OS-SDK	OpenStudio Software Development Kit
PA	Program Administrator
PNNL	Pacific Northwest National Laboratory
PSD	Performance Systems Development
PUC	Public Utilities Commission
PV	Present Value

Acronym	Description
R&D	Research & Development
SDK	Software Development Kit
SHW	Service Hot Water
SME	Subject Matter Expert
TRM	Technical Reference Manual

1. Introduction

The Building Energy Modeling (BEM) program in the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Building Technologies Office (BTO) commissioned an impact evaluation of the Emerging Technologies (ET) program's Building Energy Modeling (BEM) subprogram. This independent evaluation, conducted by Corner Alliance and its partners (collectively referred to as "the evaluation team" throughout this report), quantified the energy, environmental, and economic impacts attributable to the BTO's investment in BEM research and software development.

1.1 BEM Background

DOE EERE BTO funds a network of national laboratory, university, small business, and industry partners to develop innovative and cost-effective energy-saving solutions for U.S. buildings, the single largest energy-consuming sector in the nation.[1] According to DOE, Americans, "spend over $400 billion each year to power [their] homes and commercial buildings that consume 75% of all electricity used in the U.S."[2] On average, Americans waste over 30% of this energy and money.[3]

BTO's ET program primarily supports BEM technologies via research and development (R&D) of open-source BEM software, including the whole-building energy simulation program EnergyPlus. BTO investments in BEM technologies aim to improve the capabilities, accuracy, speed, and usability of BEM to advance building energy efficiency by way of R&D, market stimulation, and building codes and products. Their mission is to support a transition to a decarbonized energy system by the year 2050.[4]

1.1.1 Building Energy Modeling

BEM is physics-based whole-building software simulation of building energy use given a description of the building's physical assets (e.g., envelope, lighting systems, heating, ventilation, and air-conditioning [HVAC] systems, and service water-heating systems), its operations (e.g., occupancy schedules, thermostat set points, and lighting and plug-load schedules), and surrounding weather conditions. BEM is used to predict and analyze building energy use. Users of BEM software enter inputs to construct a virtual replica of a building and quantitatively estimate the building's energy use and related metrics.

BEM is primarily used to calculate:

- Space heating and cooling loads (based on climate, envelope characteristics, occupancy and other internal loads, and ventilation rates) at hourly (or finer) time steps;
- End use impacts of all common major building systems and equipment, e.g., space heating and cooling, lighting, service water heating, refrigeration, cooking, and plug loads;
- Interactions among building systems (otherwise known as interactive effects); and

[1] U.S. Energy Information Administration. (May 2021). "How much energy is consumed in U.S. buildings?" https://www.eia.gov/tools/faqs/faq.php?id=86&t=1.

[2] Office of Energy Efficiency & Renewable Energy. "About the Building Technologies Office." Accessed November 30, 2021: https://www.energy.gov/eere/buildings/about-building-technologies-office.

[3] Ibid.

[4] Ibid.

- Energy use by fuel type.

According to BTO, "BEM supports system-level 'integrative design' for new construction and retrofits that simultaneously optimize the building's envelope, systems, and their controls to match its anticipated use profile and local conditions. [It also has the potential] to support 'integrative operations' in which a model incorporates real-time information from sensors, weather forecasts, and/or the building's energy management system to satisfy key energy and Indoor Environmental Quality objectives. Finally, at a larger scale, BEM also supports energy-efficiency codes, rating and labeling systems, energy efficiency incentive programs, product design, research, and education."[5]

Predecessor activities of BEM can be traced back to 1971 (as illustrated in Figure 1), when the U.S. Postal Service created a computer program to analyze energy use in post offices called the "Post Office Program." CAL-ERDA, the first modern whole-building energy modeling tool, was created in 1977 by the Energy Research and Development Administration (ERDA) and California Energy Commission. CAL-ERDA was based on the National Aeronautics and Space Administration's Energy-Cost Analysis Program. Also in 1977, ERDA merged with the Federal Energy Administration to create the modern DOE. DOE continued developing CAL-ERDA under the new name DOE-1 and eventually created its successors, DOE-2 and DOE-2.1.[6]

The Electric Power Research Institute and James J. Hirsch & Associates developed and distributed DOE-2.2 in the 1990s. To avoid overlapping development with DOE-2.1, DOE began developing a new program independent and separate from DOE-2 in 1996. This program was based around the Department of Defense's Building Loads And System Thermodynamics (BLAST) program. DOE released this new tool in 2001 as EnergyPlus. In 2012, DOE made the software available under an open-source license. To this day, DOE regularly updates EnergyPlus.[7]

The evaluation summarized in this report focused specifically on BEM tools funded by DOE between 2000 and 2020. To increase the portfolio of DOE-funded BEM use cases, BTO is focused on improving the capabilities, accuracy, speed, and usability of BEM. BTO has done this by supporting the R&D of open-source BEM software that embodies this research. BTO has developed a suite of DOE-funded BEM software packages and funds the maintenance and expansion of the ASHRAE Standard 140, which is the test method for BEM engines.

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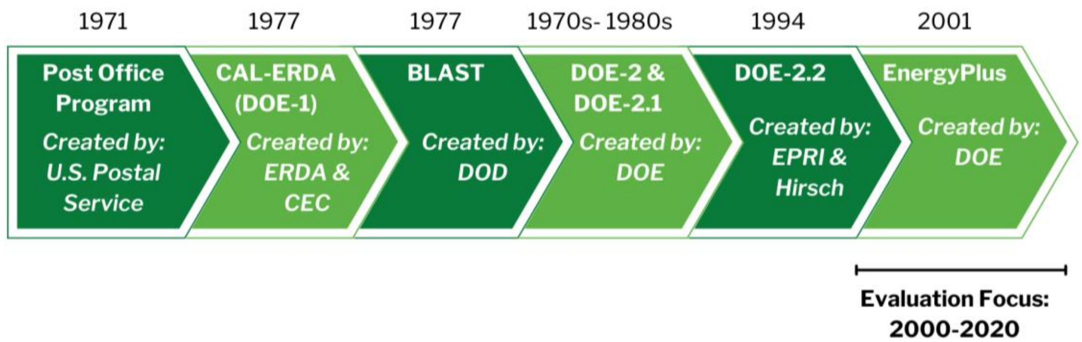
[5] Barbour et al. (February 2016). ***Research & Development Roadmap for Building Energy Modeling*** [Draft for review only]. Building Technologies Office. https://www.energy.gov/sites/prod/files/2016/02/f29/DOE-BTO-BEM-Roadmap-DRAFT-2-1-2016.pdf.

[6] Office of Energy Efficiency & Renewable Energy. (November 2020). ***Innovations in Building Energy Modeling: Research and Development Opportunities Report for Emerging Technologies***. DOE/GO-102020-5467. https://www1.eere.energy.gov/buildings/pdfs/77835.pdf.

[7] Ibid.

Figure 1: Historic Timeline of BEM Tool Development



1.1.2 Energy Efficiency Codes

The evaluation focused specifically on the ASHRAE Standard 90.1 ***Energy Standard for Buildings Except Low Rise Residential Buildings*** model code for commercial buildings. Energy efficiency codes are state laws establishing a minimum energy efficiency requirement for buildings. There is no federal-level building code (except for energy conservation standards for manufactured housing)[8], so states often adopt or change model codes developed by ASHRAE or the International Codes Council (ICC). Most states adopt various updates of the ASHRAE Standard 90.1 code, and how ASHRAE uses BEM in its development is known.

Other energy efficiency codes include the California Energy Commission's (CEC) Title 24 and the ICC's International Energy Conservation Code (IECC). Title 24 is similar to ASHRAE 90.1 in the development process but is used only in California. IECC has a different development process than ASHRAE Standard 90.1, and is less commonly used for commercial buildings in the U.S.

Table 1 below details examples of building codes (and standards that can be adopted as code) with development support from DOE-funded BEM tools.

Table 1. Select Building Codes Whose Development is Supported by DOE-Funded BEM Tools[9]

Standard Organization	Standard Number	Standard Subject
ASHRAE	90.1	Minimum performance of commercial buildings
ASHRAE	90.2	Minimum performance of residential buildings
ASHRAE	90.4P	Minimum performance of data centers
ASHRAE	189.1	High performance of commercial buildings
California Energy Commission	Title 24	Whole building performance

[8] See https://www.federalregister.gov/d/2021-17684 for additional information.

[9] Barbour et al. (February 2016). ***Research & Development Roadmap for Building Energy Modeling***. Building Technologies Office. https://www.energy.gov/sites/prod/files/2016/02/f29/DOE-BTO-BEM-Roadmap-DRAFT-2-1-2016.pdf.

1.1.3 Energy Efficiency Incentive Programs

Energy efficiency incentive programs are state and local financial programs that help building owners execute energy efficiency projects by lowering cost burdens through:

- Public benefits funds, grants, loans, or property-assessed clean energy financing;
- Personal, corporate, property, and sales tax incentives;
- Assistance with permitting fee reduction or elimination.

To increase energy efficiency, utilities (as well as some government agencies and third-party entities[10]) offer incentives to reduce energy consumption.[11] Nationally, the U.S. building sector consumes 40% of the total primary energy produced each year.[12] Annually, utility rebate and energy efficiency incentive programs provide approximately $3.6 billion[13] in funding to lower energy consumption and peak demand. Currently, 32 states offer financial incentives and assistance to consumers for the adoption of new energy-efficient equipment and energy audits. Typically, each program is managed at the state level with major utility providers.

The evaluation report categorizes rebate and energy efficiency incentive programs into the following groups:

- Public purpose programs administered by utilities, state agencies, or other third parties and paid for by utility ratepayers, typically through a non-bypassable system benefits charge instituted as part of restructuring legislation or rules;
- Utility programs administered by local utilities and paid for by utility ratepayers through bundled rates.
- Programs sponsored by state agencies designed to promote energy efficiency and renewable energy, usually funded out of general tax revenues.

While specifics vary from program to program, savings categories often include financial incentives for HVAC systems, water heaters, building insulation, appliances, weatherization, lighting, and other energy-efficient improvements. A subset of programs use prototypical BEM to calculate savings. For the prescriptive programs considered in this study (as opposed to custom programs), incentives are not provided for a project based on its specific site details. Rather, they are calculated for the typical application of an efficiency measure. These calculations are often justified by Technical Reference Manuals (TRMs), real-world measurement and verification of savings, and in-house engineering calculation tools.

[10] York, D. (2012). ***Overview: Administrative Structures for Utility Customer Energy Efficiency Programs in the United States*** [PowerPoint slides]. American Council for an Energy-Efficient Economy. https://www.raponline.org/wp-content/uploads/2016/05/iea-pepdee-utilitycustomereeprogramsus-2012-apr-18.pdf.

[11] U.S. Energy Information Administration. (July 2013). "State Energy Efficiency Program Evaluation Inventory." https://www.eia.gov/efficiency/programs/inventory/pdf/inventory.pdf.

[12] U.S. Energy Information Administration. (January 2022). ***Monthly Energy Review***. DOE/EIA-0035. https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf.

[13] U.S. Energy Information Administration. (June 2018). "State efficiency incentives averaged $24 per customer, ranged from $0 to $128 in 2016." https://www.eia.gov/todayinenergy/detail.php?id=36512.

2. Scope

The scope of the evaluation outlined in this report was to determine the degree to which prior energy savings identified from the development of energy efficiency building codes and energy efficiency incentive programs are attributable to BTO investments in BEM tools and activities.

The primary evaluation questions, which highlight the scope of this evaluation, the use cases of focus, and the intended evaluation outputs, were as follows:

1. To what extent have DOE investments in BEM tools and activities influenced the development of: A) energy efficiency building codes and B) energy efficiency incentive programs?

2. What are the DOE-funded BEM-attributed energy, emissions, environmental-related health, and economic outcomes resulting from the use cases identified above?

3. To what extent does the monetary value of DOE-funded BEM-attributable benefits resulting from the use cases identified above exceed DOE's expenditures in BEM tools and activities?

2.1 Focus

The evaluation focused on prototypical uses of DOE-funded BEM. Prototypical uses stand in contrast to custom uses that examine individual existing or planned buildings. DOE-funded BEM performed on specific buildings supports use cases such as new construction and retrofit design, performance calculations for code compliance, energy ratings, and energy efficiency incentives. It also supports emerging operational use cases like performance monitoring, fault diagnosis, and model-predictive control.

The rationale to focus the evaluation on prototypical uses of DOE-funded BEM is as follows: practitioner communities are better defined and more easily identifiable, and several have been independently evaluated for energy savings. Prototypical use of DOE-funded BEM includes the development of energy efficiency codes, guidelines, energy efficiency incentive programs, and energy efficiency products. For the purposes of this study, the evaluation defined prototypical uses as any stock-level building energy analysis of energy efficiency codes or energy efficiency incentive program updates performed using DOE commercial and residential prototype building models, DOE modeling software such as EnergyPlus, and the OpenStudio (OS) Software Development Kit (SDK). By studying prototypical uses that have already been evaluated for energy savings, the evaluation was able to cross-reference energy savings data from building types, climate zones, and end uses with technology category and state level criterion used in this evaluation.

2.2 Portfolio Approach

The evaluation methodology employs a portfolio approach to analyze the impacts of the DOE-funded BEM program. This approach offers an efficient way to determine if a portfolio of investments has generated an economic benefit without analyzing a program's entire collection of portfolios. It provides a lower-bound estimate of benefits because not all DOE-funded BEM investments and use cases are included, yet economic benefits are measured against the total DOE-funded BEM program investment cost. As previously mentioned, this study focused on the portfolio of investments for prototypical BEM use cases.

The portfolio for this evaluation represents the following set of projects and activities funded by the BEM subprogram of the Emerging Technologies (ET) Program from 2000 through 2020:

1. EnergyPlus BEM Engine: EnergyPlus is a detailed, physics-based whole-building energy modeling engine that can simulate building envelopes, shading and daylighting, HVAC, refrigeration, water heating systems, and controls.
2. OpenStudio Software Development Toolkit: OpenStudio is a collection of software modules that support whole-building energy modeling using EnergyPlus. The OpenStudio SDK helps software developers develop applications and services that use EnergyPlus, automate energy modeling tasks such as applying energy efficiency measures to models, and perform large scale parametric simulations.
3. ASHRAE Standard 140 "Standard Method of Test for BEM Computer Programs": A set of analytical and comparative tests for BEM engines along with reference results from multiple engines that promote increased and convergent accuracy in BEM engines and increase confidence in BEM.
4. Prototype Building Models: A set of commercial and residential code-compliant building energy models created in EnergyPlus that represent various sector building types across 19 climate zones. Prototype models enable researchers to demonstrate energy savings and cost impacts of broad policy updates such as the development of new code updates and energy conservation measures (ECMs) offered by state and regional utility programs.

Aside from the four activities listed above, the DOE BEM program includes additional activities not included in this study. These were excluded as they do not support prototypical BEM use cases. They are:

1. Empirical Validation Using Instrumented Test Facilities: A collection of projects to develop an empirical test suite for ASHRAE Standard 140 using well-characterized instrumented test facilities. The tests focus on heating and cooling loads in various configurations, and include some airflow and HVAC tests.
2. BuildStock: A high-dimensional database of joint probability distributions of building asset and operational characteristics. This database was created by combining data from mostly public and a few proprietary data sets followed by stock-level calibration to utility demand load shapes. Whereas the prototype buildings target analysis for new construction, BuildStock targets analysis of the existing building stock.
3. ASHRAE Standard 229P: A proposed standard that aims to improve accuracy, consistency, and outcome predictability in projects using rule-set based performance calculations.
4. Spawn: A next-generation BEM engine that targets building and district HVAC control applications. Spawn reuses the lighting, envelope, and load models of EnergyPlus and uses co-simulation to couple them to new HVAC and controls models that are simulated in a dynamic, state-based way.
5. URBANopt: An advanced analytics platform for high-performance buildings and energy systems within one geographically cohesive area within a city (e.g., a city block or district).

Table 2 summarizes ET portfolio investment costs (in thousands of dollars) in prototypical BEM between 2000 and 2020. Between 2011 and 2020, DOE invested over $45 million in BEM projects targeting prototypical use cases. Two of these projects, EnergyPlus and OpenStudio, constitute the two largest investments in the BEM program overall.

Table 2. BTO ET BEM Portfolio Investment Costs (2000–2020)

Year	BEM Activities Targeting Prototypical Use Cases				Current-Year Dollars Total ($000)	Constant 2020 Dollars Total, Undiscounted ($000)
	Energy Plus ($000)	Open Studio SDK[14] ($000)	ASHRAE Standard 140 ($000)	Prototype Building Models ($000)		
2000	Investment cost data was not available from BTO for this period. Total ET BEM portfolio investment costs between 2000 and 2010 are based on estimates from BTO rather than from historical data.				4,091	5,959
2001					4,091	5,827
2002					4,091	5,738
2003					4,091	5,627
2004					4,091	5,480
2005					4,091	5,313
2006					4,091	5,154
2007					4,091	5,018
2008					4,091	4,924
2009					4,091	4,893
2010					4,091	4,835
2011	2,870	0	3,577	0	3,090	3,577
2012	2,795	0	3,489	0	3,070	3,489
2013	1,980	1,060	3,697	0	3,310	4,188
2014	2,100	1,450	4,188	0	3,820	4,188
2015	2,650	1,200	4,733	180	4,360	4,733
2016	1,975	1,350	4,030	150	3,750	4,030
2017	2,750	1,080	4,588	220	4,350	4,588
2018	3,316	1,698	6,980	1,200	6,776	6,980
2019	3,308	1,450	5,929	700	5,858	5,929
2020	3,645	1,550	6,772	1,077	6,772	6,772
Totals	**27,389**	**3,402**	**3,527**	**10,838**	**90,156**	**106,752**

[14] NREL developed OpenStudio under the Laboratory Directed Research and Development Program between 2009–2012. Table 2 does not reflect NREL investment costs.

Due to unavailability of program investment cost data for the period 2000–2010, BTO recommended we apply the same investment rate as the 2011–2020 timeframe. This resulted in a total estimated investment of roughly $90 million between 2000–2020. From this portfolio, the evaluation selected two prototypical applications of DOE-funded BEM for detailed evaluation: development of energy efficiency codes and energy efficiency incentive programs.

The evaluation selected development of energy efficiency codes and energy efficiency incentive programs use cases based on approval of program staff, a review of program documents, and interviews with building science experts. Selection factors included: (1) available proof points that demonstrate clear linkages between BTO's ET program BEM portfolio being used in the prototypical use cases; (2) available documented gross energy savings for prototypical use cases; and (3) data available to calculate BEM-attributed realized energy, emissions, and environmental health impacts.

The evaluation further subdivided the use case for building energy efficiency codes into commercial building energy codes and residential building energy codes. The evaluation defined the use cases as follows:

- ASHRAE 90.1 Commercial Building Energy Code: ASHRAE Standard 90.1 ***Energy Standard for Buildings Except Low Rise Residential Buildings*** is a model code for commercial buildings. Various updates of the code are adopted in most states. At regular three-year intervals, ASHRAE aggregates all addenda accrued in the previous three years to define a new version of the standard. The ASHRAE code iterations relevant to this evaluation were 2004, 2007, 2010, 2013, 2016, and 2019. ASHRAE 2001 was not considered in the evaluation because its development predates the release of EnergyPlus. The standard is next scheduled for release in 2022.
- IECC Residential Building Energy Code: The IECC is a model energy code that a vast majority of states have adopted to some degree for residential buildings. The ICC releases updates to the IECC codes on a three-year cycle through a public consensus process. The IECC code iterations relevant to this evaluation were 2003, 2006, 2009, 2012, 2015, and 2018. The 2000 IECC update was not considered in the evaluation because its development predates the release of EnergyPlus. The most recent version of the code is from 2021.
- Energy Efficiency Incentive Programs: In many U.S. states, territories, and the District of Columbia, state agencies or utilities offer financial incentives to assist consumers with the adoption of new energy-efficient equipment, energy audits, and water conservation efforts. Typically, states manage each program in conjunction with major utility providers.

The evaluation determined a quantitative analysis was not appropriate for the residential energy efficiency codes and energy efficiency incentive program use cases. This limited those use cases to qualitative findings based on research and expert interviews.

2.3 Logic Models

This section presents the visual logic models indicating the relationships between inputs, activities, outputs, outcomes, and impacts. Originally, the evaluation planned for the methods for attribution (via interviews, Delphi instrument, and survey) to be consistent across all use cases. However, preliminary research, stakeholder interviews, and the energy efficiency incentive program meta-analysis determined that a Delphi panel would not be appropriate for the residential energy efficiency codes or energy efficiency incentive programs use cases. With concurrence from the BTO team, it was agreed to qualitatively analyze these use cases.

2.3.1 Energy Efficiency Codes Logic Model

The ICC and ASHRAE organizations develop energy efficiency codes for residential and commercial buildings. These organizations use BEM tools and other factors to inform large-scale analyses that support building energy code updates every three years. Increased code stringency and adoption is intended to result in energy savings, which lead to energy, environmental health impacts, and economic benefits.

DOE-funded BEM tools influence energy efficiency code program development through the following theory of change (depicted below in Figure 2):

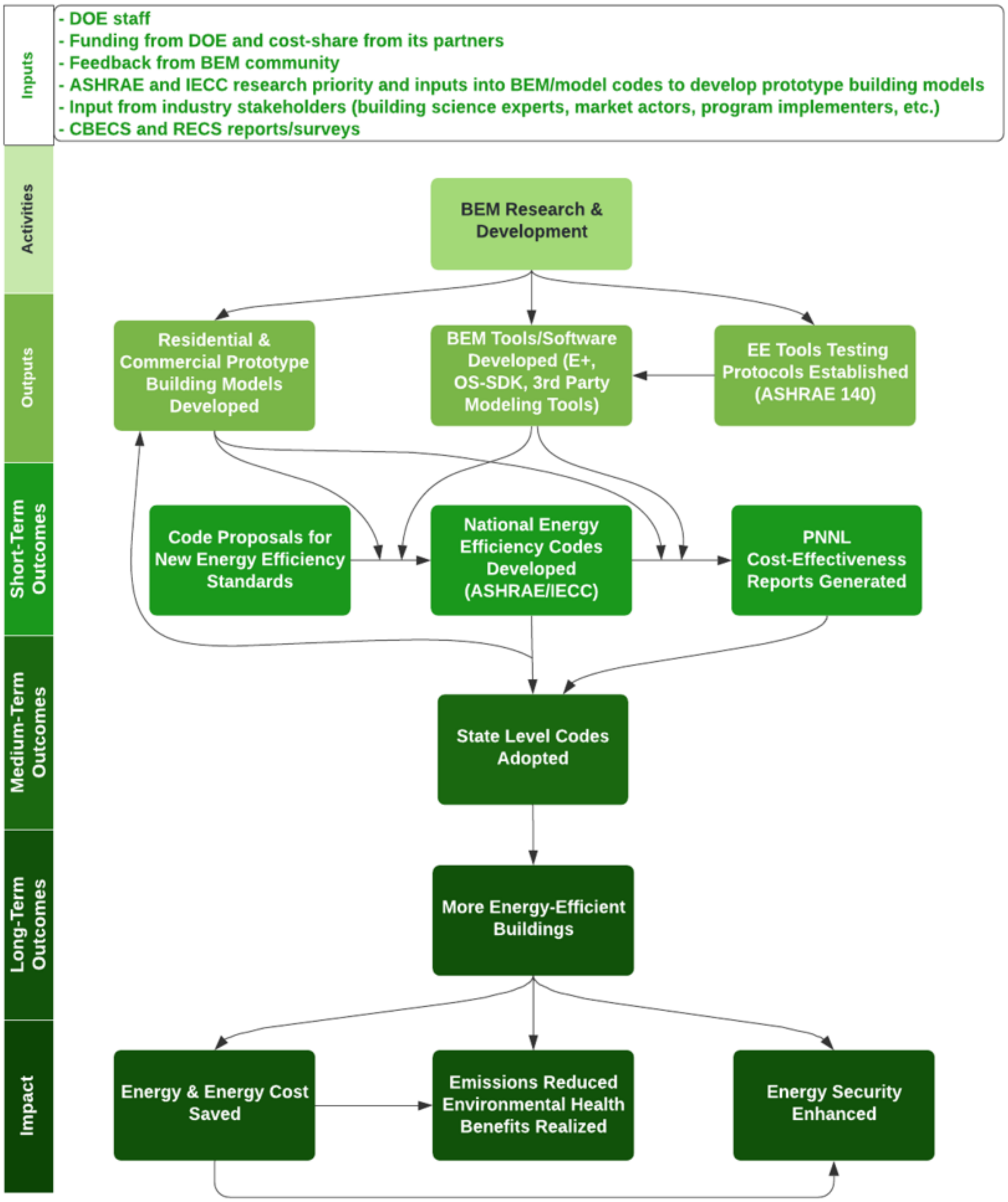
1. EnergyPlus, OpenStudio Software Development Toolkit, ASHRAE Standard 140, and Residential and Commercial Prototype Building Models Enable Energy Efficiency Code Development: EnergyPlus simulation of the DOE-funded building prototypes is used to evaluate proposed code amendments for energy savings and cost-effectiveness. The use of a single engine and a single set of prototype models support a consistent evaluation of amendments. In the case of ASHRAE Standard 90.1, using BEM to demonstrate amendment cost-effectiveness is a part of the standard-making process.

2. EnergyPlus, OpenStudio Software Development Toolkit, ASHRAE Standard 140, and Residential and Commercial Prototype Building Models Enable the Development of State-Level Cost-Effectiveness Reports: At the end of a code cycle, all the accepted amendments are aggregated to create a new version of the code. At that point, the Pacific Northwest National Laboratory (PNNL) uses EnergyPlus simulation of the DOE prototype buildings to conduct a state-by-state analysis of the energy savings and cost-effectiveness associated with adopting the new version of the code relative to the previous version. These reports, called "determinations," inform code adoption.

3. Updated Versions of the Prototype Models Form the Basis for the Next Code Cycle: At the end of a code cycle, PNNL creates and publishes a new version of the prototype models that reflects all accepted amendments. This new set forms the basis for analysis for the following code cycle. In this way, code updates build on one another.

4. PNNL Conducts State-Level Technical Analysis: Based on the methodology established by DOE, PNNL reviews state energy codes based on IECC and ASHRAE Standard 90.1 to include any significant amendments. This helps states understand how their codes compare to the national model codes and provides a portrait of national code adoption.

Figure 2: Logic Model Describing the Influence of DOE-Funded BEM Tools on Energy Efficiency Code Development[15]



[15] E+ refers to EnergyPlus; OS-SDK refers to OpenStudio Software Development Kit.

2.3.2 Energy Efficiency Incentive Programs Logic Model

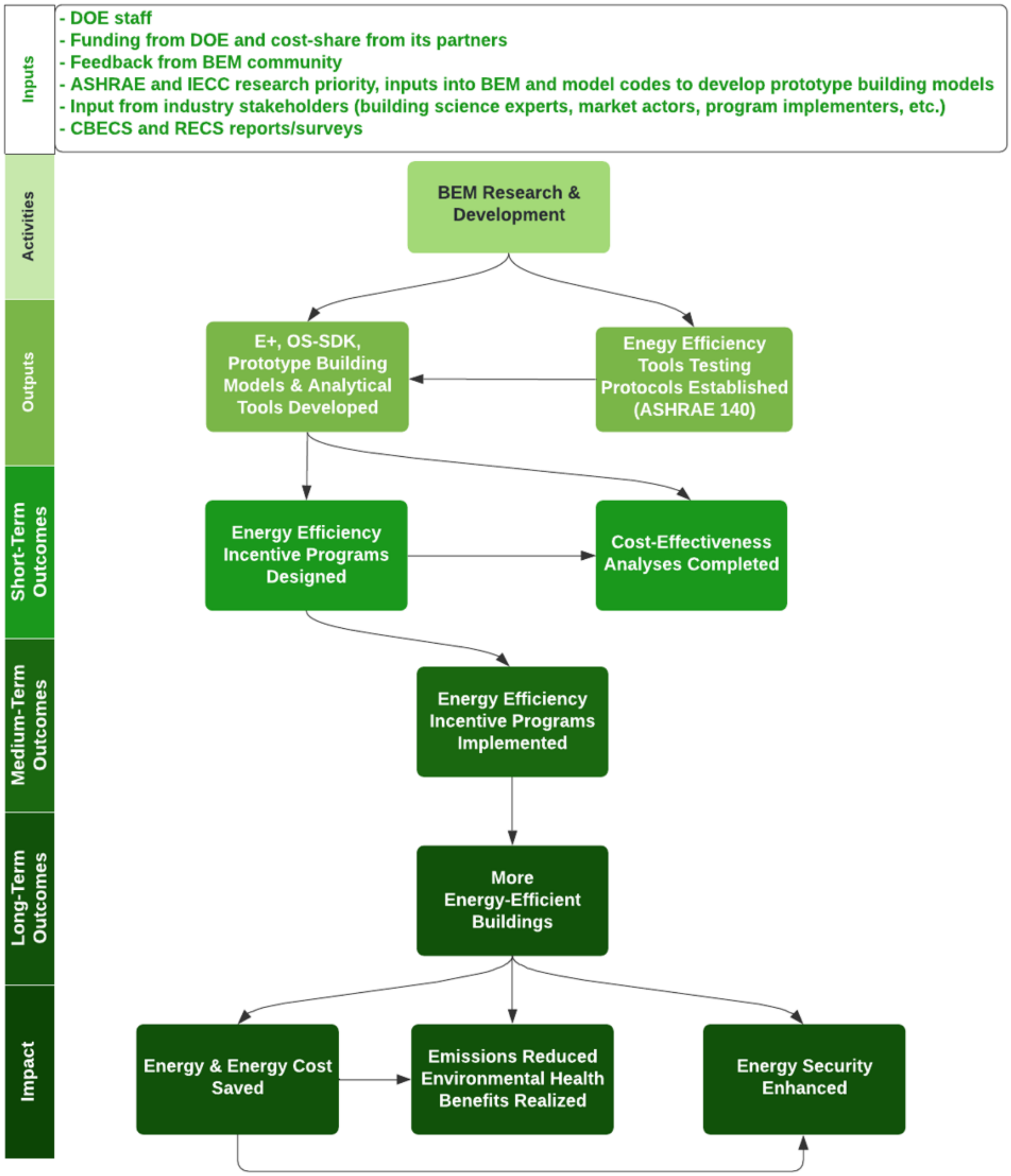
State and regional energy programs, utilities, and third-party energy efficiency program administrators (PAs) use DOE prototypes, DOE-funded BEM tools, and design guides to identify available ECMs and understand their expected energy and cost savings. The PAs also use DOE-funded BEM tools to design new, more diverse ECM program offerings and evaluate how new or existing measures may help their programs meet increasingly stringent regulatory energy savings requirements. The PAs develop programs to incentivize the adoption of ECMs through rebates and financing that offset the investment cost of purchasing energy-efficient products. This can include marketing and outreach as well as training of builders, contractors, and the design community. These incentives steer stakeholder purchase, retail stocking, and commercial production decisions toward energy-efficient technologies for new building construction and retrofit. Incentivizing measures that meet or exceed more ambitious energy performance targets results in the design of more energy-efficient buildings, which leads to increased energy and cost savings.

DOE-funded BEM also helps reduce barriers to program enrollment for architects, builders, and other DOE stakeholders by enabling PAs to develop prescriptive pathways for whole-building energy efficiency programs. Participants in prescriptive energy efficiency programs do not need to invest in developing a specific building model; instead, they may rely on prescriptive pathways such as the Advanced Energy Design Guides. DOE prototypes simplify the complex process of developing building models and can increase participation rates in energy efficiency incentive programs. The significant time, resources, and technical ability required to develop building models ground-up can discourage a segment of DOE stakeholders from enrolling in energy efficiency incentive programs if not for DOE-funded BEM tools. Prescriptive pathways developed using DOE building prototypes enable PAs to determine whether a building will meet the energy efficiency design standards required by these programs.

The evaluation team developed the following theory of change explaining how DOE-funded BEM tools could influence energy efficiency incentive program development (depicted below in Figure 3):

1. EnergyPlus and Residential and Commercial Prototype Building Models Support the Design of State Energy Efficiency Incentive Programs: State and regional energy efficiency programs, utilities, and PAs use EnergyPlus simulation on the DOE prototype models to evaluate typical savings for candidate ECMs. The process mirrors how ASHRAE evaluates code amendments. However, rather than a rigid a priori cost-effectiveness criterion, the energy efficiency program can use the savings estimate to calculate an incentive that would make an otherwise cost-ineffective ECM into a cost-effective one. Energy efficiency programs use this type of analysis to meet their energy savings targets while staying within program (i.e., incentive) budgets.

Figure 3: Logic Model Describing the Influence of DOE-Funded BEM Tools on Energy Efficiency Incentive Program Development



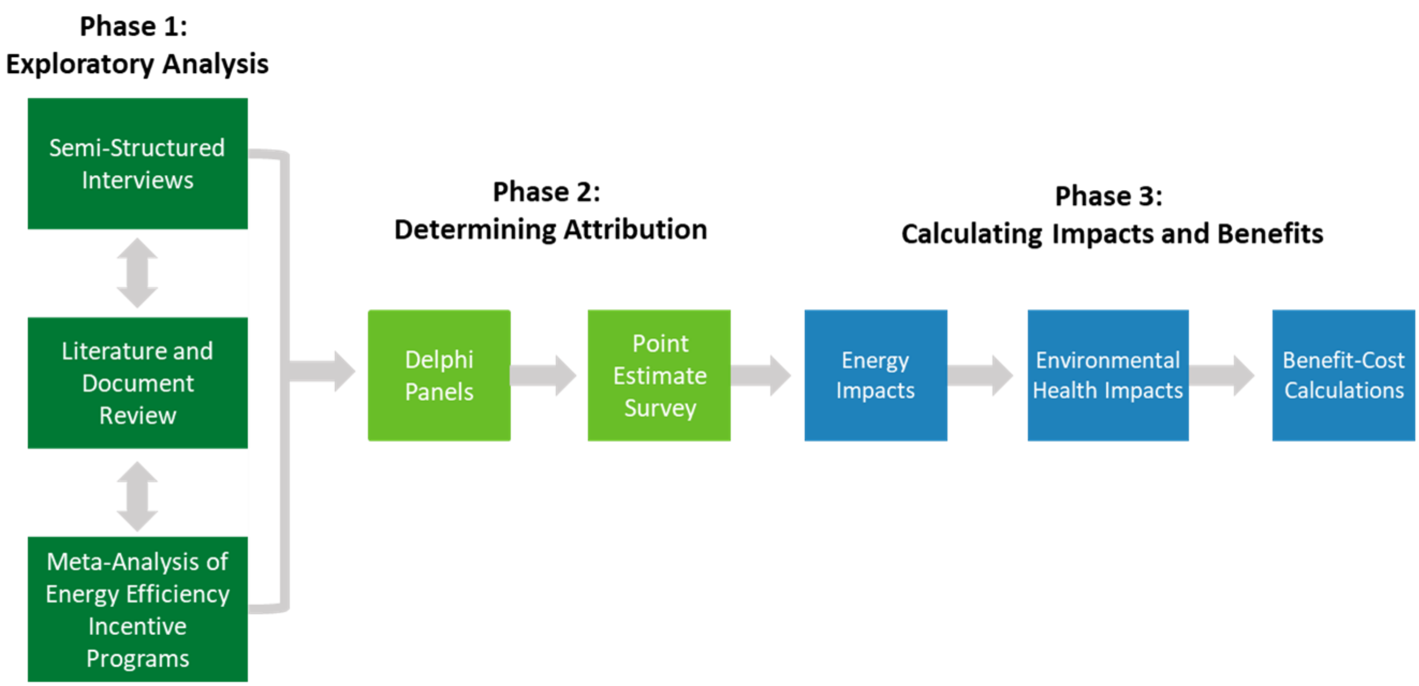
3. Methodology

This evaluation used both quantitative and qualitative methodologies for the evaluated use cases, as described in the following sections.

3.1 Evaluation Design

The evaluation was conducted through the course of three interrelated phases: exploratory analysis, determining attribution, and calculating impacts and benefits. Figure 4 outlines the overall approach for each use case and the following sections detail the original evaluation design.

Figure 4: Phased Approach to Evaluation



3.1.1 Phase One: Exploratory Analysis

Phase One used four methods to identify:

1. Rival factors that also influenced code and energy efficiency incentive program development;
2. Alternative tools and approaches to developing codes and energy efficiency incentive programs if DOE-funded tools were not developed;
3. Potential impacts of using these alternative tools and approaches; and
4. Potential Delphi panelists for Phase Two.

Refer to Table 3 for the information collected from each Phase One method.

Table 3. Information Collected from Phase One Methods

Method	Information Collected from Each Method
Semi-Structured Interviews	• Factors that influence code and incentive development • Alternative tools and approaches that could have been used if DOE-funded BEM tools were not developed • Specific state programs to investigate for inclusion in energy efficiency incentive program use case • Potential impacts on code and incentive development if DOE-funded BEM tools were not developed • Potential Delphi panel participants
Literature and Document Review	• Factors that influence code and energy efficiency incentive program development • Alternative tools and approaches that could have been used if DOE-funded BEM tools were not developed • Potential impacts of alternative tools and approaches • Specific state programs to investigate for the incentives program use case • Potential Delphi panel participants
Meta-Analysis of Past Energy Efficiency Incentive Program Evaluations	• Selected energy efficiency incentive programs to include for the use case • Factors that influence energy efficiency incentive program development • Selected timeframe for evaluating impacts based on available data for energy efficiency incentive program use case • Counts of the ASHRAE AEDG references in state program documentation • Overall annotated energy savings of energy efficiency incentive programs

3.1.2 Phase Two: Determining Attributable Influence of DOE-Funded Activities

In Phase Two, the evaluation used the Phase One findings, Delphi panels, and an expert survey to determine DOE's attributable influence on code and energy efficiency incentive program development. The Delphi method consists of sequential rounds interspersed by group feedback that seeks to gain the most reliable consensus of opinion from a panel of experts. For an in-depth explanation of the Delphi panel method of data collection, refer to Section 3.2.4. Evaluators planned to wield the consensus information to field a survey gathering point estimates on the impact of DOE-funded BEM tools on incentive and code development.

The focus of data collection from Phase Two is outlined in Table 4. Phase Two evaluation efforts determined how DOE investments in BEM tools influenced code developments. By utilizing the Delphi panel and additional surveys, the evaluation team developed point estimates to determine how much of the energy savings identified under the evaluated use cases is attributable to DOE investments. Evaluators used the point estimates in Phase Three to conduct energy and environmental health impacts and economic benefit calculations.

Table 4. Information Collected from Phase Two Methods

Method	Information Collected from Each Method
Delphi Panel	• Demographic information and experience of panelists • Additional factors that influence code development • Consensus on the primary rival factors that influence code development • Consensus on potential impacts of alternative tools and approaches if DOE-funded BEM tools were not developed

Method	Information Collected from Each Method
	• Consensus on the potential magnitude of alternative tools and approaches impacts on code development if BEM tools were not developed
End of Panel Survey	• Point estimates of DOE-funded BEM tools contribution to code development by technology category • Point estimates of the change in energy efficiency to codes if DOE-funded BEM tools were not developed by technology category

3.1.3 Phase Three: Calculating Impacts and Benefits

In Phase Three, the evaluation used past analyses of energy savings, along with the point estimates from Phase Two, to calculate energy savings attributable to DOE-funded BEM activities. From BEM-attributable energy savings, evaluators calculated energy dollar savings, avoided emissions, environmental health impacts, and economic benefits. The benefit-cost analysis used historical total DOE BEM investment cost data and attributable monetized benefits from the commercial energy efficiency codes use case to calculate economic benefits. The benefit-cost analysis also included a sensitivity analysis on the attributions from the Delphi process to derive a range of low- and high-end case energy and environmental health economic benefits. Phase Three also included the qualitative assessment of the relationship between BEM and residential efficiency codes and efficiency incentive programs.

Table 5 outlines the information collected from Phase Three. Refer to Section 4 for detailed results.

Table 5. Information Collected from Phase Three Methods

Method	Information Collected from Each Method
Energy Impacts	• Avoided energy use by year, by fuel type and by state
Emissions and Environmental Health Impacts	• Avoided emissions by year, by fuel type and by state • Avoided environmental health benefits, by year
Benefit-Cost Calculations	• BTO program expenditures by year (portfolio investment costs) • Gross Benefits • Present value of investments • Present value of benefits • Net present value • Benefit-to-cost ratio • Internal rate-of-return • Sensitivity analyses using 3 and 7 percent discount rates and low- and high-end case attribution rates
Qualitative Analysis for Residential Efficiency Codes and Energy Efficiency Incentive Programs	• Interviews with IECC residential code committee members and energy efficiency incentive program design and implementation managers regarding the potential use of BEM in any process related to either code updates or incentive program metrics

3.2 Data Collection

Primary data collection occurred in Phases One and Two through web-based research, semi-structured interviews, and the Delphi panel.

3.2.1 Web-Based Research

The evaluation team began preliminary data collection by conducting Internet research on the ASHRAE and ICC committee rosters for each relevant code iteration to identify contacts who can recommend potential interview topics, Delphi panelists, and survey respondents. The evaluation team also reviewed the American Council for an Energy-Efficient Economy (ACEEE) scorecards published since 2006 to identify energy efficiency incentive program staff to serve as primary sources. Additional online resources reviewed include the California Measurement Advisory Council and Database of State Incentives for Renewables & Efficiency (DSIRE) published by the North Carolina State University Clean Energy Technology Center, to help determine primary points of contact from relevant commercial and industrial (C&I) new construction prescriptive incentive programs. Evaluators reviewed previous evaluation reports such as the Savings By Design Market Potentials, Characterization and Best Practices Enhanced Program Participation Study to identify specific contacts with relevant program administrators.

Evaluators also reviewed the following secondary research data sources, which were used in the evaluation as described in sections below:

- PNNL reports;[16]
- Fuel oil savings data from utility programs in the northeast U.S.;
- Energy Information Administration (EIA) Monthly Energy Review;
- Environmental Protection Agency (EPA) COBRA tool and reports;
- EPA AVoided Emissions and geneRation Tool (AVERT); and
- State energy savings databases and reports.

Combined, these sources provided the background and framework for the evaluation.

3.2.2 Primary Interviews

The evaluation team conducted primary interviews with ASHRAE and IECC committee members familiar with multiple code iterations and with an understanding of how BEM may or may not support the development, technical justification, and approval of code updates. The evaluation team asked participants about the overall process of developing code iterations, the role of DOE-funded BEM tools, resources or tools other than BEM that contribute to the code development or update process, and additional contacts knowledgeable on the code update process. Refer to Appendix A for the list of interview participants.

The evaluation team conducted additional primary interviews with consultants and program administrators involved in energy efficiency incentive programs. Evaluators asked relevant stakeholders about the incentive program design process, the availability and use of BEM tools, and their familiarity with prescriptive design guides. In addition, interviewers asked about evaluation reports, savings data, rival factors, and additional contacts knowledgeable of the incentive program development process and how BEM tools may or may not inform incentive program development. Refer to Appendix B for the list of interview questions discussed with participants.

3.2.3 Study Population

The study population consisted of experts involved in the development of ASHRAE 90.1 code iterations and the development of proposed changes to the IECC residential code, as well as energy efficiency incentive program

[16] Specifically, the evaluation used the Final Determination Quantitative and Qualitative Analyses for each ASHRAE 90.1 code iteration.

staff familiar with DOE-funded BEM capabilities whose programs potentially use DOE-funded BEM in the development of nonresidential new construction and retrofit incentive programs.

The evaluation team researched ASHRAE and ICC committee rosters for each code iteration relevant to this evaluation (2000–2020) to find contacts who could recommend potential people to interview, Delphi panelists, and survey respondents. Phase One interviews focused on committee members familiar with multiple code iterations and an understanding of how BEM may or may not support the development, technical justification, and approval of code updates. Evaluators engaged stakeholders who reviewed or contributed to code addenda specific to envelope, lighting, HVAC, and other energy components to determine whether BEM tools are more or less likely to influence certain elements of code updates.

Evaluators conducted Internet research and interviews with current committee leadership to compile a list of relevant stakeholders from earlier ASHRAE committees. Interviews and Internet research informed Delphi panel recruitment criteria. The panelist inclusion criteria for the commercial energy efficiency code (ASHRAE 90.1) Delphi panel were:

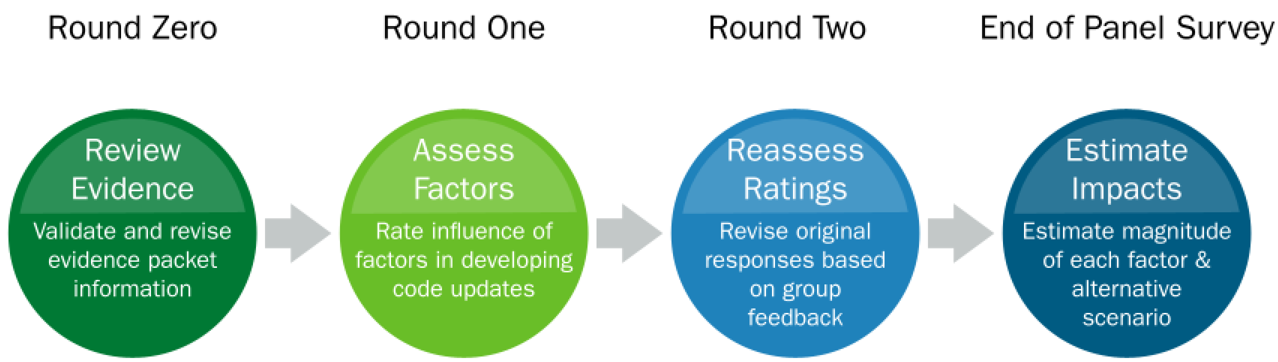
- Level of knowledge on the development of codes;
- Number of code update cycles participated in since 2003;
- Most recent participation in code update activities;
- Understanding of BEM's role in codes development;
- Balance of panel experience and employment; and
- Availability to participate in multiple rounds of surveys as part of the Delphi process.

Based on the preliminary research, the evaluation team anticipated the population to be fairly homogenous and did not expect any significant stratification of Delphi panelists based on observed characteristics. Evaluators measured panel composition through a demographic and experience survey to ensure a balanced panel and that no set of similar individuals would skew the results. After concurrence from the BTO team, the evaluation did not consider any stratification or sampling given the small number of potential panelists and low email response rate.

3.2.4 Delphi Panel

The Delphi panel method is a series of sequential questionnaires (or "rounds") interspersed by group feedback that seeks to gain the most reliable consensus of opinion from a panel of experts. Inherently, the Delphi method enables individuals to review their answers, the group's answers, and the group's rationales before adjusting their answers. This allows participants to reflect on their position in light of the opinions and reasoning of other participants and often leads to consensus. Figure 5 details the Delphi process used during this evaluation.

Figure 5: Delphi Panel Process



Seven industry experts participated in Rounds Zero, One, and Two of the Delphi panel. The evaluation measured the demographic makeup of the Delphi panel through an introductory survey to ensure each panelist was qualified to take part. All panelists had previously been members of the ASHRAE Standards Committee, and many also had experience on the ASHRAE Technical Committee and Standards Committee. In addition, two panelists had non-ASHRAE experience on ICC committees. The specific demographics of the Delphi panel were:

- Gender: 6 men, 1 woman
- Highest Level of Education: 4 Bachelor's, 2 Master's, 1 PhD
- Degree Type: 5 Mechanical Engineering, 2 Chemical Engineering
- Years of Experience: In total, panelists had over 116 years of collective experience.

The Delphi panel proceeded as follows:

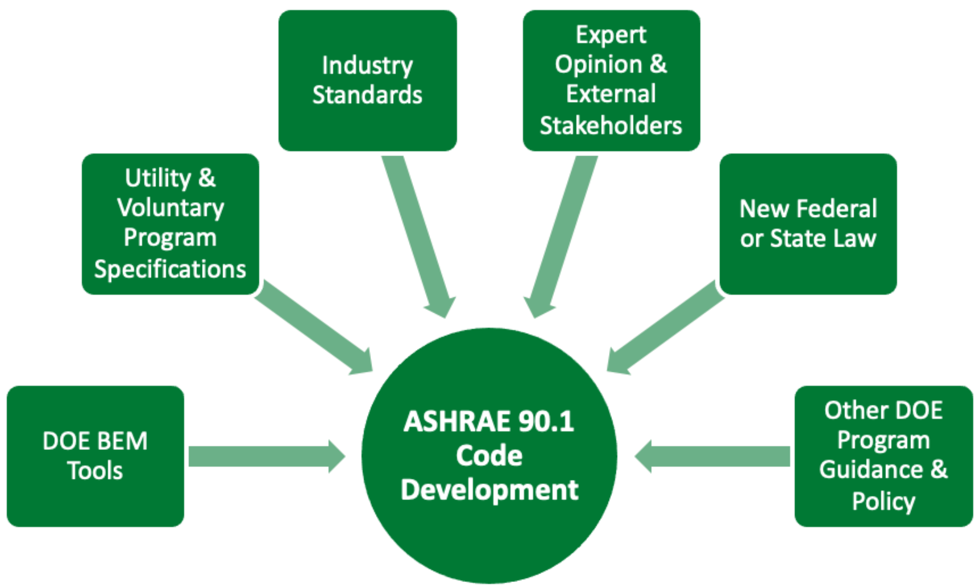
- Prior to Round Zero, Panelists received an ASHRAE 90.1 evidence packet that included a detailed description of the DOE BEM program, an overview of the Delphi methodology, and appropriate background information summarizing the ASHRAE 90.1 code development process, major code changes, the technology categories, rival factors, and alternative scenarios without DOE-funded BEM tools. (Refer to Appendix C for the evidence packet provided to panelists.)
- In Round Zero, the evaluation team introduced evidence, based on web-based research and primary interviews, on factors that influenced code development and alternative scenarios if BEM tools had not been funded. Evaluators asked panelists to confirm the information and add any missing factors or scenarios. (Refer to Section 4.1.1 and Appendix D for a summary of panelist input during Round Zero.)
- In Round One, evaluators asked panelists to indicate their agreement with a series of statements about factors that influenced code development using Likert scale responses (i.e., 1 - Totally Disagree and 9 - Totally Agree) and describe their rationale for each rating in a short, written response of one to three sentences.
- In Round Two, panelists reviewed the group's ratings and various rationales for those ratings. Then, panelists could adjust their ratings and provide a rationale for any adjustments to their answers for the same questions asked in Round One. (Refer to Appendix E for detailed information about the Delphi panel instrument, including the questions asked during each round.)

Rival factors are potentially additional or separate components that can play a role in code development. The evaluation team developed the following list of rival factors through a series of in-depth interviews with ASHRAE committee members and other experts:

- DOE-Funded BEM tools;
- Utility and voluntary program specifications;
- Industry standards;
- Expert opinion and external stakeholders;
- New federal or state law;[17] and
- Other DOE program guidance and policy.[18]

The rival factors were presented to the panelists in the context that these factors were relevant over the entire study period. Figure 6 illustrates the six rival factors that were presented to Delphi panelists.

Figure 6: Rival Factors That Influence ASHRAE 90.1 Code Development



The evaluation team surveyed Delphi panelists to assess their expert opinions on the importance and relevance of each factor's role in the development of each building technology category. The technology categories included in the Delphi process are based on ASHRAE 90.1 prescriptive paths for code compliance. They include:

- Building Envelope;
- Heating, Ventilation, and Air Condition (HVAC);
- Service Water Heating;
- Power;
- Lighting.

The panel concluded with an End of Panel Survey after the completion of Round 2. This survey asked Delphi panelists to provide specific percentage point estimates (i.e., individual percentages that add up to 100%) for each

[17] Based on feedback during Round 0 of the Delphi panel, this rival factor was revised to "New federal or state law and regulations".

[18] Refer to Table C-1 in Appendix C and Table D-1 in Appendix D for the list of rival factors before and after panelist input, respectively.

rival factor identified in the development of ASHRAE 90.1 code changes by code technology. Also, panelists provided specific percentage point estimates on how energy efficiency would change (increase or decrease) in each alternative scenario presented if DOE did not develop BEM tools (e.g., -10% or +5%). Refer to Table 6 for the alternative scenarios formulated prior to Round Zero.

Table 6. Alternative Scenarios

Alternative (Counterfactual) Scenario	Description
Independent Tool Development	New modeling tools equivalent to DOE-funded BEM tools would have been independently developed by the private sector, influencing the code in the same manner as DOE-funded BEM tools, and therefore the DOE-funded BEM tool-related code updates would have occurred anyway.
Alternative Tools Use	Code update committees would have used alternative tools such as DOE-2, Trane TRACE 700, or others to evaluate and justify code updates. Without the same functionality of DOE-funded BEM tools, code updates would have less stringent/specific requirements, leading to changes in potential energy efficiency.
Energy-Related Updates Not Approved or Significantly Delayed	Code updates whose evaluation requires BEM features not available in other tools would not have been developed or approved or faced significant delays. Therefore, ASHRAE 90.1 would have fewer code updates that impact energy savings.

Figure 7 shows the sliding scale used by survey participants to assign point estimates to each alternative scenario. The evaluation team gathered additional point estimates from experts who did not participate in the Delphi panel via an online survey for a total of nine responses.

Figure 7: Alternative Scenarios Change in Energy Efficiency Sliding Scale

3.3 Approach to Energy and Resource Benefit Estimation

The evaluation used publicly available ASHRAE commercial code energy savings data along with the aforementioned Delphi panel survey of relevant experts to estimate all retrospective energy, emissions, and environmental health benefits attributable to DOE-funded BEM tools over the study period.

The impacts from the incentive program and residential code use cases were found to be logistically unquantifiable as described in detail in Section 3.7. Therefore, the conservative, lower-bound impact estimates only include the commercial code use case: ASHRAE Standard 90.1's prescriptive requirements for commercial new construction. The evaluation team generated the estimates in accordance with the stepwise guidance for calculation of said impacts and economic performance in DOE's Evaluating Realized Impacts of DOE/EERE R&D Programs, Standard Impact Evaluation Method document, henceforth referred to as the "DOE Guide."[19]

Per the DOE Guide, the impact analysis calculated the benefits and economic performance metrics by state, by fuel type, and by year (from 2000 to 2020), for the benefits described below:

- Energy Impacts accrue from the energy savings attributable to DOE-funded BEM tools through the increased efficiency of the ASHRAE commercial building energy code iterations, resulting in avoided energy costs.
- Emissions and Environmental Health Impacts accrue from the avoided ambient air and greenhouse gas (GHG) emissions due to these energy savings, and resulting in avoided adverse health events and healthcare costs due to reduced air pollution.
- Combined Energy and Environmental Health Benefits are the sum of the above two benefits.

3.4 Approach to Gross Energy and BEM-Attributed Estimation

The evaluation determined the estimates of the energy impacts due to DOE-funded BEM tools' influence on ASHRAE 90.1 by first calculating the total gross energy savings generated by the code. The evaluation then estimated the influence of DOE-funded BEM tools through a Delphi panel survey of code committee members, as described in Sections 3.4.1 through 3.4.3 below.

3.4.1 Gross ASHRAE Energy Savings

Gross ASHRAE energy savings were calculated from publicly available estimates of energy savings from ASHRAE Standard 90.1 2004, 2007, 2010, 2013, and 2016 code addenda modeled by PNNL[20] in EnergyPlus using DOE's Commercial Prototype Building Models.[21] PNNL calculated savings by subtracting, aggregating, and averaging BEM end use by fuel type for each version of the ASHRAE standard and its previous version, across the gross floor area of all commercial building types in each climate zone to produce gross energy savings per gross floor area (intensity) by ASHRAE code iteration, by BEM end use, and by fuel type.

Savings intensities were converted to energy savings by state and by year according to the following formulas (where ***i*** represents each state and ***t*** represents each year of the study period):

$$Annual\ Savings = \sum_{i=1}^{50} \quad Energy\ Savings\ Intensity * State\ New\ Construction\ Area$$

[19] Office of Energy Efficiency & Renewable Energy. (August 2014). ***Evaluating Realized Impacts of DOE/EERE R&D Programs: Standard Impact Evaluation Method***. DOE/EE-1117. https://www1.eere.energy.gov/analysis/pdfs/evaluating_realized_rd_mpacts_9-22-14.pdf.

[20] Athalye et al. (October 2016). ***Impacts of Model Building Energy Codes***. Pacific Northwest National Laboratory. PNNL-25611. https://doi.org/10.2172/1334003.

[21] Office of Energy Efficiency & Renewable Energy Building Energy Codes Program. "Prototype Building Models." Accessed December 17, 2021, https://www.energycodes.gov/prototype-building-models.

$$Gross\ ASHRAE\ Energy\ Savings = \sum_{t=0}^{20} (Annual\ Savings + Annual\ Savings_{t-1})$$

The evaluation assigned intensities from each ASHRAE code iteration to each state and year according to which iteration was in effect, as reported by a recent PNNL study[22] and research conducted on DOE's Commercial Building Energy Codes Program website[23] (assuming uniform adoption across each state's jurisdictions). Electricity and natural gas savings by state by year were calculated by multiplying each state's new construction floor area (calculated using national estimates from EIA's Commercial Building Energy Consumption Survey)[24] with the new construction state-level weighting factors from PNNL.[25] Each year's savings are included in the savings of every subsequent year, because all ASHRAE 90.1 measures built in that year will continue to accrue these savings throughout their lifetimes, which are assumed to exceed the 20-year study period. This evaluation conservatively neglected any savings continuing beyond the study period (i.e., based on expected useful life of end-use technologies).

The gross energy savings described above represent the total energy saved across the nation during the study period by states mandating new construction to follow the increasing energy efficiency of ASHRAE 90.1 code iterations, a portion of which is due to DOE -funded BEM tools' enablement of the code's changes. The DOE-funded BEM tool attribution portion was determined by the Delphi panel attributions as described below.

3.4.2 Attributions From Delphi Panel

The portion of gross ASHRAE energy savings attributable to DOE-funded BEM tools was determined through the Delphi panel and additional surveys conducted by the evaluation team. The following formula (where ***n*** represents each of the three counterfactual scenarios (refer to Table 6) which could have occurred if DOE-funded BEM tools were not present) was used in this calculation:

$$Counterfactual = \sum_{n=1}^{3} Scenario\ likelihood * Scenario\ impact$$

$$Attribution = DOE\ funded\ BEM\ tool\ influence * Counterfactual$$

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[22] Athalye et al. (October 2016). ***Impacts of Model Building Energy Codes***. Pacific Northwest National Laboratory. PNNL-25611. https://doi.org/10.2172/1334003.

[23] Office of Energy Efficiency & Renewable Energy. "Status of State Energy Code Adoption - Commercial." Building Energy Codes Program. Accessed December 17, 2021: https://www.energycodes.gov/status/commercial.

[24] Energy Information Administration. (2018). "Commercial Buildings Energy Consumption Survey (CBECS) Data." https://www.eia.gov/consumption/commercial/data/2018/index.php?view=characteristics.

[25] Lei et al. (June 2020). ***Development of National New Construction Weighting Factors for the Commercial Building Prototype Analyses (2003-2018)***. Pacific Northwest National Laboratory. PNNL-29787. https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-29787.pdf.

Here, ***DOE-Funded BEM tool influence*** is the actual percentage of code energy savings generated by DOE-funded BEM tools during the study period, while ***Attribution*** is the portion of that influence which would not have occurred without DOE-funded BEM tools.

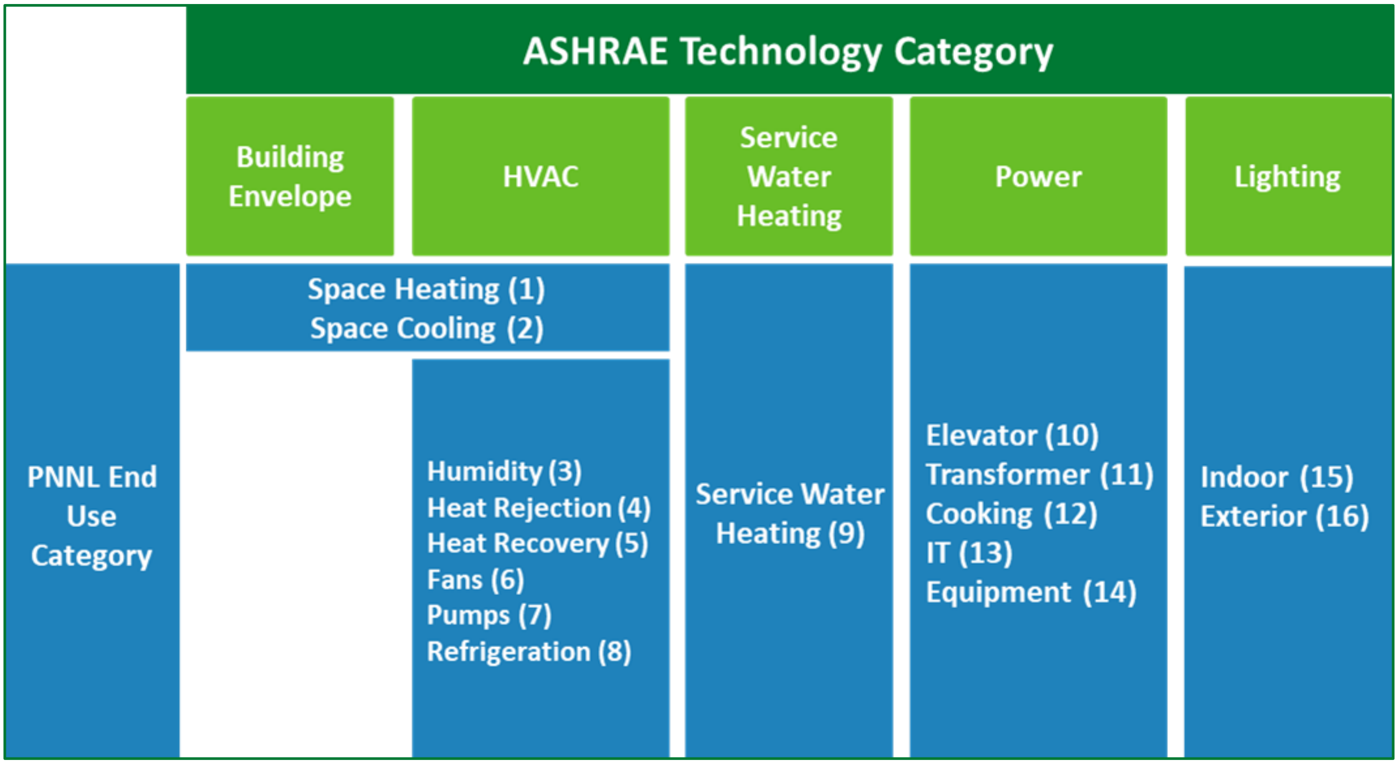
To calculate the above formulas, the point estimates of the impact on energy efficiency for each counterfactual scenario were multiplied by the estimates of each scenario's estimated likelihood, creating the ***Counterfactual*** factor. This was then multiplied by the median estimate for the influence that DOE-funded BEM tools played on the code during the study period (***DOE-funded BEM tool influence***), creating attribution percentages for each ASHRAE Standard 90.1 technology category (***Attribution***).

Each ASHRAE Standard 90.1 technology category was mapped to the 16 corresponding end uses modeled by PNNL, as shown in Figure 8. The Building Envelope category was mapped to both the space heating and space cooling end uses using allocations of relative energy savings from commercial building envelope improvements reported in DOE's ***Window and Building Envelope Research and Development: Roadmap for Emerging Technologies***.[26]

The evaluation used this mapping to apply the attributions by technology category to the end uses. These attributions by category were assumed to not change across the code iterations, aligning with the boundaries of the questions asked in the Delphi panel. This assumption is reasonable since these categories are fixed and technical in nature; hence, they would likely change very little over time. Furthermore, it would have been too great of a cognitive load upon the panelists to try to recall this change over the decades and estimate attributions by both technology category and iteration (25 attributions), rather than just by technology category (5 attributions).

[26] Sawyer, K. (February 2014). ***Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies***. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy. DOE/EE-0956. https://www.energy.gov/sites/prod/files/2014/02/f8/BTO_windows_and_envelope_report_3.pdf.

Figure 8: BEM End-Use to Technology Category Mapping



3.4.3 Net DOE-Funded BEM Energy Savings

The evaluation calculated the net DOE-funded BEM energy savings for each year and state by multiplying the gross ASHRAE savings for each end use by their mapped attributions to DOE-funded BEM tools, following this formula (where ***n*** represents the end uses modeled by PNNL):

$$Net\ DOE\ Funded\ BEM\ Savings = \sum_{n=1}^{16} Gross\ ASHRAE\ Savings * Attribution$$

The energy cost savings were calculated by multiplying net DOE-funded BEM energy savings for each year and state by each state's corresponding historical annual state-level utility rate for each year from EIA.[27]

3.5 Approach to Emissions and Environmental Health Estimation

The evaluation calculated emissions of NO_x, $PM_{2.5}$, SO_2, VOC, and NH_3 by multiplying net DOE-funded BEM energy savings by various emissions factors from EPA's AVoided Emissions and geneRation Tool (AVERT) tool[28]

[27] U.S. Energy Information Administration. (January 24, 2019). "Annual Energy Outlook 2019." https://www.eia.gov/outlooks/archive/aeo19/.

[28] U.S. Environmental Protection Agency. "AVoided Emissions and geneRation Tool (AVERT)." Accessed December 17, 2021: https://www.epa.gov/avert.

(electricity) and EPA's AP-42 Compilation of Air Emissions Factors[29] database (natural gas). The evaluation similarly calculated CO_2e emissions using emissions factors from Emissions & Generation Resource Integrated Database[30] for electricity and EPA's Greenhouse Gas Emission Factors Hub[31] for natural gas. The emissions tables in Appendix F provide these factors.

The evaluation team converted constituent emissions (NOx, PM2.5, SO2, VOC, NH3) into avoided health endpoints and healthcare costs using EPA's COBRA tool.[32] The evaluators population-adjusted the COBRA results using U.S. Census Data[33] to reflect the changing U.S. population during each year of the study period. Finally, evaluators summed the avoided healthcare costs with energy cost savings to produce the combined monetized energy and environmental health benefits.

3.6 Approach to Economic Performance Estimation

The above attributed-BEM benefits for energy and environmental were converted from current to constant (2020$) inflation adjusted dollars using the Gross Domestic Product (GDP) Implicit Price Deflators from the Bureau of Economic Analysis.[34] The evaluation conducted a benefit-cost analysis to compare those benefits against BEM tool investment data provided by DOE, creating the following six economic metrics for combined energy and health co-benefits of air: gross benefits, present value of investment, present value of benefits, net present value, benefit-to-cost ratio, and return on investment.

The evaluation presents these costs and benefits in constant 2020 dollars (2020$) and net present value as of January 1, 2000 (the first year of investment costs), using both 3% and 7% economic discount rates and the present value multipliers in Appendix H. Present value (PV) (for costs and benefits), net present value (NPV), and benefit-to-cost ratio (BCR), and internal rate of return (IRR) were calculated using the standard formulas below, which are also shown in Appendix G and were sourced from Table II.7-1 of the DOE Guide.

Present Value (PV)

$$PV = CF_y \frac{1}{(1+r)^{2000-y}}$$

[29] U.S. Environmental Protection Agency. (2009). "AP-42: Compilation of Air Emissions Factors." https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors.

[30] U.S. Environmental Protection Agency. "Emissions & Generation Resource Integrated Database (eGRID)." Accessed December 17, 2021: https://www.epa.gov/egrid.

[31] U.S. Environmental Protection Agency. "GHG Emission Factors Hub." Accessed December 17, 2021: https://www.epa.gov/climateleadership/ghg-emission-factors-hub.

[32] U.S. Environmental Protection Agency. "CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA)." Accessed December 17, 2021: https://www.epa.gov/cobra.

[33] Census Bureau. "National Population Totals: 2010-2019." Accessed December 17, 2021: https://www.census.gov/data/datasets/time-series/demo/popest/2010s-national-total.html.

[34] U.S. Bureau of Economic Analysis. (March 26, 2021). "Gross Domestic Product." https://www.bea.gov/data/gdp/gross-domestic-product.

where CF_y is constant dollars in year y; r is the discount rate; $1/(1+r)^n$ is the PV multiplier; and 2000-y is the number of years between the year in question and 2000.

Net Present Value (NPV)

$$NPV = \{\sum_{y=2012}^{2020} B_y(1+r)^{2000-(y+1)}\} - \{\sum_{y=2000}^{2020} C_y(1+r)^{2000-y}\}$$

where B_y is benefits in year y; C_y is costs in year y; and r is the discount rate.

Note that while program costs were incurred beginning in 2000, energy savings and associated benefits from the use case began to accrue starting in 2012. Consistent with the DOE Guide, the portfolio investment costs were incurred on the first day of the year while all energy and environmental benefits were incurred on the last day of the year.

Benefit-to-Cost Ratio (BCR)

$$BCR = \{\sum_{y=2012}^{2020} B_y(1+r)^{2000-(y+1)}\}/\{\sum_{y=2000}^{2020} C_y(1+r)^{2000-y}\}$$

Internal Rate of Return (IRR)

$$\{\sum_{y=2012}^{2020} By(1+r*)^{2000-(y+1)}\} = \{\sum_{y=2000}^{2020} Cy(1+r*)^{2000-y}\}$$

Monetarized GHG emissions were not included in the economic performance calculation because of the degree of uncertainty associated with the social cost of carbon.

Lastly, the evaluation conducted sensitivities around attributions (evaluating the 25th and 75th percentile around the median), creating a range of values for the metrics.

3.7 Approach to Qualitative Analysis for Residential Energy Efficiency Codes and Energy Efficiency Incentive Programs

The evaluation qualitatively assessed the residential codes and energy efficiency incentive programs use cases. The approach is described in the following sections.

3.7.1 Residential Energy Efficiency Codes

Stakeholder interviews and detailed research into all IECC code amendments during the study period revealed that the influence from DOE-funded BEM tools on the code's development was insignificant, due to proposals based on DOE-funded BEM tools being consistently rejected by the code's nontechnical "public hearing" process. The only pathway of influence which DOE-funded BEM tools had on the IECC during the study period was not on the code's development but rather on its adoption, in that states would adopt the code motivated by PNNL's cost-effectiveness determinations, which used DOE-funded BEM tools.

The evaluation could not quantify this sole pathway of influence using a Delphi panel because each state's motivations for code adoption would be unique, requiring survey research far beyond the scope of this study. Therefore, the approach for this use case was shifted to a qualitative one, focused on demonstrating this lack of quantifiable influence of DOE-funded BEM tools on the IECC as well as the obstacles behind it. These detailed findings from research and stakeholder interviews are provided in Section 4.5.1.

3.7.2 Energy Efficiency Incentive Programs

Research and stakeholder interviews found no consistent involvement between DOE-funded BEM tools and energy efficiency incentive programs, rendering this use case unquantifiable. Therefore, the evaluation shifted to a qualitative case study approach, focused on uncovering the obstacles preventing DOE-funded BEM tool adoption and the incentives which could encourage it.

The following sources provided the bulk of the data for investigating this use case:

- Evaluation reports published by energy efficiency incentive programs, detailing the savings and justifications behind their programs on an annual basis (where available), including those collected by EIA's State Energy Efficiency Program Evaluation Inventory. Evaluators selected energy efficiency incentive programs from these reports for investigation into whether DOE-funded BEM tools played a role in their development.
- Interviews with energy efficiency incentive program decision-makers, including those at utilities identified by the Meta-Analysis (refer to Section 4.5.2).
- State-developed TRMs, which may have potentially been used by the selected energy efficiency incentive programs to justify their incentive determinations, were also reviewed for potential impact from DOE-funded BEM tools.

The detailed findings of the research which led to this shift in approach, as well as the obstacles and incentives uncovered by the case studies, are provided in Section 4.5.2.

3.8 Study Assumptions and Limitations

The evaluation used conservative assumptions to provide a lower-bound estimate of impacts. This section describes the key assumptions used and the necessary study limitations.

3.8.1 Assumptions

The evaluation makes the following key assumptions for conservativeness and feasibility:

- The evaluation only quantified savings associated with ASHRAE 90.1, due to the unquantifiability of the IECC residential building energy code and energy efficiency incentive program use cases.
- The evaluation developed ASHRAE 90.1 attributions at the building category level rather than by iteration, due to shared features at that level and to manage the cognitive load on the Delphi panelists.
- There is a two-year lag after a state adopts a code (to conservatively account for grace periods and construction delays) before it is enforced in all of its jurisdictions. At that point, all new construction complies with it.

- The 2016 PNNL study's national average energy use intensities can be applied across the states, as they are aggregated from more detailed modeling on numerous building types and climate zones.
- Energy benefits accrue exclusively from electricity and natural gas savings developed by PNNL and explicitly available from DOE's Commercial Prototype Building Models.
- Fuel oil (and therefore energy security) impacts were neglected, due to data availability issues and for conservativeness.
- The study conservatively neglects some of the secondary impacts of DOE-funded BEM tool investment, including:
    - Any renovation projects which may have had to follow.
    - Any use of ASHRAE 90.1 outside of mandatory code, such as "stretch codes."
    - Any impacts to the following areas where data was insufficient for analysis: water use, solid waste generation, carbon monoxide emissions, and technology acceleration.
- The effective useful lifetimes of all ASHRAE 90.1 measures exceed the period of savings within the study period, but for these savings beyond the study period are neglected.

3.8.2 Limitations

The following are a summary of the necessary limitations of the study which result from the above assumptions:

- A fixed level of granularity was necessary (e.g., uniform code adoption by state rather than by jurisdiction, and savings by total new construction rather than by building type) for feasibility.
- Due to the portfolio approach used (refer to Section 2.2) and conservative assumptions above, the calculated energy savings do not represent the entirety of the benefits from DOE-funded BEM tool investments.
- Energy savings were based on PNNL modeling. The evaluation assumed that PNNL internally validated its modeling, and that the data was the best representation of the actual real-world environment.
- Evaluators determined the attributions by using a small sample size of nine experts who participated in the Delphi panel or survey, so the accuracy of the attributions greatly depends on the expertise of each panelist.

To mitigate this final limitation of small sample size, evaluators targeted individuals that had a breadth of experience over the entire study period (2000–2020), rather than those with recent involvement with the latest code iteration. This ensured that survey respondents knew the historical context for how the code change process had evolved over that timeframe.

While these experts' estimates play an important role in this evaluation, the Paperwork Reduction Act limits systematic data collection from non-federal entities to nine people/organizations without obtaining an information collection request approval, which was not obtained for this evaluation. As such, the Delphi panel was limited to nine non-federal respondents. Evaluators selected Delphi panelists based on their professional reputation and experience, and their ability to provide informed responses to the evaluation's specific questions. However, the small number of respondents may not be a statistical representation of their peer group. That said, it should be noted that Delphi panel guidance indicates that panels with as few as ten individuals are recommended where qualifications for panelists are homogeneous, as they were for this panel.[35]

[35] Skulmoski et al. ***Journal of Information Technology Education***. (Vol. 6, 2007). "The Delphi Method for Graduate Research."

3.8.2.1 Threats to Validity

The evaluation team acknowledges threats to internal validity including the potential for selection bias. In a Delphi panel, selection bias can occur through bias in selecting panelists or researcher bias inadvertently introduced in the formulation of survey or interview questions. These threats to validity are discussed below:

- Researcher Bias: This bias could occur if the researcher (evaluator) introduces information that could have unintended influence on the study population, or a portion thereof. In one example, scenario questions that may have been unintentionally leaning toward hinting of negative consequences for the “without BEM scenario” could have influenced some members of the Delphi panel. Secondly, the absence of a focus group forum with all the participants being able to actively discuss the inclusion, exclusion, or modification of rival factors and alternative scenarios may have led to unintended bias, as the only interactions were between the researchers and the panelists. Additionally, it should be noted that any changes to rival factors proposed by the panelists did not convey that they would have to be evaluated for cost-effectiveness. This could have led panelists to believe that rival factors can be relevant in the code change process in absence of a cost-effectiveness test.
- Bias in Selection of Panelists: This bias may occur if the panelists selected are predisposed to be favorable to the research subject. To mitigate this, the following steps were taken:
    - There were no personal relationships between researchers and potential panelists which could have introduced bias.
    - Panelists were selected purely based upon their involvement with the ASHRAE 90.1 code development process so that they would all have the shared motive of accurately describing the influences on their decision-making and not have any ulterior motives. The inclusion criteria described in Section 3.1.4 was used to assess each potential panelist. One of the panelist inclusion criteria was an understanding of how BEM is used in codes development. It was necessary to ensure panelists knew how BEM is utilized in developing ASHRAE addenda so that they would have enough background knowledge and experience to participate fully in the panel. However, the evaluation team acknowledges that this could have biased panelists toward ascribing higher attributions to BEM.
    - Evaluators measured panel composition through a demographic and experience survey to ensure that the panel was balanced and not skewed towards any particular group.
    - As part of the Delphi method’s multiple rounds of review, panelists reviewed their answers, group answers, and group rationales before adjusting their answers, improving the overall understanding behind their estimates.
    - The evaluation team did not ask panelists to estimate BEM’s attribution to identified savings while validating the list of rival factors and counterfactuals, so that the list would strictly represent their direct experience of the code development process. Due to these measures, any potential bias in panelist selection would likely not change the overall findings of which factors and counterfactuals to include in the survey.

4. Findings

This section presents the findings for the evaluated use cases. The commercial energy efficiency codes use case was evaluated via a Delphi panel, which resulted in attribution of energy savings to DOE-funded BEM tools over the study period (Sections 4.1 through 4.4). The evaluation of the residential energy efficiency code and energy efficiency incentive program use cases followed a case study approach after the assumptions of their respective logic models could not be quantified. These approaches yielded qualitative results exploring obstacles to BEM use (Section 4.5).

4.1 Commercial Energy Efficiency Codes Energy Results

Following the approach described in Section 3, the evaluation calculated all relevant energy, emissions, environmental health, and economic metrics related to the energy savings attributed to DOE-funded BEM tool investment. Table 7 presents a summary of the net energy savings which are attributed to DOE-funded BEM tools in total and by electricity and natural gas fuel type. On average, net energy savings equate to about 10% of the gross energy savings (i.e., the total energy saved by the code, due to DOE-funded BEM tools and all other factors that influence ASHRAE code development.

Table 7. Net DOE-Funded BEM Energy Savings (2000-2020)

Fuel Type	Units	Net DOE-Attributed BEM Energy Savings
Total Site Electricity Savings	GWh	6,416
Total Site Natural Gas Savings	Million Therms	179
Total Site Energy Savings - All Fuels	Million MMBtu	40

Table 8 presents a summary of the net energy savings (by electricity and natural gas fuel type) and their monetized value, which are attributed to DOE funded BEM tools for the base case (corresponding to the median value of attribution estimates from the Delphi panel) alongside similar data for the low-end and high-end cases.

Table 8. Energy and Energy Cost Savings (2000-2020)

Metric	Units	Base Case	Low End	High End
Total site energy savings - all fuels	Million MMBtu	40	19	66
Total Site electricity savings	Million kWh	6,416	3,054	10,608
Total site natural gas savings	Million therms	179	85	297
Monetary value of energy savings @ 7% real discount rate	Million 2020$	$227	$107	$670
Monetary value of energy savings @ 3% real discount rate	Million 2020$	$466	$222	$952

4.1.1 Delphi Panel Results

The evaluation assessed the commercial energy efficiency codes use case via a Delphi panel consisting of industry experts involved in developing ASHRAE Standard 90.1. This section describes the results of the Delphi panel, which evaluators used to develop BEM-attributed energy savings.

During Round Zero of the Delphi process, panelists had the opportunity to provide feedback on the original list of rival factors (refer to Section 3.2.4) as well as to suggest other factors they believe impact ASHRAE 90.1 code development. All but one panelist during Round Zero indicated that the six rival factors presented were relevant to ASHRAE 90.1 code development. The one dissenting panelist suggested removing utility and voluntary program specifications as a factor. Given that all other panelists supported the relevance of the factor, it was retained for subsequent Delphi rounds.

The original list of rival factors were:

- DOE-Funded BEM tools;
- Utility and voluntary program specifications;
- Industry standards;
- Expert opinion and external stakeholders;
- New federal or state law;[36] and
- Other DOE program guidance and policy.[37]

Panelists also suggested adding five additional factors plus modification of the definition for two factors. The evaluation team determined that all of the panelist's suggestions fell under the original six rival factors provided (refer to Table 9). These suggestions helped the evaluation team determine that greater clarification was needed for several of the original factors. In addition, panelists recommended clarifying several factor definitions and their supporting examples. Table 10 summarizes the changes made to the names, definitions, and examples of the rival factors to incorporate input from Delphi panelists during Round Zero. Refer to Table D-1 in Appendix D for the updated factor names, definitions, and examples.

[36] Based on feedback during Round 0 of the Delphi panel, this rival factor was revised to "New federal or state law and regulations".

[37] Refer to Table C-1 in Appendix C and Table D-1 in Appendix D for the list of rival factors before and after panelist input, respectively.

Table 9. Proposed Additional Rival Factors

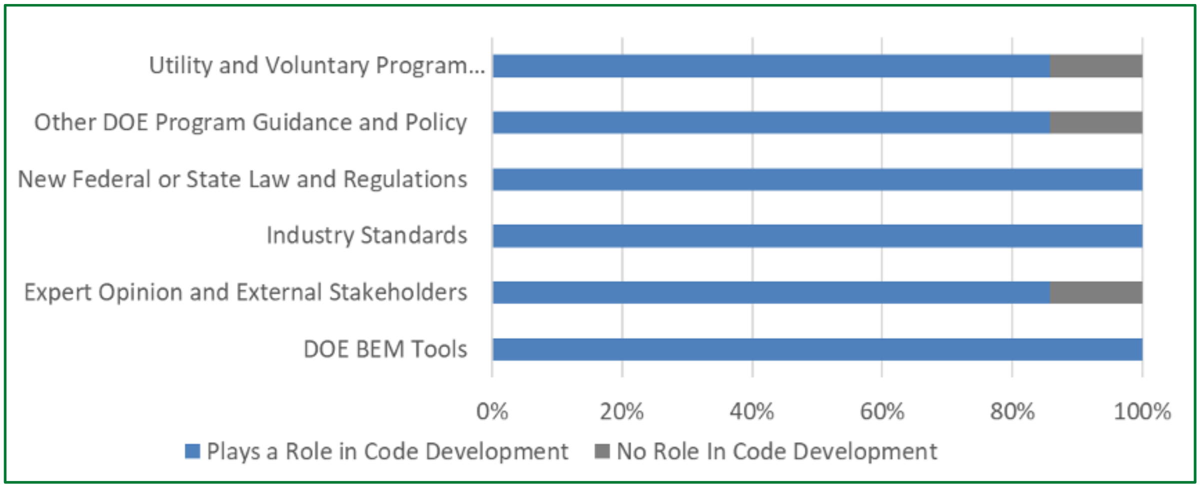
Proposed by Panelist			Determination Made by the Evaluation Team
Factor	Definition	Impact	
Economic Analysis	Changes to ASHRAE Standard 90.1 are supposed to pass a cost-effectiveness test based on committee-developed economic parameters.	If a proposed change to the standard has a scalar value that is higher than the limit allowed, then it is not cost effective and will not be added to the Standard.	Included in existing factor: DOE-funded BEM Tools
Committee Generated Proposals	Proposals that are based on expertise of the committee members	Many proposals are based on committee members' own experience and expertise.	Included in existing factor: Expert Opinions and External Stakeholders
NGOs	Nongovernmental organizations	Organizations with a mission to save energy through influence of code and guideline processes	Included in existing factor: Expert Opinions and External Stakeholders
Manufacturer Innovations are Ready for Inclusion in Equipment	Technological advances that have not previously been justified for rollout due to expense increase to manufacturer over current market	Several non-patentable energy-saving advances were available for inclusion in equipment of all participating manufacturers.	Included in existing factor: Expert Opinions and External Stakeholders
Energy Codes	The Evidence Packet refers to other Energy Efficiency Codes and even implies IECC is not widely adopted, which appears incorrect. IECC is more widely adopted and applied across the commercial market than A90.1.	Other codes have a big impact on adoption of energy efficiency measures.	Included in existing factor: New Federal or State Law and Regulations
Adoption of New Technologies in Commercial Buildings	ASHRAE reviews new technologies that were not in previous versions of the Standard (such as Direct Outdoor Air Systems and Variable Refrigerant Flow air conditioners and heat pumps).	ASHRAE has to decide whether to add text or tables about new technologies, and to decide about the appropriate efficiency requirement(s).	Included in existing factor: Expert Opinions and External Stakeholders
ASHRAE Guidance	Occasionally other committees at ASHRAE influence changes in the standard (such as the resolution of data centers in forming a new Standing Standard Project Committee 90.x).	Political forces sometimes influence the direction of the standard.	Included in existing factor: Expert Opinions and External Stakeholders

Table 10. Changes to Rival Factors After Round Zero Input From Delphi Panelists

Rival Factor	Amendments After Round Zero Feedback
DOE-Funded BEM Tools	• Added clarification that only EnergyPlus, ASHRAE Standard 140, and the commercial prototype building models are DOE funded and that other tools like DOE-2 are not DOE-funded BEM products
Utility and Voluntary Program Specifications	• Added stretch codes and ASHRAE 189.1 to the definition • Clarified that cost-effectiveness is not a requirement for inclusion
Industry Standards	• No amendments suggested
Expert Opinions and External Stakeholders	• Added external organizations (NGOs) to the definition • Added manufacturer technology trends to the definition • Adjusted the wording to remove the suggestion that DOE-funded BEM is not generally used for proposals coming from private organizations
New Federal or State Law and Regulations	• Added "and regulations" to the name and definition • Added "when new information is available regarding an appliance or technology" to the definition • Corrected the example to reference Energy Star and not California Energy Commission's Appliance Efficiency Regulations • Added the Energy Policy Act (EPACT) as an additional example
Other DOE Program Guidance and Policy	• No amendments suggested

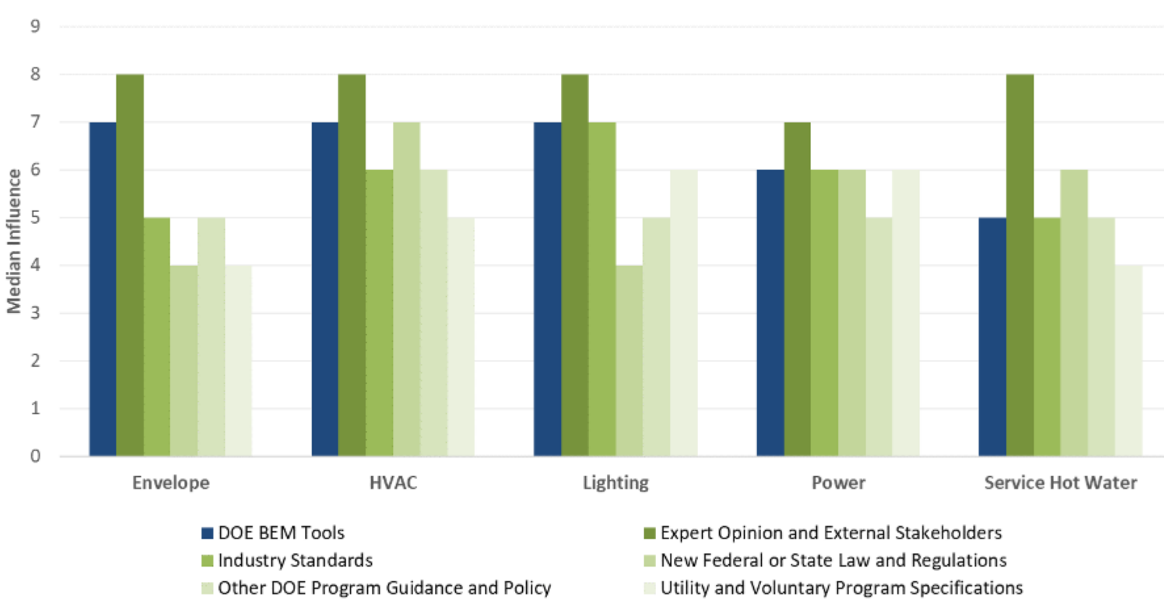
Most panelists believed that all six factors impact ASHRAE 90.1 code development. The panelists reached a consensus (100%) regarding the role of three of the six factors: new federal and state laws or regulations, industry standards, and DOE-funded BEM tools (Figure 9). Six of the seven panelists (86%) believed the other three factors play a role in code development. In each of these non-consensus cases, the dissenting panelist remained unpersuaded throughout the Delphi process, as their answers remained unchanged between Round One and Round Two.

Figure 9: Percent of Respondents Indicating Whether a Particular Factor Plays a Role in Code Development



To understand the magnitude of influence the rival factors have on ASHRAE 90.1 code development, panelists scored each rival factor's influence on five distinct building technology categories: envelope, HVAC, lighting, power, and service hot water (SHW). Panelists attributed the highest median influence score to expert opinion and external stakeholders for all five technology categories (Figure 10). DOE-funded BEM tools received the second-highest median influence score in four of the five technology categories and the third-highest median influence score for SHW. The median influence values remained unchanged between Round One and Round Two of the Delphi process. However, the standard deviation of the influence scores was reduced in all cases where panelists revised their answers, as panelists typically adjusted their responses to align with their peers more closely.

Figure 10: Median Score for a Factor's Influence on Code Development for each Technology Category



The evaluation team presented panelists with three alternative scenarios had DOE-funded BEM tools not been developed: (1) independent tool development, (2) alternative tools use[38], and (3) energy-related updates not approved or significantly delayed.[39] Similarly to the rival factors, the panelists had the opportunity during Round Zero of the Delphi process to suggest additional alternative scenarios and to comment on the three presented.

Panelists agreed that the three alternative scenarios provided in the evidence packet accurately represented the ways in which ASHRAE 90.1 code may have evolved in the absence of DOE-funded BEM tools, and that all three scenarios were distinct and should remain separate. Only one panelist suggested an additional alternative scenario: industrial tool use. The evaluation team deemed that industrial tool use should be included within the alternative tool use scenario and adjusted the definition of that scenario to indicate as much.

During Round Zero, panelists also provided suggested edits to the definitions of the three alternative scenarios listed above. Panelists unanimously agreed with the definition of the independent tool development scenario. No changes were made to that scenario prior to Round One of the Delphi process. One panelist suggested the definition for alternative tool use include reference to standard engineering calculations. Another panelist suggested the third scenario include reference to delayed codes, not merely unapproved codes. These two updates were included for Round One and Round Two of the Delphi process. See Table 11 for the summary of changes to the Alternative Scenarios.

Table 11. Changes to Alternative Scenarios After Round Zero Input From Delphi Panelists

Alternative Scenario Name	Amendments After Round Zero Feedback
Existing Tools Used, and Independent New Tool Development	• Scenario name amended to include use of existing BEM tools.
Existing Tools Used, and No New Tools Developed	• Scenario name amended to include “No New Tools Developed”. • “Standard engineering calculations” as an existing tool was added to the description.
Energy-Related Updates Not Approved or Significantly Delayed	• Added “BEM is not capable of modeling some of the approved code changes” to the scenario description.

For each of these alternative scenarios, panelists estimated the likelihood the alternative scenario would have occurred. They also estimated the impact on energy savings for each alternative scenario relative to the energy savings with DOE-funded BEM tools. Panelists gave rationales for their ratings.

Five of the seven panelists rated the likelihood of independent BEM tool development with similar functionality to DOE-funded BEM in the absence of DOE-funded BEM as three or lower (rating scale: 1 – low likelihood, 9 – high likelihood) (Figure 11). The theme across many of the responses was that independent tool development would have been unlikely because creating BEM tools is a slow and complex process that requires funding and alignment from an unbiased third party. Some of the panelists suggested that the development of independent tools may have occurred within specific technology categories, but that the disparate needs of various stakeholders across these categories would have slowed or decreased the development of whole-building models.

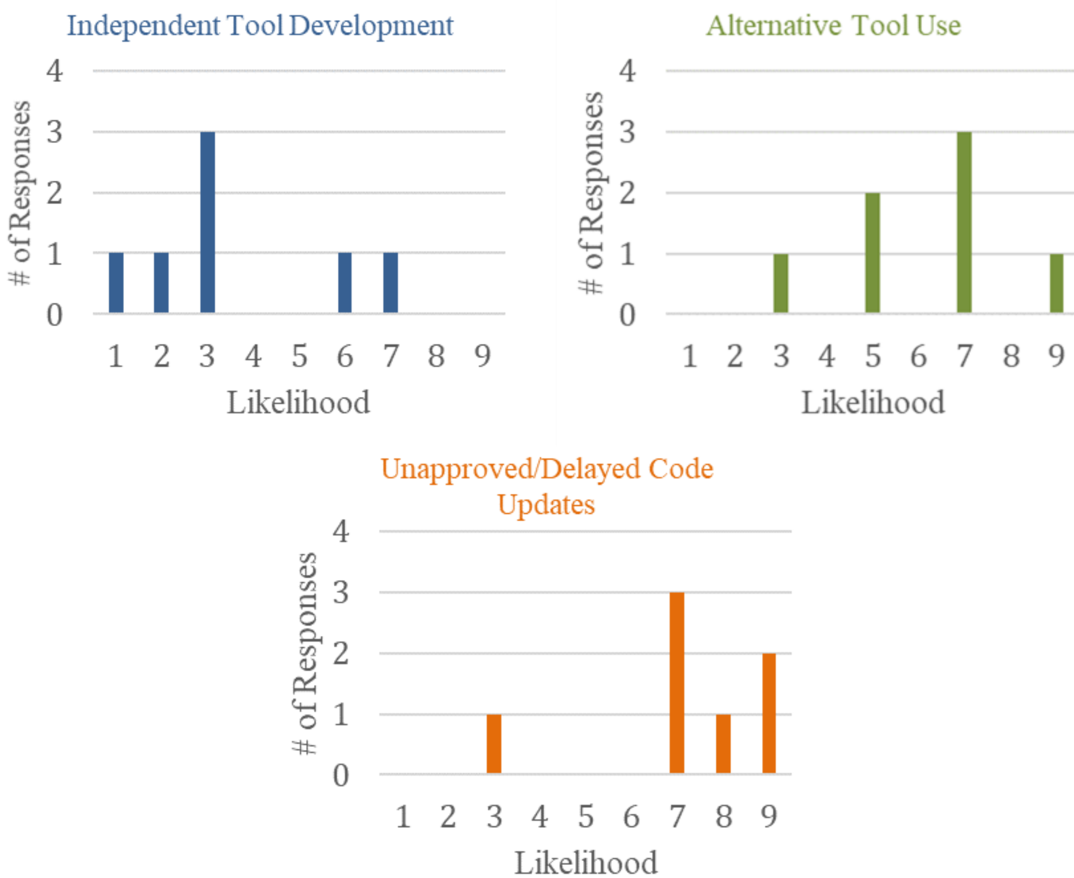
[38] Refer to Appendix C, Table C-9 for additional information on alternative tools.

[39] Refer to Appendix C, Table C-8 for additional information on the alternative scenarios.

Four of seven panelists rated the likelihood that alternative BEM tool use would have been used to develop and justify code updates in the absence of DOE-funded BEM as seven or higher (Figure 11). The theme across the respondents was that code development would have had to rely on alternative tools (e.g., DOE-2 and other existing tools) and that past use of alternative tools suggests the use of similar tools in DOE-funded BEM's absence. The panelists who rated the likelihood lower suggest that while alternative tools may well have been used in the absence of DOE-funded BEM, the usefulness of these alternative tools for broad, nationwide, whole-building analysis on prototypical models would not have matched that of DOE-funded BEM.

Six of seven panelists rated the likelihood that energy-related updates would not have been approved or would have been significantly delayed in the absence of DOE-funded BEM as seven or higher (Figure 11). The theme across many of these responses was that DOE-funded BEM is highly useful in modeling both energy savings and cost savings of proposed code updates. Panelists suggested that the savings modeled by DOE-funded BEM help build consensus within the ASHRAE 90.1 committee and support savings reported by proprietary tools. Several panelists stated that DOE-funded BEM is valuable because moving beyond efficiencies from earlier code updates requires whole building simulation.

Figure 11: Response Frequency of the Likelihood of Alternative Scenarios (1 – low, 9 – high)

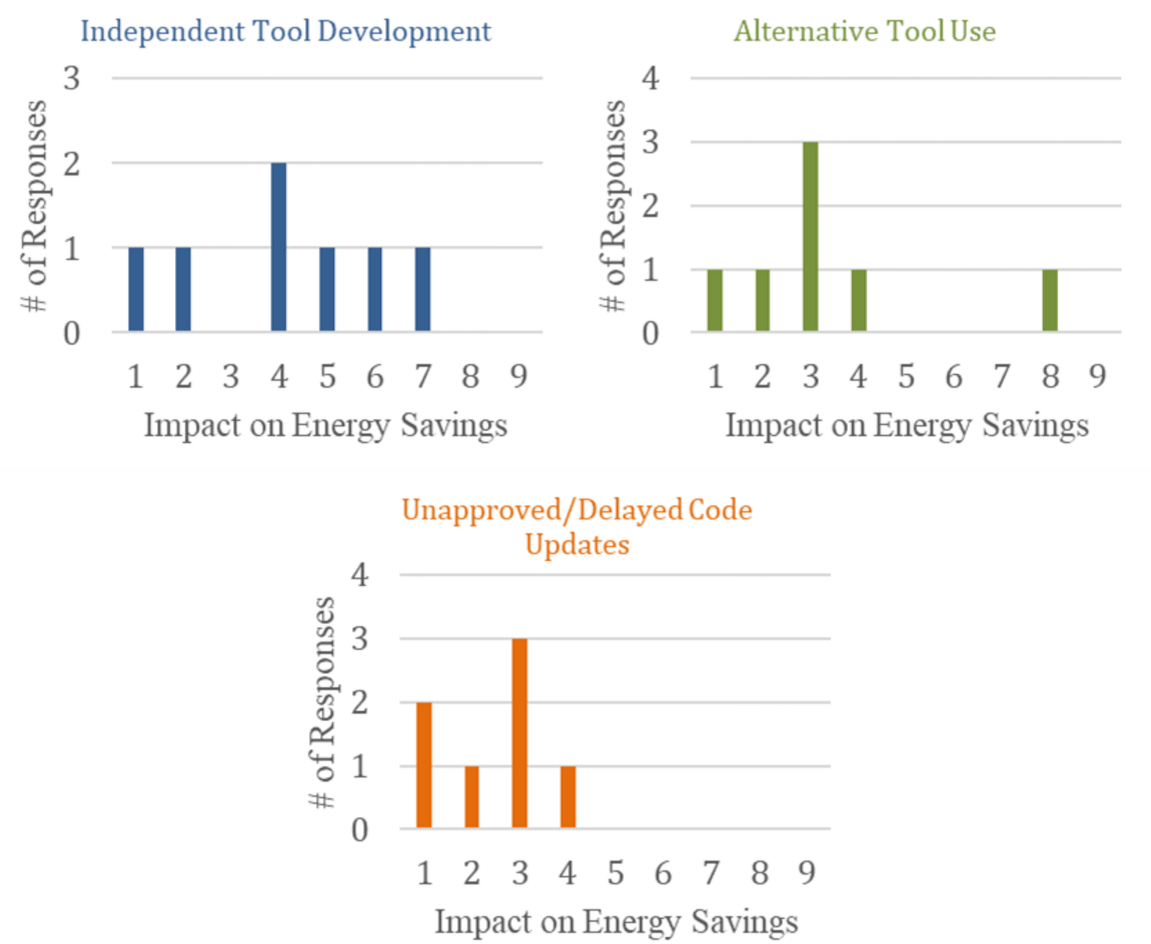


Between Round One and Round Two of the Delphi panel, one panelist adjusted their estimation of the likelihood that each alternative scenario would have occurred in the absence of DOE-funded BEM. In three instances, panelists adjusted their estimate closer to the median, which lowered the standard deviation of responses.

Collectively, panelists believed that, in the absence of DOE-funded BEM, equivalent independent tools would not likely have been developed, that existing non-DOE funded BEM tools would have been used to develop and justify code updates, and that these code updates would have been fewer or significantly delayed.

Generally, panelists estimated that energy savings would have been lower under all three alternative scenarios as compared to the energy savings experienced with DOE-funded BEM tools (Figure 12). There was consensus amongst panelists that unapproved or delayed ASHRAE 90.1 code updates would have led to lower energy savings (with all responses less than or equal to 4) and near consensus (all responses less than or equal to 4 and one at 8) that the use of alternative tools would have led to lower energy savings relative to DOE-funded BEM tools. Panelists, however, were more divided on whether the development of independent tools would have led to similarly lower energy savings (4 responses less than or equal to 4 and 3 responses greater than 4).

Figure 12: Response Frequency of the Impact on Energy Savings of Alternative Scenarios (1 – reduced energy savings, 9 – increased energy savings)



4.1.1.1 End of Panel Survey Data – Rival Factors and Their Influence on ASHRAE 90.1 Code Development

The End of Panel Survey asked Delphi panelists and two additional industry experts (n=9) to provide specific percentage point estimates of the relative importance of each factor's influence on ASHRAE 90.1 code development for each rival by code technology (Table 12). The individual percentages add up to 100%.

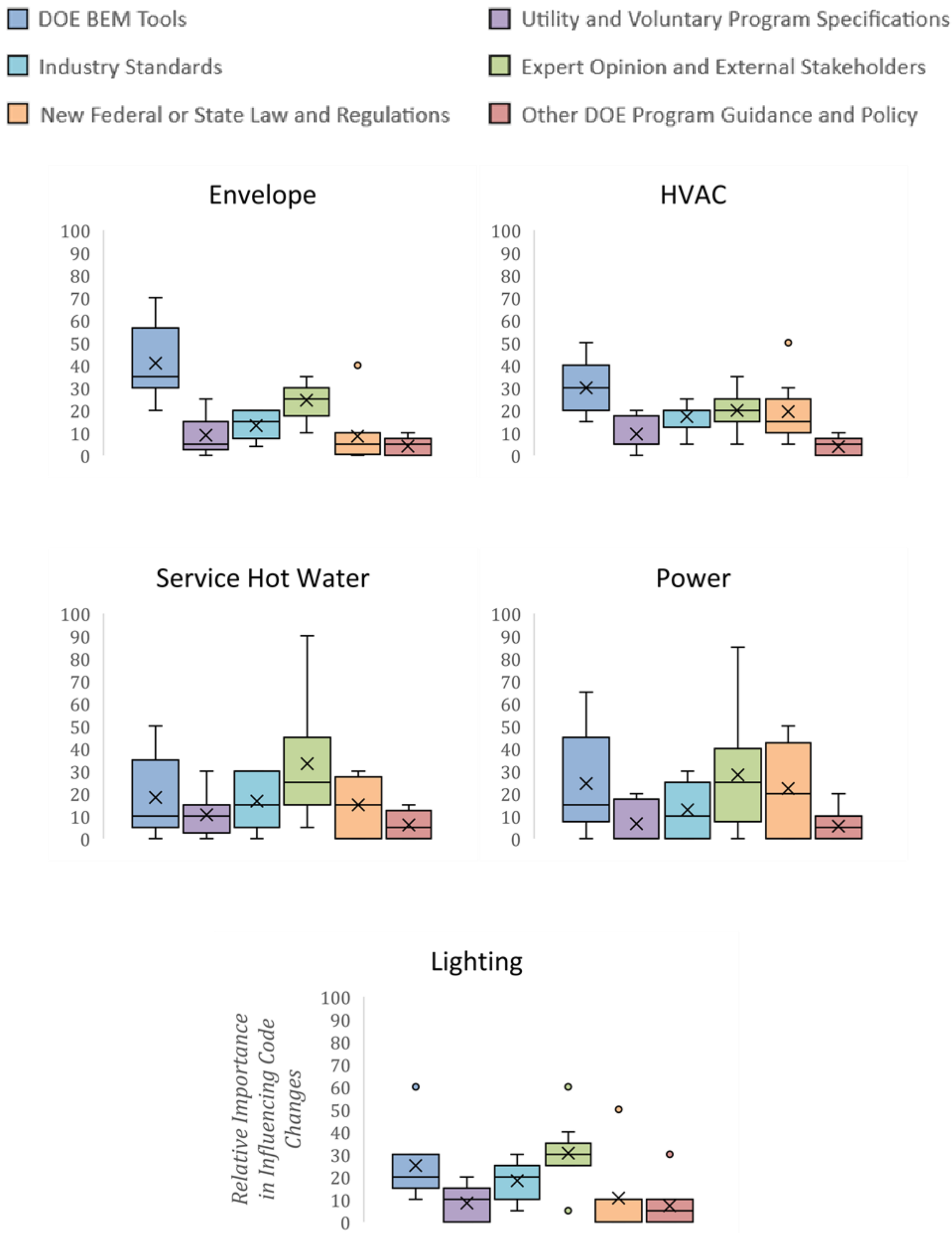
Table 12. Median Relative Importance of each Factor's Influence on ASHRAE 90.1 Code Development for each Technology Category

Technology Category	DOE-Funded BEM Tools	Utility and Voluntary Program	Industry Standards	Expert Opinion & External Stakeholders	New Federal or State Law and Regulation	Other DOE Program Guidance/ Policy
Envelope	35%	5%	15%	25%	5%	5%
HVAC	30%	5%	20%	20%	15%	5%
Service Hot Water	10%	10%	15%	25%	15%	5%
Power	15%	0%	10%	25%	20%	5%
Lighting	20%	10%	20%	30%	10%	5%

Panelists estimated DOE-funded BEM tools and expert opinion and external stakeholders to be the two most important factors influencing ASHRAE 90.1 code development across all five technology categories. Their combined influence scores ranged from 50 (HVAC) to 65.3 (envelope) out of 100. Panelists also estimated DOE-funded BEM tools as the most important relative factor for the envelope and HVAC technology categories by significant margins. Expert opinion and external stakeholders hold an outsized influence on the SHW technology category. Industry standards had moderate and relatively even influence across all technology categories, while new federal or state laws and regulations ranged from a low relative influence for envelope to a significant influence on the power category. Utility and voluntary programs and other DOE program guidance and policy were the two least influential factors to affect ASHRAE 90.1 code development across all technology categories, apart from envelope. The utility and voluntary programs are slightly more influential than new federal or state laws and regulations in the envelope category.

The spread of responses varied by technology category (refer to Figure 13). Respondents aligned for the envelope, HVAC, and lighting technology categories. There was more spread in the estimation of influence on code development for the power and SHW technology categories.

Figure 13: Relative Importance in Influencing Code Changes for Each Technology Category



4.1.1.2 End of Panel Survey Data – Alternative Scenarios in the Absence of DOE-Funded BEM

Survey respondents also gave specific percentage point estimates on how energy efficiency would change (more or less energy efficiency) in each alternative scenario presented if BEM tools were not developed (e.g., -10% or +5%). With near consensus, respondents expected less energy efficiency under each alternative scenario (Figure 14). The median response was that there would be 18.5% less energy efficiency under the independent tool development scenario, 20% less for alternative tool use, and 50% less for unapproved or delayed code updates. Refer to Table 13 for the calculated mean, median, and standard deviation for each scenario.

Figure 14: Change in Energy Efficiency for Each Alternative Scenario

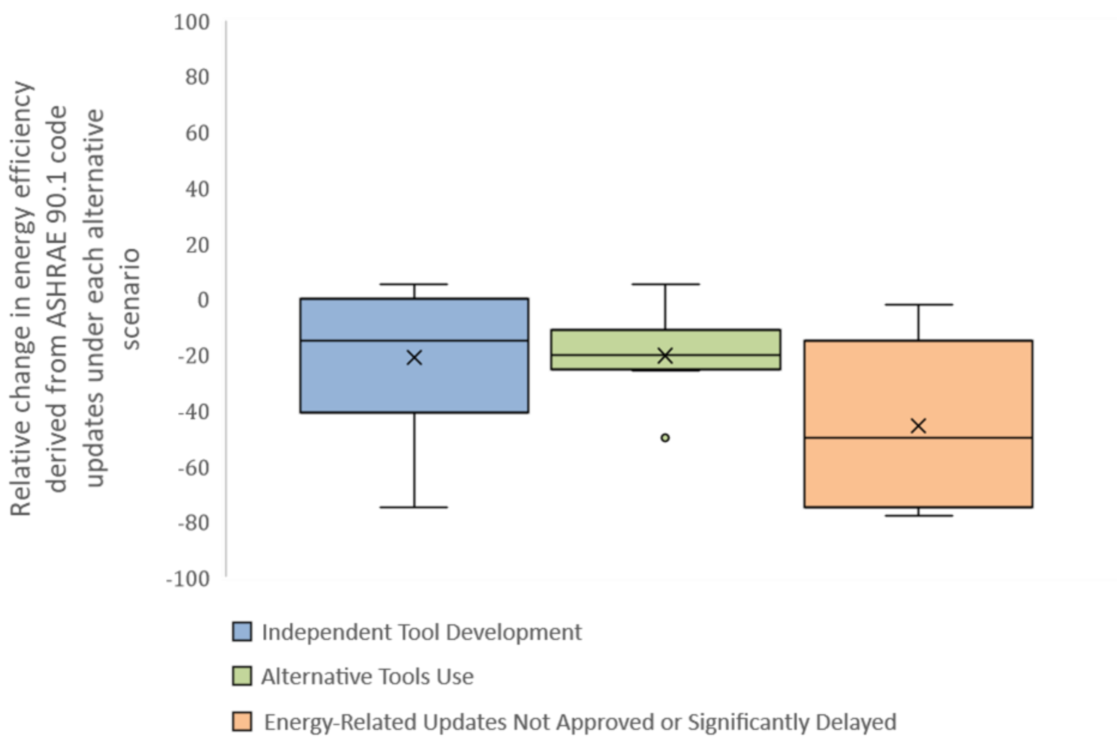


Table 13. Change in Energy Efficiency for Each Alternative Scenario (n=9)

	Independent Tool Development	Alternative Tools Use	Energy-Related Updates Not Approved or Significantly Delayed
Mean	-23.6%	-20.3%	-45.6%
Median	-18.5%	-20.0%	-50.0%
Std. Dev.	28.6%	15.0%	28.7%

4.1.1.3 Attribution of Energy Savings to DOE-Funded BEM Tools

The evaluation calculated the percentage of the gross energy savings attributable to DOE-funded BEM tools for each technology category from the results of the Delphi panel.[40] To conduct a sensitivity analysis,[41] the evaluation team determined the low-end and high-end attributions for DOE-funded BEM tools by taking the 25th and 75th percentile of the Delphi panel's point estimates of DOE-funded BEM tool influence on each technology category, respectively. The base, low-end, and high-end attribution cases are provided in Table 14.

Table 14. Attribution of Energy Savings to DOE-Funded BEM Tools

Technology Category	Base Case Attribution (Median Value)	Low-End Attribution	High-End Attribution
Envelope	12.3%	6.7%	21.8%
HVAC	10.5%	4.4%	16.5%
Service Hot Water	3.5%	2.2%	8.2%
Power	5.3%	2.2%	16.5%
Lighting	7.0%	4.4%	12.4%

4.1.2 Gross Energy Results

The evaluation developed gross energy savings by state, year, and fuel type from energy intensity savings (as previously defined in Section 3.4.1) developed by PNNL (by iteration of ASHRAE Standard 90.1, using DOE's prototypical commercial building models) and commercial new construction floor area data from EIA. Gross energy savings are presented for electricity and natural gas in Table 15 and represent the total prescriptive commercial energy efficiency codes energy savings that are available, each year, from DOE-funded BEM and all other rival factors.

Table 15. Gross ASHRAE Energy Savings (2000-2020)

Year	Gross ASHRAE 90.1 Electricity Savings (Million kWh)	Gross ASHRAE 90.1 Natural Gas Savings (Million therms)	Gross ASHRAE 90.1 Total Energy Savings (Million MMBtu)*
2000	0	0	0
2001	0	0	0
2002	0	0	0
2003	0	0	0

[40] Refer to Section 4.1.2 for a detailed description of how these calculations were completed.

[41] Refer to Section 4.4 for more information on the sensitivity analysis.

Year	Gross ASHRAE 90.1 Electricity Savings (Million kWh)	Gross ASHRAE 90.1 Natural Gas Savings (Million therms)	Gross ASHRAE 90.1 Total Energy Savings (Million MMBtu)*
2004	0	0	0
2005	0	0	0
2006	0	0	0
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
2012	229	8	2
2013	766	28	5
2014	1,674	60	12
2015	2,972	98	20
2016	4,544	141	30
2017	7,087	197	44
2018	11,331	277	66
2019	15,670	358	89
2020	20,009	438	112
Total	64,283	1,606	380
Notes: * Gross ASHRAE 90.1 Total Energy Savings (Million MMBtu) is the sum of Gross ASHRAE Electricity Savings (Million kWh) and Gross ASHRAE Natural Gas Savings (Million therms) that have been separately converted from native to common units of MMBtu.			

4.1.3 BEM-Attributed (Net) Energy Results

The evaluation developed BEM-attributed energy savings by state, year, and fuel type by multiplying gross energy savings by the attributions obtained from the Delphi panel. BEM-attributed energy savings are presented for electricity and natural gas in Table 16. They represent the commercial energy efficiency codes energy savings, by year, which are attributed to DOE-funded BEM tools in the evaluation and, on average, are about 10% of the gross energy savings.

Table 16. Net DOE-Funded BEM Energy Savings (2000-2020)

Year	Net DOE-Funded BEM Electricity Savings (Million kWh)	Net DOE-Funded BEM Natural Gas Savings (Million therms)	Net DOE-Funded BEM Total Energy Savings (Million MMBtu)
2000	0	0	0
2001	0	0	0
2002	0	0	0
2003	0	0	0
2004	0	0	0
2005	0	0	0
2006	0	0	0
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
2012	25	1	0
2013	84	3	1
2014	182	7	1
2015	317	11	2
2016	477	16	3
2017	724	22	5
2018	1,125	31	7
2019	1,535	40	9
2020	1,946	49	12
Total	6,416	179	40

Notes:
* Net DOE-funded BEM Total Energy Savings (Million MMBtu) is the sum of Net DOE-funded BEM Electricity Savings (Million kWh) and Net DOE-funded BEM Natural Gas Savings (Million therms) that have been separately converted from native to common units of MMBtu.

4.2 Commercial Energy Efficiency Codes Environmental Emissions Results

The following section describes how the evaluation calculated environmental emissions results.

4.2.1 Avoided Emissions Results

The BEM-attributed energy savings presented in Table 16 result in the avoided downstream emissions presented in Table 17. They were calculated, for each year, using annual national-level electric emissions factors from EPA's AVERT tool and natural gas emissions factors from EPA's AP-42 Compilation of Air Emissions Factors database.

Table 17. Total Avoided Emissions (2000-2020)

Year	$PM_{2.5}$ (Short Tons)	SO_2 (Short Tons)	NO_x (Short Tons)	NH_3 (Short Tons	VOC (Short Tons	CO_2e (Metric Tons)
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	0	0	0	0	0	0
2003	0	0	0	0	0	0
2004	0	0	0	0	0	0
2005	0	0	0	0	0	0
2006	0	0	0	0	0	0
2007	0	0	0	0	0	0
2008	0	0	0	0	0	0
2009	0	0	0	0	0	0
2010	0	0	0	0	0	0
2011	0	0	0	0	0	0
2012	2	34	23	0	1	22,066
2013	7	103	72	1	2	71,844
2014	14	226	153	3	4	154,539
2015	24	344	247	5	7	260,626
2016	35	381	354	7	11	385,071
2017	41	407	443	11	16	550,049
2018	54	567	654	17	23	798,549

Year	$PM_{2.5}$ (Short Tons)	SO_2 (Short Tons)	NO_x (Short Tons)	NH_3 (Short Tons	VOC (Short Tons	CO_2e (Metric Tons)
2019	79	704	853	21	31	1,017,593
2020	100	778	985	28	38	1,267,290
Total	356	3,544	3,784	93	132	4,527,627

4.2.2 Environmental Health Benefit Results

The avoided emissions presented in Table 17 result in the annual average avoided health end points presented in Table 18. They were developed on an annual basis using EPA's COBRA tool.

Table 18. Average Annual Change in Incidence, By Health Effect (2000-2020)

Health Effect	Average Annual Change Incidence
Mortality (average estimate)	3
Infant Mortality	0
Nonfatal Heart Attacks (average estimate)	1
Hospital Admits, All Respiratory	0
Hospital Admits, All Respiratory Direct	0
Hospital Admits, Asthma	0
Hospital Admits, Chronic Lung Disease	0
Hospital Admits, Cardiovascular (except heart attacks)	0
Acute Bronchitis	3
Upper Respiratory Symptoms	47
Lower Respiratory Symptoms	33
Emergency Room Visits, Asthma	1
Minor Restricted Activity Days	1,406
Work Loss Days	238
Asthma Exacerbation	49
Asthma Exacerbation, Cough	11

Health Effect	Average Annual Change Incidence
Asthma Exacerbation, Shortness of Breath	15
Asthma Exacerbation, Wheeze	23

4.3 Commercial Energy Efficiency Codes Economic Performance Results

The net DOE-funded BEM-attributed energy savings presented in Table 16 result in the energy cost savings presented in Table 19. They were calculated by multiplying the BEM-attributed energy savings by year and fuel type by corresponding state-level energy price data from EIA, then converted to constant dollars using the GDP Implicit Price Deflator and present value at 3 and 7 percent economic discount using the present value multipliers in Appendix H.

Table 19. Energy Savings Benefits (2000-2020)

Year	Constant 2020$, Undiscounted (Millions)	Constant 2020$, Discounted at 3% (Millions)	Constant 2020$, Discounted at 7% (Millions)
2000	$0.00	$0.00	$0.00
2001	$0.00	$0.00	$0.00
2002	$0.00	$0.00	$0.00
2003	$0.00	$0.00	$0.00
2004	$0.00	$0.00	$0.00
2005	$0.00	$0.00	$0.00
2006	$0.00	$0.00	$0.00
2007	$0.00	$0.00	$0.00
2008	$0.00	$0.00	$0.00
2009	$0.00	$0.00	$0.00
2010	$0.00	$0.00	$0.00
2011	$0.00	$0.00	$0.00
2012	$3.74	$2.55	$1.55
2013	$12.39	$8.19	$4.81
2014	$27.43	$17.61	$9.94
2015	$44.85	$27.95	$15.19

Year	Constant 2020$, Undiscounted (Millions)	Constant 2020$, Discounted at 3% (Millions)	Constant 2020$, Discounted at 7% (Millions)
2016	$64.46	$39.00	$20.41
2017	$97.61	$57.33	$28.88
2018	$144.50	$82.41	$39.96
2019	$190.68	$105.57	$49.27
2020	$234.16	$125.87	$56.55
Total	$819.82	$466.48	$226.56

The net energy cost savings presented in Table 19 are summarized by electricity and natural gas fuel types in Table 20.

Table 20. Savings by Fuel Type (2000-2020)

Fuel Type	Constant 2020$ Undiscounted	Constant 2020$ 3% Discount Rate	Constant 2020$ 7% Discount Rate
Electricity	$671,632,237	$381,644,446	$185,009,483
Natural Gas	$148,184,393	$84,835,969	$41,550,295
Total	$819,816,631	$466,480,415	$226,559,778

The avoided health end points presented in Table 18 were monetized and presented at 3 and 7 percent economic discount rates by EPA's COBRA, and then post-processed to adjust for population and constant dollars. The evaluation is adjusted for constant dollars using the GDP Implicit Price Deflator. Table 21 presents the base case alongside the low- and high-end cases. This table reflects sensitivities applied to Delphi attribution results to account for uncertainty and accordingly decrease and increase net energy savings and avoided downstream environmental and health end point impacts.

Table 21. Present Value of Emissions-Related Environmental Health Benefits (2000-2020)

Year	3% Discount Rate *(Constant 2020$)*			7% Discount Rate *(Constant 2020$)*		
	Low End	High End	Base Case (Median Value)	Low End	High End	Base Case (Median Value)
2000	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2001	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2002	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Year	3% Discount Rate *(Constant 2020$)*			7% Discount Rate *(Constant 2020$)*		
	Low End	High End	Base Case (Median Value)	Low End	High End	Base Case (Median Value)
2003	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2004	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2005	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2006	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2007	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2008	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2009	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2010	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2011	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
2012	$0.97	$3.50	$2.17	$0.59	$2.13	$1.32
2013	$3.04	$10.97	$6.79	$1.78	$6.43	$3.99
2014	$6.63	$23.85	$14.74	$3.74	$13.47	$8.32
2015	$10.70	$38.15	$23.45	$5.81	$20.74	$12.75
2016	$13.51	$47.86	$29.29	$7.07	$25.04	$15.32
2017	$15.88	$55.68	$33.85	$8.00	$28.05	$17.05
2018	$22.66	$78.65	$47.49	$10.99	$38.13	$23.03
2019	$29.94	$103.44	$62.25	$13.97	$48.28	$29.06
2020	$35.22	$225.80	$72.91	$15.82	$225.80	$32.76
Total	$138.55	$587.90	$292.94	$67.79	$408.08	$143.59

The environmental health benefits for the base case presented in Table 21 are also shown in Table 22 alongside the constant dollar undiscounted environmental health benefits.

Table 22. Environmental Health Benefits (2000-2020)

Year	Constant 2020$, Undiscounted (Millions)	Constant 2020$, Discounted at 3% (Millions)	Constant 2020$, Discounted at 7% (Millions)
2000	$0.00	$0.00	$0.00
2001	$0.00	$0.00	$0.00
2002	$0.00	$0.00	$0.00
2003	$0.00	$0.00	$0.00
2004	$0.00	$0.00	$0.00
2005	$0.00	$0.00	$0.00
2006	$0.00	$0.00	$0.00
2007	$0.00	$0.00	$0.00
2008	$0.00	$0.00	$0.00
2009	$0.00	$0.00	$0.00
2010	$0.00	$0.00	$0.00
2011	$0.00	$0.00	$0.00
2012	$3.18	$2.17	$1.32
2013	$10.28	$6.79	$3.99
2014	$22.96	$14.74	$8.32
2015	$37.63	$23.45	$12.75
2016	$48.41	$29.29	$15.32
2017	$57.62	$33.85	$17.05
2018	$83.27	$47.49	$23.03
2019	$112.43	$62.25	$29.06
2020	$135.64	$72.91	$32.76
Total	$511.43	$292.94	$143.59

The net energy savings and environmental health benefits presented in Table 19 and Table 22, respectively, are summed and presented as total benefits in Table 23. They represent the sum of monetized benefits from energy savings that accrue from both avoided energy costs and health endpoints.

Table 23. Total Benefits (2000-2020)

Year	Constant 2020$, Undiscounted (Millions)	Constant 2020$, Discounted at 3% (Millions)	Constant 2020$, Discounted at 7% (Millions)
2000	$0.00	$0.00	$0.00
2001	$0.00	$0.00	$0.00
2002	$0.00	$0.00	$0.00
2003	$0.00	$0.00	$0.00
2004	$0.00	$0.00	$0.00
2005	$0.00	$0.00	$0.00
2006	$0.00	$0.00	$0.00
2007	$0.00	$0.00	$0.00
2008	$0.00	$0.00	$0.00
2009	$0.00	$0.00	$0.00
2010	$0.00	$0.00	$0.00
2011	$0.00	$0.00	$0.00
2012	$6.92	$4.71	$2.87
2013	$22.67	$14.99	$8.79
2014	$50.39	$32.34	$18.26
2015	$82.48	$51.40	$27.94
2016	$112.86	$68.28	$35.73
2017	$155.23	$91.18	$45.93
2018	$227.77	$129.90	$62.98
2019	$303.11	$167.83	$78.33
2020	$369.80	$198.79	$89.31
Total	$1,331.24	$759.42	$370.15

4.3.1 BEM Investment Costs (2000-2020)

BEM portfolio investment costs provided by BTO are presented in Table 24. For years where data was available, investment costs were itemized by year and technology (i.e., EnergyPlus, OpenStudio SDK, ASHRAE Standard 140, and Prototype Building Models). Otherwise, the investment costs were averaged and apportioned equally across all other years. The evaluation converted current-year dollars to constant dollars using the GDP Implicit Price Deflator and present value at 3 and 7 percent economic discount rates.

Table 24. Portfolio Investment Costs (2000-2020)

Year	Nominal (Current - Year) $ (Millions)	GDP Deflator Implicit Price Deflator	Constant 2020$, Undiscounted (Millions)	Constant 2020$, Discounted at 3% (Millions)	Constant 2020$, Discounted at 7% (Millions)
2000	$4.09	78.025	$5.96	$5.96	$5.96
2001	$4.09	79.783	$5.83	$5.66	$5.45
2002	$4.09	81.026	$5.74	$5.41	$5.01
2003	$4.09	82.625	$5.63	$5.15	$4.59
2004	$4.09	84.843	$5.48	$4.87	$4.18
2005	$4.09	87.504	$5.31	$4.58	$3.79
2006	$4.09	90.204	$5.15	$4.32	$3.43
2007	$4.09	92.642	$5.02	$4.08	$3.13
2008	$4.09	94.419	$4.92	$3.89	$2.87
2009	$4.09	95.024	$4.89	$3.75	$2.66
2010	$4.09	96.166	$4.83	$3.60	$2.46
2011	$3.09	98.164	$3.58	$2.58	$1.70
2012	$3.07	100.000	$3.49	$2.45	$1.55
2013	$3.31	101.751	$3.70	$2.52	$1.53
2014	$3.82	103.654	$4.19	$2.77	$1.62
2015	$4.36	104.691	$4.73	$3.04	$1.72
2016	$3.75	105.740	$4.03	$2.51	$1.37
2017	$4.35	107.747	$4.59	$2.78	$1.45
2018	$6.78	110.321	$6.98	$4.10	$2.07
2019	$5.86	112.294	$5.93	$3.38	$1.64
2020	$6.77	113.648	$6.77	$3.75	$1.75
Total	$90.16	N/A	$106.75	$81.13	$59.92

Year	Nominal (Current - Year) $ (Millions)	GDP Deflator Implicit Price Deflator	Constant 2020$, Undiscounted (Millions)	Constant 2020$, Discounted at 3% (Millions)	Constant 2020$, Discounted at 7% (Millions)
Notes: Nominal costs were converted to constant 2020 dollars by multiplying by the 2020 GDP implicit price deflator and then dividing by the current-year deflator. GDP implicit price deflators are from the BEA, Table 1.1.9: Implicit Price Deflators for Gross Domestic Product, available at https://www.bea.gov/data/gdp/gross-domestic-product.					

4.3.2 Economic Benefit

Net economic benefits presented in Table 25 and Table 26 result from the addition of portfolio investment costs (Table 24) with energy cost savings (Table 19) and environmental health co-benefits (Table 22). Table 25 and Table 26 presents this progression from the buildup of total economic benefits that accrue from monetized energy savings and health endpoints, in current dollars, which are converted to constant dollars using the GDP Implicit Price Deflator, and then added to the portfolio investment costs to derive net economic benefits.

Table 25. Economic Performance (Current Dollars) (2000-2020)

Year	Energy Cost Savings ($Million Current)	Environmental Health Benefits ($Million, Current)	Total Economic Benefits ($Million, Current)	Portfolio Investment Cost ($Million, Current)	GDP Deflator Implicit Price Deflator
2000	$0.00	$0.00	$0.00	$4.09	78.025
2001	$0.00	$0.00	$0.00	$4.09	79.783
2002	$0.00	$0.00	$0.00	$4.09	81.026
2003	$0.00	$0.00	$0.00	$4.09	82.625
2004	$0.00	$0.00	$0.00	$4.09	84.843
2005	$0.00	$0.00	$0.00	$4.09	87.504
2006	$0.00	$0.00	$0.00	$4.09	90.204
2007	$0.00	$0.00	$0.00	$4.09	92.642
2008	$0.00	$0.00	$0.00	$4.09	94.419
2009	$0.00	$0.00	$0.00	$4.09	95.024
2010	$0.00	$0.00	$0.00	$4.09	96.166
2011	$0.00	$0.00	$0.00	$3.09	98.164
2012	$3.29	$2.80	$6.09	$3.07	100.000
2013	$11.10	$9.20	$20.30	$3.31	101.751
2014	$25.02	$20.94	$45.96	$3.82	103.654

Year	Energy Cost Savings ($Million Current)	Environmental Health Benefits ($Million, Current)	Total Economic Benefits ($Million, Current)	Portfolio Investment Cost ($Million, Current)	GDP Deflator Implicit Price Deflator
2015	$41.32	$34.67	$75.98	$4.36	104.691
2016	$59.97	$45.04	$105.01	$3.75	105.740
2017	$92.54	$54.63	$147.17	$4.35	107.747
2018	$140.27	$80.84	$221.11	$6.78	110.321
2019	$188.40	$111.10	$299.50	$5.86	112.294
2020	$234.16	$135.64	$369.80	$6.77	113.648
Total	$796.07	$494.85	$1,290.92	$90.16	N/A
Notes: Column (4) = Column (2) + Column (3)					

Table 26. Economic Performance (Constant Dollars) (2000-2020)

Year	Energy Cost Savings ($Million Constant 2020$)	Health Co-Benefits ($Million, Constant 2020$)	Total Economic Benefits ($Million, Constant 2020$)	Portfolio Investment Cost ($Million, Constant 2020$)	Net Economic Benefits ($Million, Constant 2020$)
2000	$0.00	$0.00	$0.00	$5.96	-$5.96
2001	$0.00	$0.00	$0.00	$5.83	-$5.83
2002	$0.00	$0.00	$0.00	$5.74	-$5.74
2003	$0.00	$0.00	$0.00	$5.63	-$5.63
2004	$0.00	$0.00	$0.00	$5.48	-$5.48
2005	$0.00	$0.00	$0.00	$5.31	-$5.31
2006	$0.00	$0.00	$0.00	$5.15	-$5.15
2007	$0.00	$0.00	$0.00	$5.02	-$5.02
2008	$0.00	$0.00	$0.00	$4.92	-$4.92
2009	$0.00	$0.00	$0.00	$4.89	-$4.89
2010	$0.00	$0.00	$0.00	$4.83	-$4.83
2011	$0.00	$0.00	$0.00	$3.58	-$3.58
2012	$3.74	$3.18	$6.92	$3.49	$3.43

Year	Energy Cost Savings ($Million Constant 2020$)	Health Co-Benefits ($Million, Constant 2020$)	Total Economic Benefits ($Million, Constant 2020$)	Portfolio Investment Cost ($Million, Constant 2020$)	Net Economic Benefits ($Million, Constant 2020$)
2013	$12.39	$10.28	$22.67	$3.70	$18.97
2014	$27.43	$22.96	$50.39	$4.19	$46.20
2015	$44.85	$37.63	$82.48	$4.73	$77.75
2016	$64.46	$48.41	$112.86	$4.03	$108.83
2017	$97.61	$57.62	$155.23	$4.59	$150.64
2018	$144.50	$83.27	$227.77	$6.98	$220.79
2019	$190.68	$112.43	$303.11	$5.93	$297.18
2020	$234.16	$135.64	$369.80	$6.77	$363.03
Total	$819.82	$511.43	$1,331.24	$106.75	$1,224.49

Notes:

- Column (2) = Column (2) from table above converted to constant 2020 dollars by multiplying by the 2020 GDP implicit price deflator and then dividing by the current-year deflator
- Column (3) = Column (4) from table above converted to constant 2020 dollars by multiplying by the 2020 GDP implicit price deflator and then dividing by the current-year deflator
- Column (4) = Column (2) + Column (3)
- Column (5) = Column (5) from table above converted to constant 2020 dollars by multiplying by the 2020 GDP implicit price deflator and then dividing by the current-year deflator
- Column (6) = Column (4) – Column (5)

The constant-dollar undiscounted net economic benefits presented in Table 25 and Table 26 are represented in Table 27 alongside the same benefit presented at 3 and 7 percent economic discount rates.

Table 27. Net Economic Benefits (2000-2020)

Year	Constant 2020$, Undiscounted (Millions)	Constant 2020$, Discounted at 3% (Millions)	Constant 2020$, Discounted at 7% (Millions)
2000	-$5.96	-$5.96	-$5.96
2001	-$5.83	-$5.66	-$5.45
2002	-$5.74	-$5.41	-$5.01
2003	-$5.63	-$5.15	-$4.59
2004	-$5.48	-$4.87	-$4.18
2005	-$5.31	-$4.58	-$3.79
2006	-$5.15	-$4.32	-$3.43
2007	-$5.02	-$4.08	-$3.13
2008	-$4.92	-$3.89	-$2.87
2009	-$4.89	-$3.75	-$2.66
2010	-$4.83	-$3.60	-$2.46
2011	-$3.58	-$2.58	-$1.70
2012	$3.43	$2.27	$1.32
2013	$18.97	$12.47	$7.26
2014	$46.20	$29.57	$16.64
2015	$77.75	$48.36	$26.22
2016	$108.83	$65.77	$34.36
2017	$150.64	$88.40	$44.47
2018	$220.79	$125.80	$60.92
2019	$297.18	$164.44	$76.69
2020	$363.03	$195.04	$87.56
Total	$1,224.49	$678.29	$310.23

4.3.3 Overall Economic Performance

The economic performance of DOE-funded BEM tools is presented in Table 28. They show the 20-year portfolio investment cost of $107 million produced net economic benefits (combined energy and environmental health) of

$1,224 million and resulted in a benefit-to-cost ratio of 6.18 (7% discount rate) and an internal rate of return of 21% when considering combined energy and environmental health benefits.

Table 28. Economic Performance Metrics (2000-2020)

Metric	Units	Energy Benefits	Combined Energy and Environmental Health Benefits
Portfolio Investment Cost - undiscounted	Million, 2020$	$107	$107
Gross Economic Benefits - undiscounted	Million, 2020$	$820	$1,331
Net Economic Benefits - undiscounted	Million, 2020$	$713	$1,224
Net Present Value at 7% real discount rate	Million, 2020$	$167	$310
Net Present Value at 3% real discount rate	Million, 2020$	$385	$678
Benefit-to-Cost Ratio (BCR) at 7% real discount rate	Ratio	3.78	6.18
Benefit-to-Cost Ratio (BCR) at 3% real discount rate	Ratio	5.75	9.36
Internal Rate of Return	Percent	20%	21%

4.4 Sensitivity Analysis for ASHRAE 90.1 Benefits Estimation

The evaluation conducted a sensitivity analysis around the median Delphi panel attributions used as the base case of the study, creating upper and lower bounds for energy and environmental impacts.

The medians were selected as the base case rather than the means because the median is a better representative of a non-normal or skewed distribution than its mean. Furthermore, the mean was on average higher than the median, indicating the presence of high-end outliers in the dataset, (as shown in Table 29) making the median a conservative estimate.

The evaluation team then determined the low-end and high-end attributions for each technology category by taking the 25th and 75th percentile of the Delphi panel's influence and counterfactual estimates, respectively. These percentiles are the quartiles around the median (i.e., the 50th percentile). The median, low-end, and high-end attributions are shown in the table below, alongside the unused mean attributions.

Table 29. Sensitivity Analysis for Delphi Panel Estimates by Technology Category

	Envelope		HVAC		Service Hot Water		Power		Lighting	
Value	Value	Diff. from Median	Value	Diff. from Median	Value	Diff. from Median	Value	Diff. from Median	Value	Diff. from Median
Median (Base)	12.25%	-	10.50%	-	3.50%	-	5.25%	-	7.00%	-

Value	Envelope		HVAC		Service Hot Water		Power		Lighting	
	Value	Diff. from Median	Value	Diff. from Median	Value	Diff. from Median	Value	Diff. from Median	Value	Diff. from Median
25th Percentile (Low End)	6.67%	-5.58%	4.45%	-6.05%	2.22%	-1.28%	2.22%	-3.03%	4.45%	-2.55%
75th Percentile (High End)	21.82%	+9.57%	16.47%	+5.97%	8.24%	+4.74%	16.47%	+11.22%	12.35%	+5.35%
Mean	13.09%	+0.84%	9.60%	-0.90%	5.87%	+2.37%	7.83%	+2.58%	8.00%	+1.00%

Across the technology categories, the low-end attributions to DOE-funded BEM tools ranged from roughly 2–7%, and the high-end attributions ranged from roughly 8%–22%. We applied these low-end and high-end attributions to the gross ASHRAE energy savings, creating the range of economic impacts presented in Table 30. This range indicates that DOE's investment in BEM tools is cost-effective even when using the low-end attribution and only considering energy resource benefits.

Table 30. Range of Economic Impacts Attributable to DOE-Funded BEM Tools (2000-2020)

Metric	Units	Energy Benefits	Combined Energy and Environmental Health Benefits
Portfolio Investment Cost - undiscounted	Million, 2020$	$107	$107
Gross Economic Benefits - undiscounted	Million, 2020$	$390 - $1,356	$632 - $2,201
Net Economic Benefits - undiscounted	Million, 2020$	$283 - $1,249	$525 - $2,094
Net Present Value at 7% real discount rate	Million, 2020$	$48 - $610	$115 - $1,018
Net Present Value at 3% real discount rate	Million, 2020$	$140 - $871	$279 - $1,458
Benefit-to-Cost Ratio (BCR) at 7% real discount rate	Ratio	1.79 – 11.18	2.92 – 18.00
Benefit-to-Cost Ratio (BCR) at 3% real discount rate	Ratio	2.73 – 11.73	4.44 – 18.98
Internal Rate of Return	%	13% - 25%	14% - 26%
Monetary value of energy and other resource impacts	Million, 2020$	$390 - $1,356	$390 - $1,356
Monetary value of avoided adverse health incidence due to air emissions	Million, 2020$	0%	$242 - $845

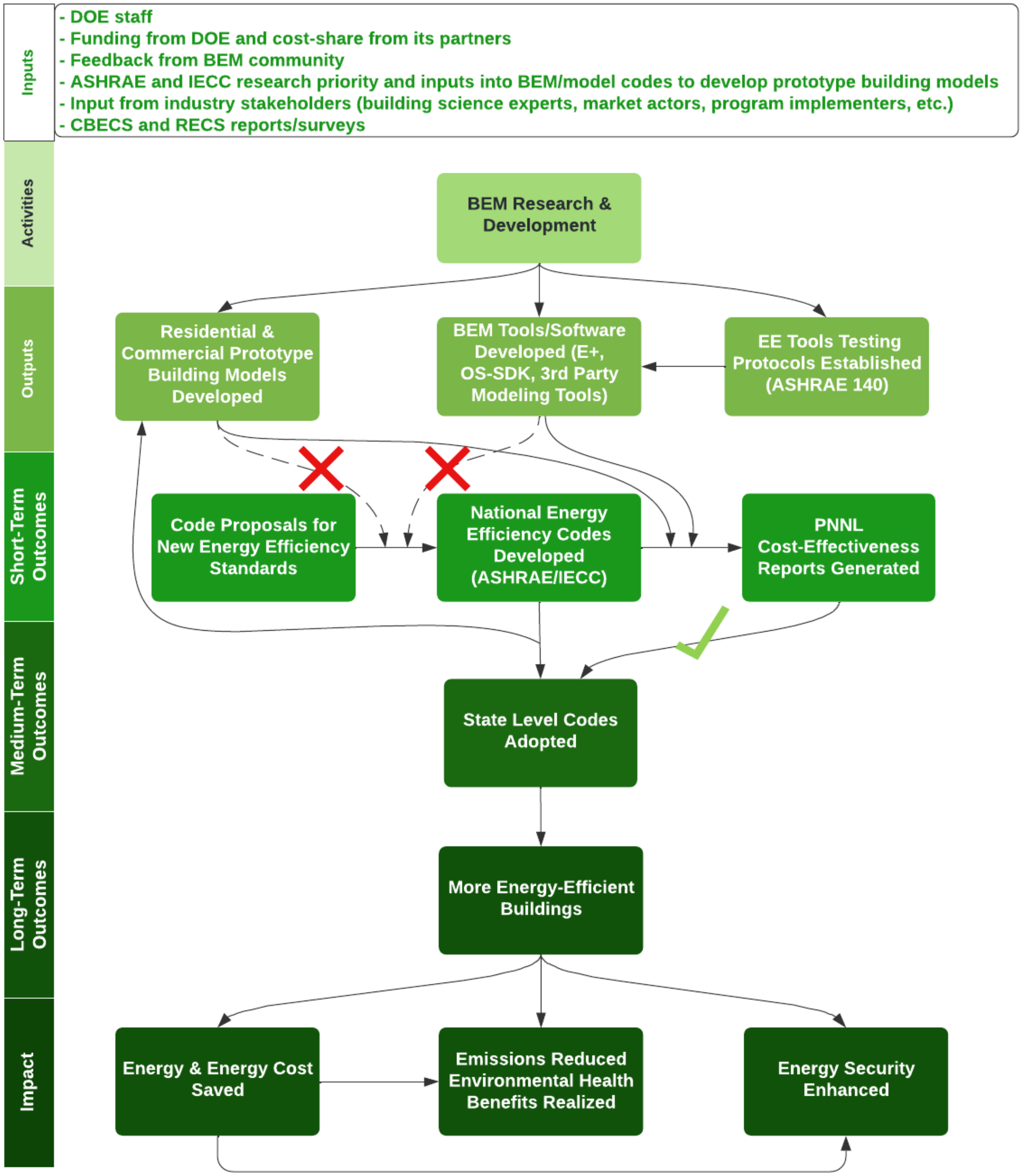
4.5 Qualitative Results for Residential Energy Efficiency Codes and Energy Efficiency Incentive Programs

This section details the qualitative results from research into residential energy efficiency codes and energy efficiency incentive programs.

4.5.1 Residential Energy Efficiency Codes

The original logic model in Section 2.3.1 assumed that both the commercial and residential energy efficiency code use cases had similar scales and processes of impact. However, research into the actual IECC code amendments during the study period revealed that several pathways of the logic model (marked with red Xs in Figure 15 below) simply did not occur within IECC.

Figure 15: Evaluation of Energy Efficiency Codes Logic Model (specific to IECC)



While several approved ASHRAE 90.1 amendments referenced DOE-funded BEM tools, the few IECC amendments which did so were all proposed by DOE and rejected by the IECC committee. Interviews with stakeholders corroborated this finding. They suggested that the only impact DOE-funded BEM tools had on the IECC occurred during the adoption phase by states motivated by PNNL's cost-effectiveness determinations, which used DOE-funded BEM tools (the green check mark in Figure 15).

The evaluation could not quantify this sole pathway using a Delphi panel because each state's motivations for code adoption would be unique, requiring survey research far beyond the scope of this study. Therefore, the findings for the residential energy efficiency code use case are purely qualitative.

4.5.1.1 Negligible Presence of Evidence of DOE-Funded BEM Tool Impact on IECC

A thorough review was conducted on the complete list of public comments (i.e., proposed changes and subsequent committee decisions) for all available iterations of the IECC during the study period (2006, 2009, 2012, 2015, and 2018). The evaluation team searched for references to "EnergyPlus," "prototypical," "ASHRAE 90.2," "Energy Efficiency Codes Coalition" (a group which used DOE-funded BEM tools in their proposed changes), and any other source based on DOE-funded BEM tools. The evaluation placed special focus on approved changes that contributed to energy efficiency (Table 31), with the goal of finding at least one approved change justified by DOE-funded BEM tools.

Table 31. IECC Code Changes Impacting Energy Efficiency (EE) From 2006 to 2018 by Technology Category

Year	Total Changes Impacting EE	Building Envelope	HVAC	Domestic Service Hot Water Systems	Lighting	Power
2006	3	3	-	-	-	-
2009	11	8	2	-	1	-
2012	20	12	4	1	2	1
2015	7	2	2	3	-	-
2018	13	5	5	-	1	2

Having reviewed every public comment for each of these IECC iterations, the evaluation could not trace any proposed changes based on DOE-funded BEM tools to the finalized code. The IECC committees initially disapproved almost all proposals, largely because they were either impractical or unnecessary. The negligible presence of evidence is the basis for determining that the residential energy efficiency code use case is unquantifiable.

4.5.1.2 Obstacles to BEM Tool Impact on IECC

Based on discussions with stakeholders, DOE-funded BEM tools do not influence residential code development because IECC follows a nontechnical public hearing process. Therefore, IECC is much more beholden to the perspectives of stakeholders like builders and manufacturers than to BEM-based analyses. IECC does not require amendments to be tested for cost-effectiveness. In reviews of code amendments, committees consistently rejected amendments tested for cost-effectiveness using DOE-funded BEM tools because they believed they were counter to their real-world experiences.

Another obstacle was that the IECC adopted very few significant amendments in several of the iterations within the study period. While there was a roughly ten percent efficiency improvement in both the 2009 and 2012 iterations, the IECC committee did not consider DOE-funded BEM tools in the code development process until DOE included them in its "Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes," published in 2012.[42] The following iterations published in 2015 and 2018 had almost no improvement in efficiency. In those years, the code "flatlined" to focus on adoption and compliance with the previous jumps in efficiency. This reduced pool of code changes did not include any evidence of DOE-funded BEM tool influence, suggesting a minor to insignificant role of BEM in IECC code adoption.

One positive sign for future DOE-funded BEM tool influence is that IECC has recently turned to ANSI-approved standards for its code development process. This may encourage a compulsory BEM-based cost-effectiveness test for amendments wherever it would provide benefit.

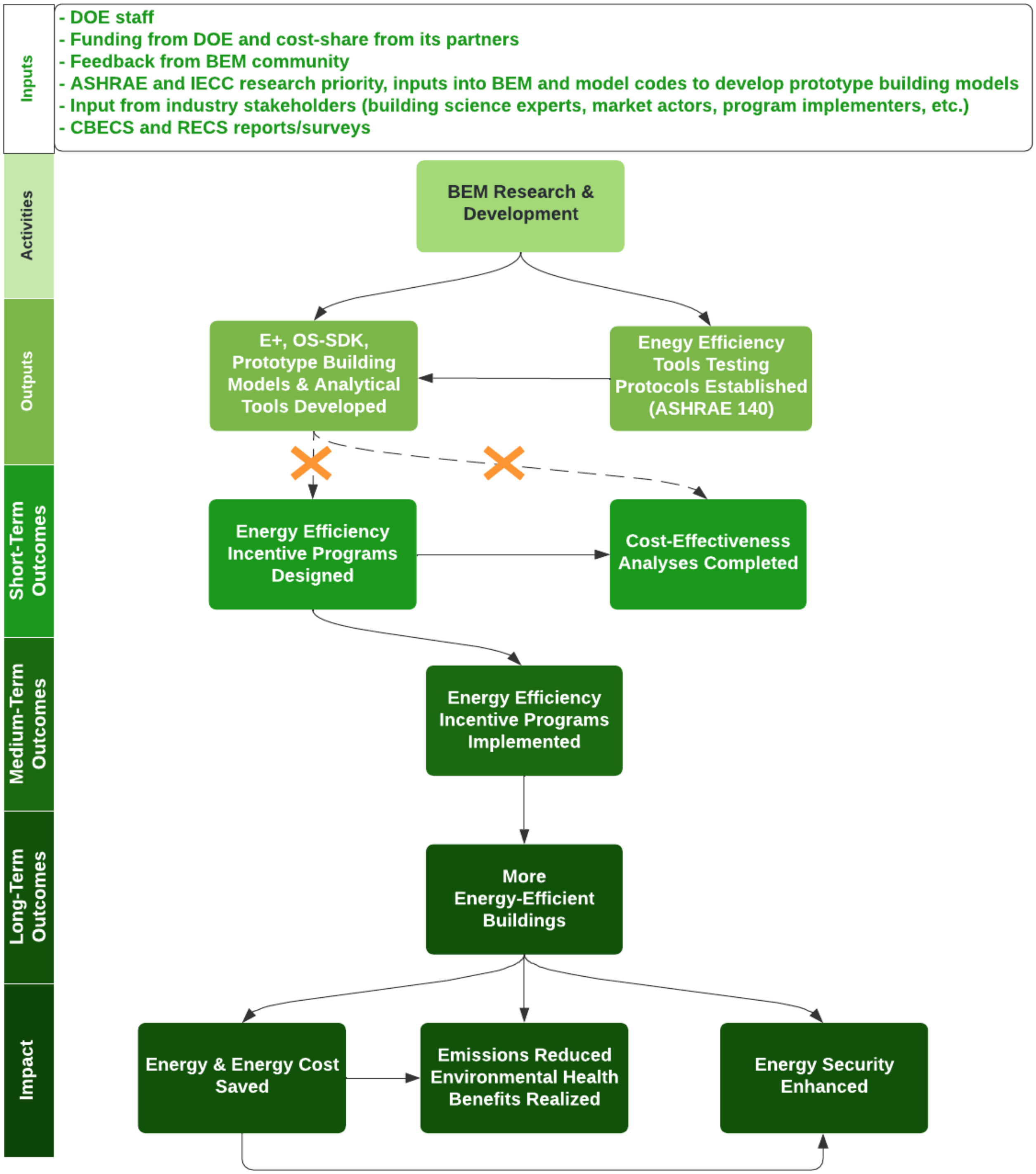
4.5.2 Energy Efficiency Incentive Programs

The evaluation team considered a quantitative analysis similar to the commercial codes use case for the energy efficiency incentive programs use case as well. However, evaluators determined through preliminary research and stakeholder interviews that a Delphi panel approach would not be appropriate for this use case. This is because no consistent involvement between DOE-funded BEM tools and energy efficiency incentive programs was found. Furthermore, state programs lack the standardization in program development, such that any specific panelist from one energy efficiency incentive program would not necessarily have knowledge outside of their own program– the state-level drivers vary by state. Even utility billing is not standard across states or cities. These factors made the Delphi panel instrument inappropriate, so the evaluation shifted to a case study approach.

As described in the following sections, these case studies found that the pathways of the energy efficiency incentive programs' original logic model in Section 2.3.2 occurred on such a rare basis that the evaluation team determined the BEM effect is unquantifiable for the purposes of this study. These pathways are marked in Figure 16 with orange X's (rather than red, to signify the very small but non-zero impact they had).

[42] Taylor et al. (April 2012). ***Methodology for Evaluating Cost-Effectiveness of Residential Energy Code Changes.*** Building Technologies Program. PNNL-21294. https://doi.org/10.2172/1773018.

Figure 16: Evaluation of Energy Efficiency Incentive Program Logic Model



4.5.2.1 Energy Efficiency Incentive Program Meta-Analysis

The evaluation conducted a meta-analysis to identify which state-level energy efficiency incentive programs were most likely to have used DOE-funded BEM tools during program development and execution.

Initially, the evaluation team selected states for exploration based on ACEEE's scorecard data, which analyzes third-party evaluations on state energy efficiency incentive programs and associated energy savings. Using this data, the evaluation team conducted a literature and document review to identify an initial set of energy efficiency incentive programs to analyze for each state. The inclusion criteria were:

- Years of data analyzed in the evaluation;
- The potential role of DOE-funded BEM tools;
- The quality of the evaluation; and
- Indications of prescriptive commercial and industrial whole-building and new construction components.

Because energy efficiency incentive programs are managed by their respective states, there is no standardized reporting structure or metric for energy savings by Evaluation, Measurement and Verification evaluators that is consistent with the needs of this evaluation. States often do not disaggregate savings according to sector or include major retrofits in their reporting. The meta-analysis findings identified programs with data that the evaluation could combine to estimate total BEM-attributable savings from selected energy efficiency incentive programs.

Based on these criteria, the evaluation team organized a series of semi-structured interviews with subject matter experts (SMEs) to complement and confirm literature and document findings and provide insight on the attribution of DOE-funded BEM tools to energy efficiency incentive program development. Research originally yielded over 100 state energy efficiency incentive programs, which the evaluation team analyzed and downselected to six energy efficiency incentive programs meeting all the criteria for inclusion.

However, through discussions with key decision-makers at these programs during the study period, as well as reviews of these programs' evaluation reports, the evaluation found no significant evidence of DOE-funded BEM tool use.

Furthermore, in a broader review of the 329 evaluation reports contained in EIA's program evaluation inventory, the evaluation team selected over 15 of those programs for deeper investigation based upon their relevance to this study. The evaluation did not find significant evidence of DOE-funded BEM tool use. Evaluators found small references to EnergyPlus and BEopt (a residential BEM tool based on EnergyPlus) for a handful of insignificant measures such as guest room energy management, but these impacts were far too small to be worth quantifying.

The evaluation determined this use case to be currently insignificant at a national level. As a result, the evaluation qualitatively evaluated this use case to uncover the obstacles to adopting DOE-funded BEM tools and the incentives which could encourage future adoption. Evaluators conducted interviews with managers and technical staff at the following programs included in the meta-analysis and considered the most relevant:

- ComEd (Illinois)
- Mass Save (Massachusetts)
- New York State Energy Research and Development Authority (NYSERDA)
- Energy Trust of Oregon
- Vermont Energy Investment Corporation
- Xcel Energy (Colorado)
- California Savings by Design

These interviews revealed current obstacles to DOE-funded BEM tool adoption as well as future incentives which could encourage DOE-funded BEM tool adoption, as detailed in the following sections.

4.5.2.2 Obstacles to DOE-Funded BEM Tool Adoption by Energy Efficiency Incentive Programs

Interviews uncovered that energy efficiency incentive programs commonly use BEM tools not funded by DOE, particularly DOE-2 or eQUEST. The evaluation found that the specific use of EnergyPlus and DOE-funded BEM tools is limited in scope and coverage and nascent (within the last two or three years of the study period). Interviewees attributed this recent rise in the use of EnergyPlus to DOE's continued investment in and promotion of the tool, its increased measure functionality, and its open-source transparency when compared to alternative BEM tools. Where used, EnergyPlus more commonly supported whole-building custom programs, ad hoc exploratory research efforts, and code compliance, rather than prototypical use to underpin prescriptive programs.

The following are the current obstacles which, according to the interviewees, limited DOE-funded BEM tool use at the energy efficiency incentive programs:

- Inertia around existing savings methods and software tools. The energy efficiency incentive programs are generally BEM software agnostic. Interviewees often stated that technical consultants selected a BEM tool based on preference rather than by the program. Often, the consultant team was more familiar with older DOE-2 tools (like eQUEST) not funded by DOE or proprietary HVAC software (like Trane Trace). Interviewees mentioned consultants were resistant to undergo training for EnergyPlus. Therefore, the DOE-funded BEM tool was not adopted.
- Skill set required by EnergyPlus. One of the reasons cited for this resistance was that EnergyPlus does not have the user interface and user-friendliness of other free tools like eQUEST (partly to not compete with the private BEM software sector). It is not easy to use "right out of the box" and needs considerable training, especially around programming if used on a large scale. This learning curve has deterred many energy efficiency incentive program analyst teams. Occasionally, programs develop an in-house tool based on the EnergyPlus engine to facilitate its use. However, this proprietary tool is not shared with other programs and thus it has a limited impact.
- Shrinking energy efficiency incentive program budgets. With codes advancing and reducing the savings available for above-code energy efficiency incentive programs, utilities are often looking for labor-saving savings calculation methods rather than the most accurate BEM tool on the market. Interviewees considered the training and labor required by EnergyPlus worthwhile for ad hoc tasks that needed its accuracy and functionality. However, the required skills were too costly to base the programs on.
- Lengthy regulatory processes. Some programs had to select their BEM tool to match the calculation methodology required by their state's public utilities commission (PUC). Therefore, they can only adopt EnergyPlus after it becomes part of that methodology, which often has a significant delay time. This was the case for California's Savings by Design program– the California PUC has only recently moved from eQUEST to EnergyPlus for its Database of Energy Efficiency Resources efficiency measure database.
- Rigid TRM update processes. Several energy efficiency incentive programs based the savings assigned to a given measure on the calculations in their state's TRMs, which overwhelmingly did not use EnergyPlus except for a couple of insignificant calculations. These TRMs generally predate the release of EnergyPlus. While updates do occur over the years, the majority of the BEM tools referenced within them are eQUEST or DOE-2 rather than EnergyPlus. The TRMs appear to have generally slow update processes and their committees do not seem to have much engagement with DOE.

- Specific prototype needed. One interviewee noted that there is no prototype for small commercial buildings, which is a key building type for their program.[43]

4.5.2.3 Incentives for DOE-Funded BEM Tool Adoption

The following are the potential factors which, according to the interviewees, could encourage DOE-funded BEM tool use at each program in the future:

- Future decarbonization and demand-side management mandates. Several interviewees saw EnergyPlus as unnecessarily complex for their current programs. However, some suggested that the increasing future importance of decarbonization and grid-interactive buildings might make its complexity necessary. This is because simple prescriptive measures (like lighting) have become standard. Therefore, the programs would need to reach further for more complex measures (like Variable Refrigerant Flow and other advanced HVAC measures) to meet state mandates and company goals around energy savings. If DOE were to encourage efforts requiring the complexity which EnergyPlus is best for, adoption of the tool would likely increase.
- Tools which require or utilize EnergyPlus. Programs sometimes adopted EnergyPlus because of another tool. For example, Xcel Energy makes their energy modelers undergo certification and use OpenStudio because their program uses the Energy Design Assistance Program Tracker, an NREL program administration and reporting tool requiring inputs from OpenStudio. Other interviewees referenced DesignBuilder and Cove.tool, two proprietary tools built around EnergyPlus, as easier to use than native EnergyPlus. If DOE encouraged the development of more tools like this, adoption of DOE-funded BEM would likely increase.
- Training. Several interviewees noted that EnergyPlus trainings available from providers like Performance Systems Development (PSD) and BigLadder were crucial to their ability to use the tool in any capacity. One interviewee noted the importance of trainings on how to use programming to build apps and scripts around the tool, not just trainings on the tool itself. DOE should continue to offer training opportunities at perhaps an increased frequency. In addition, with the recent launch of Spawn-of-EnergyPlus, it is important that DOE introduce new features to the user base to ensure widespread adoption and application.
- User-friendliness and tool updates. If program staff are unable to develop the skills required to effectively use EnergyPlus through trainings, then energy efficiency incentive programs will only adopt the tool if the necessary skills are reduced. Suggested improvements include:
    - Add incremental capital costs for measures in OpenStudio so that they are visible on the front end rather than having to be added in the back end.
    - Create a more visual and functional interface like that of eQUEST to make the transition smoother for those used to more commercialized and user-friendly tools.
    - Add updates to the ASHRAE Energy Design Guides, as they have become somewhat dated in the current design industry.
    - Implement a larger measure database, including those representing various levels of code, to increase the tool's built-in functionality.
- More engagement with TRMs. NYSERDA's next update to the New York TRM includes a custom measure standard based on EnergyPlus. This is due to NYSERDA's engagement with the firm PSD, which has considerable experience with the tool. If DOE could facilitate such engagements or directly engage with TRM committees more, energy efficiency incentive programs may be more likely to consider using EnergyPlus in future updates.

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[43] However, prototype models do exist for strip malls, restaurants, and small office buildings.

5. Conclusions and Recommendations

Based on the evaluation findings, the BTO BEM program is recommended to implement the following suggestions. These recommendations intend to increase the overall energy savings attributable to DOE-funded BEM tools.

5.1 ASHRAE 90.1 Commercial Energy Efficiency Codes

As detailed in Section 4.1, the evaluation estimated the energy and environmental health benefits which would not have happened without DOE-funded BEM tools through this use case alone to be large enough to make DOE's investment in DOE-funded BEM tools cost effective (the Base Case or median Benefit-to-Cost Ratio is 6.18 at the 7% discount rate). This means that there is room for investment in further initiatives, which could increase these savings without being concerned about the total investment's overall cost-effectiveness.

The evaluation team recommends the following actions which may help DOE maintain or increase the savings generated through this use case. First, maintain the existing rigor of modeling proposed ASHRAE amendments using DOE-funded BEM tools and determining their cost-effectiveness. In addition, DOE should continue all other engagements which encouraged the ASHRAE committees to base a significant attribution of their decision-making on DOE-funded BEM tools.

The evaluation team also recommends that DOE expand the applicability of the prototypical models used to inform changes to ASHRAE 90.1 and other standards. DOE should ensure that these standards can prioritize proposed changes and accurately measure the impact of those changes on energy savings. In 2016, ASHRAE 90.1 made 51 addenda to the standard that the Energy Savings Analysis completed by PNNL determined would impact energy savings. Of these, PNNL quantitatively analyzed 21 addenda using prototypical models to estimate associated energy savings. The Energy Savings Analysis excluded the other 30 addenda from the quantitative analysis for various reasons. In some cases, PNNL did not perform a quantitative estimate of energy savings because an addendum fell outside the scope of the analysis, as was the case for addenda related to federal regulation, verification, or retrofits to existing buildings. However, for 21 of the 30 addenda for which PNNL did not perform a quantitative estimate of energy savings, limitations of the prototypical models precluded their inclusion in the quantitative analysis.

In two cases, the proposed addenda are already part of the underlying assumptions of the prototypical models. For the other 19 cases, the addenda cannot be modeled because typical designs, as represented by the prototypes, do not include the technology, room type, or building component addressed by the addenda. For instance, prototypical models used for the 2016 Energy Savings Analysis did not include the following: parallel fan-powered terminal units, variable refrigerant flow systems, return and relief fans, duct heat loss, indoor pools, closed-circuit cooling towers, radiant cooling or passive chilled beams, parking garages, decorative lighting, single-ply non-adhered roofing membranes, glazed power-sliding and folding doors, perimeter heating, vestibules with cooling, and extra return or exhaust duct credit.

Continued investment in developing the prototypical models will ensure that fewer addenda are excluded from quantitative analysis due to model limitations, leading to increased accuracy in measuring energy savings associated with changes to ASHRAE 90.1 and other standards.

5.2 IECC Residential Energy Efficiency Codes

The evaluation was unable to quantify BEM energy savings associated with this use case due to these factors:

- Savings from DOE-funded BEM tools influencing adoption of IECC: The savings generated by states using DOE's determinations (utilizing DOE-funded BEM tools) to decide upon adopting the IECC were potentially substantial but simply not quantifiable by this study. This is due to the uniqueness of each state's decision-making and the logistical challenges of surveying each state.
- Savings from DOE-funded BEM tools influencing development of IECC: The evaluation found the savings generated by DOE-funded BEM tools during the actual IECC development process to be unquantifiable. Through research into IECC code amendments as well as interviews with key code stakeholders, the evaluation team attributed this to the code's "public hearing" process, in which stakeholder lobbying took precedence in determining code updates rather than BEM analysis of cost-effectiveness.

The recently adopted ANSI update process may reduce this second factor in the future by providing more structure and giving precedence to updates based on cost-effectiveness over stakeholder preferences. In addition to this potential future change, DOE can take the following recommended actions to encourage DOE-funded BEM tool savings within this use case:

- Increase engagement with the ICC regarding the IECC in light of this new ANSI code development process. Encourage them to prioritize compulsory, BEM-based cost-effectiveness tests where they provide benefits.
- Many of the rejections of DOE proposals utilizing DOE-funded BEM tools cited stakeholders' real-world experiences (e.g., feasibility of construction, market availability, and economic viability). Therefore, invest more resources into ensuring that the tools and the proposals based on them can address these concerns, such that they are palatable enough to be approved and make it into future code updates.

5.3 Energy Efficiency Incentive Programs

The evaluation was unable to quantify consistent energy savings attributable to DOE-funded BEM tools through this use case due to several factors, including:

- Resistance towards learning a new tool;
- The steep learning curve required by the tool;[44]
- Shrinking program budgets;
- Rigid regulatory and TRM update processes; and
- Specific missing features of the tool.

Future decarbonization and grid-interaction needs may mitigate these factors, making it necessary for the programs to use EnergyPlus and thereby increase adoption. In addition to these potential future changes, DOE can take the following recommended actions to encourage DOE-funded BEM tool savings within this use case:

- Continue to encourage efforts among states and utilities requiring the complexity of which EnergyPlus is best for, such as decarbonization and grid-interactive efforts.
- Encourage the development of more tools that require or utilize EnergyPlus.
- Offer EnergyPlus training opportunities at an increased frequency to encourage those who see the benefit of the tool but simply lack the access or means to learn it.
- Consider the following EnergyPlus updates for greater user-friendliness:
    - Add incremental capital costs for measures in OpenStudio so that they are visible on the front end rather than having to be added in the back end.
    - Develop a more visual and functional interface like that of eQUEST to make the transition smoother for those using more commercialized, user-friendly tools.

[44] Commercial trainings on DOE-funded BEM tools are often several days in length to overcome the steep learning curve.

  - Update the ASHRAE Energy Design Guides, as they have become somewhat dated in the current design industry.
  - Include a larger measure database, including those representing various levels of code, to increase the tool's built-in functionality.
- Engage more with TRM developers and their stakeholders, encouraging them to incorporate EnergyPlus in their development process.

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Appendix A: List of Interview Participants

Preliminary Interviews

David Cohan - Director of Technical and Policy Analysis, Institute for Market Transformation
Michael Deru - Communities and Urban Science Group Manager, National Renewable Energy Laboratory
Steve Kromer - Energy Efficiency Consultant
Jack Mayernik - Project Manager, National Renewable Energy Laboratory
Lilas Pratt - Manager of Special Projects, ASHRAE
Michael Rosenberg - Chief Scientist, Pacific Northwest National Laboratory
Amir Roth - BEM Program Technology Manager, DOE Building Technologies Office
Greg Thomas - Chief Strategy and Technology Officer, Performance Systems Development

Energy Efficiency Incentive Program Interviews

Francis Boucher - Energy Efficiency Program Manager, National Grid
Kimberly Cullinane - New Construction Energy Efficiency Supervisor, Eversource Energy
Aaron Esselink - Product Portfolio Manager, Xcel Energy
David Goldstein - Energy Co-Director, Natural Resources Defense Council
Jackie Goss - Senior Planning Engineer, Energy Trust of Oregon
Ben Heymer - Senior Manager, Slipstream
Rod Houdyshel - Senior Energy Engineer, San Diego Gas & Electric
Oliver Kesting - Commercial Sector Lead, Energy Trust of Oregon
Phil Keuhn - Principal, Carbon Free Buildings, Rocky Mountain Institute
Christopher Mahase - Multifamily Residential Senior Project Manager, NYSERDA
Jim Meyers - Director of Building Efficiency Project, Southwest Energy Efficiency Project
Brendan Owens - Principal, Black Vest Strategy
Kimberlie Schryer - Quality and Standards Program Manager, NYSERDA
Craig Simmons - Simulation Modeling Manager, Vermont Energy Investment Corporation
Cindy Strecker - Senior Engineering Manager, CLEAResult
John Stoops - Senior Principal Consultant, DNV KEMA Energy and Sustainability
Josh Talbert - Senior Energy Consultant, Vermont Energy Investment Corporation
Reddy Jagadish Tupakula - Senior Energy Engineer, National Grid
Ryan Willingham - Senior Energy Efficiency Consultant, Eversource Energy
John Zwick - Energy Efficiency Technical Services Manager, San Diego Gas & Electric

Commercial Energy Efficiency Codes Interviews

Van Baxter - Senior R&C Engineer, UT-Battelle and Oak Ridge National Laboratory
Susanna Hanson - Order Management Analyst, Trane
Roger Hedrick - Principal Engineer, NORESCO

Residential Energy Efficiency Codes Interviews

Jeremy Williams - Program Specialist, DOE Building Technologies Office
Ben Edwards - Senior Associate, Mathis Consulting Company
Victor “Rob” Salicido - Senior Building Energy Research Engineer, Pacific Northwest National Laboratory

Appendix B: List of Interview Questions

These interview questions were used as guides during conversations with energy efficiency codes and incentive programs experts.

Preliminary Scoping Interview Questions

A. Team CA's validation of PWS requirements and literature

  a. The PWS says that the DOE benefit-cost analysis model selects a few specific technology products, target use cases, and projects/activities for detailed analysis.
    i. By technology products and projects/activities we think of:
      1. EnergyPlus
      2. ASHRAE Standard 140 "Method of Test for Building Energy Simulation Computer Programs"
      3. DOE Commercial and Residential Prototype Building Model
      4. OpenStudio Software Development Kit
    ii. And by use cases we think of:
      1. energy efficiency codes
      2. prescriptive energy efficiency design and retrofit guides
      3. energy efficiency incentive programs
      4. energy-efficient products
      5. analytical tools, such as Roof Savings Calculator, RTU Comparison Calculator, and 179D Calculator
  b. Can you please validate our understanding of the technology products, use cases, and projects/activities?
  c. How would you describe ASHRAE 140 and its contributions to the overall BEM impact?
  d. Can you elaborate on how each BEM tool (EnergyPlus, OS-SDK, Commercial and Residential Prototype Building Models, and ASHRAE 140) applies to each use case? Are there tool(s) that support individual use case(s) more than others? For example, does EnergyPlus support codes more than prescriptive guides? How so?

B. Energy efficiency codes

  a. How do the BEM products help advance codes?
  b. Does the BEM program work with ASHRAE and the International Code Council (ICC) to develop changes to codes and standards? How so? Does the BEM program coordinate with the DOE's Building Codes Program on this?
  c. Has the codes upgrade process changed since the development of BEM products?
  d. Have BEM tools helped codes advance faster? Achieve more savings with each new code change (compared to code cycles before the introduction of BEM products)?
  e. Are there particular aspects of the code that BEM products are more important for improving?
  f. Do BEM tools affect the number of states that adopt building codes and adopt more advanced codes? What would statewide code adoption look like without BEM products? Would there be differences by residential or commercial codes?
  g. Are there states or regions of the country that have been impacted more by BEM products, in terms of code adoption?
  h. Does the BEM program work with, conduct outreach, or train any state agencies or advocacy groups involved in the code adoption process?

i. Do BEM products help with improving code compliance [some states, like CA and MA, have utility efficiency programs that claim savings for improving code compliance]? Exceeding codes?
j. Does the BEM program work with, conduct outreach, or train any codes program administrators?

C. Energy efficiency incentive programs.

We would like to focus on utility sponsored programs, such as Energy Upgrade California or MassSave (Massachusetts) [These are programs funded through utility rates and statewide public benefits charges and administered by electric and natural gas utilities and other independent statewide program administrators.]

a. How are the BEM products used by utility incentive programs like Energy Upgrade California or MassSave? Are there particular products that are more widely used?
b. Does the BEM program work with, conduct outreach, or train any program administrators? Or regional energy efficiency groups such as NEEP or SEEA? How about private program implementers, like PSD, CLEAResult, or ICF?
c. When it comes to the incentive program, we plan to focus on the utility/public benefits programs. What do you think?
    i. https://www.energyupgradeca.org/home-energy-efficiency/upgrading-your-home/
    ii. https://www.masssave.com/
d. Are there particular sectors (i.e., residential, commercial, industrial, educational) or types of programs that use BEM products more than others?
e. What would be the effect on these programs if there were no BEM products? Would they develop similar tools on their own? Would the absence of BEM products affect participation? Energy savings?
f. Do BEM products help programs realize more savings per project? More projects? Savings outside of incentivized projects? How?

D. Energy-efficient products

a. What energy efficiency products use BEM tools?
b. How are the BEM tools used in these products?
c. Do private energy service companies (ESCOs) use the BEM tools? Does the BEM program work with, conduct outreach, or train ESCOs?
    i. https://www.energy.gov/eere/femp/energy-service-companies-0
    ii. https://www.naesco.org/what-is-an-esco
d. Do the products result in energy savings that are not accounted for by incentive programs or codes programs?

E. Energy efficiency design and retrofit guides

a. How are BEM products used in designing energy efficiency design and retrofit guides?
b. What are some examples of energy efficiency design and retrofit guides? Who develops these guides? Do these result in energy savings that are not accounted for by incentive programs or codes programs?
c. How would these guides be developed in the absence of BEM products?

F. Logic model

a. We will share the draft logic model for your feedback.

G. Data sources

a. We plan to use data from PNNL reports on savings from codes (the codes use case) and from ACEEE state scorecards on savings from utility-sector energy efficiency programs (the energy efficiency programs use case). Do you have any suggestions for other secondary data that may be useful and relevant?
   i. https://www.energycodes.gov/technical-assistance/publications?f%5B0%5D=field_document_tyoe%3A32

H. Wrap-up

a. Are there other ways we have not discussed that the BEM products affect the use cases and result in energy savings?
b. Is there anything else you would like to add/discuss?

Energy Efficiency Codes Interview Questions

Code Development Overview and BEM Influence:

A. I understand that you have participated in the development and approval of <CODE ITERATIONS>. Can you describe a little bit about the overall process of developing a new code iteration?
   a. What are the key factors that influence the code development process?
   b. Do these factors differ by building technology? For example, lighting, envelope, and HVAC technologies?
   c. Do you remember any technical or non-technical factors influencing <CODE ITERATION> specifically?

B. Do DOE-funded BEM tools like EnergyPlus, OpenStudio, Prototype buildings, or AEDG play a role in the code development process?
   a. Are there other energy modeling tools used to inform the code development process?
   b. What about before the development of EnergyPlus and other DOE tools? Were there other energy modeling tools used?
      i. What are the advantages of EnergyPlus compared to other modeling tools?

C. How do BEM tools impact the development of new code proposals and individual code updates?
   a. Are BEM tools used to vet the expected and/or actual energy savings associated with new code proposals or existing code iterations?
   b. What would happen to the code development update process in the absence of EnergyPlus and other DOE sponsored building energy modeling tools?
      i. What makes DOE-funded BEM tools so critical to this process? How would the energy savings be different without EnergyPlus?
   c. Are you aware of other applications of building energy modeling tools that support code development?

Rival Factors and Counterfactual:

D. What tools or resources other than BEM tools contribute to the code development and update process?
   a. How do these factors affect the code development and update process?
   b. Has the relationship between different tools that support the code update process changed over time? Did these rival factors become more or less influential with individual code updates?
E. [IF NOT ALREADY MENTIONED] Our research indicates that the following factors also play a role in the code development process. Do these other factors play a role in the code update process in your experience?

  a. Code compliance tools such as COMcheck, REScheck, and TSPR
  b. EQuest Quick Energy Simulation Tool
  c. Building Rating Systems or Home Energy Rating Systems (HERs)
  d. Voluntary Programs such as LEED, ENERGY STAR, and Good Cents

Code Update Timeline and BEM Influence on Specific Measure Types:

F. What were the most impactful measure-level changes between code updates? What do you remember being the key updates for this code iteration? <IF NO ANSWER GIVEN: Reference literature review on the primary building measure types updated and nature of updates from literature review>
  a. Are BEM tools important to the development of these specific pieces of the code update?
  b. Which building measure types are more dependent on BEM than others?
G. Are you aware of how the use of BEM tools to support code development has changed over time for specific code iterations?
  a. Why have BEM tools become more or less influential on code development?
  b. [IF BEM TOOLS ARE INFLUENTIAL ON CODE DEVELOPMENT] What makes DOE-funded BEM tools more useful than other rival factors?
  c. [IF BEM TOOLS ARE NOT INFLUENTIAL ON CODE DEVELOPMENT] What barriers exist preventing groups like ASHRAE and IECC Standards Committees from using BEM tools to support their work?
H. Our team is developing a timeline of code updates and a database of code changes by building technology category and adoption by individual states to inform our energy savings calculations:
  a. Do you have any data or resources that describe how BEM tools supported the code development process that you would be willing to share?
  b. Do you have any resources that describe how non-BEM rival factors influence the code development process?
  c. Do you have any reports that detail the energy savings associated with different code iterations that may have been supported by DOE-funded BEM tools?
  d. Do you have any resources that describe code changes by year or building technology category?

Closing:

I. Do you have any understanding of how energy efficiency program administrators (e.g., utilities and regional associations) may leverage BEM tools to support the development and design of energy efficiency programs?
J. Do you have any recommendations for additional people or organizations to contact for this study that are knowledgeable of the code development process, history, and purpose/role of BEM tools in supporting new code iterations?
  a. If so, would you be willing to share their contact information?
K. Would you be willing to engage in future data collection efforts for this study?

Energy Efficiency Incentive Programs Interview Questions

Program Background/BEM Influence on Program Development

A. It seems like you have participated in the development and implementation of <INCENTIVE PROGRAM>. Can you tell me more about the program design process, particularly how ECMs are chosen and how incentive levels are set?
  a. <Optional opening question> From a program-level perspective, what was/were the main driver(s) for your <INCENTIVE PROGRAM>?

            i. Federal law, Executive Order, and/or Agency Policy; or
            ii. Congressional budget/lobbying efforts; or
            iii. Technology-driven (e.g., industry adoption of LED lights or development of new motor technologies-VSD/VFDs)
    b. What motivates an energy efficiency Program Administrator to study and approve new ECMs for inclusion in their program(s)?
        i. How do your energy efficiency program(s) evaluate whether ECMs are generating the intended energy savings and demonstrating cost-effectiveness?
        ii. How does an ECM's GHG reduction vs. cost-savings inform the energy efficiency Program Administrator's decision to include in their program? In general, which factor has a higher weight?
    c. Does this differ for whole-building programs vs. programs that focus on specific technologies (such as non-residential lighting programs or non-residential HVAC programs)?
    d. What are the key technical and non-technical factors that influence the energy efficiency incentive program development process in general?
    e. Do you remember any technical or non-technical factors influencing changes to the <SPECIFIC ECMs applicable to this PROGRAM identified in literature review> specifically during your time at <PROGRAM>?

B. How does the availability of BEM tools contribute to your program's development and effectiveness?
    a. Do BEM tools support:
        i. Analyzing proposed performance requirements when new/existing ECMs are considered?
        ii. Vetting of expected energy savings associated with the identification of new or refinement of existing ECMs?
        iii. Analysis of estimated or actual energy savings resulting from new/existing ECMs?
        iv. Promotion of monetary incentives or ECM cost effectiveness to drive greater adoption of new/existing ECMs?
        v. Are you aware of other applications of building energy modeling tools that support energy efficiency program development?
    b. How might the design of your program(s) differ if the BEM tools detailed above were not available?
        i. What alternative methods would you have considered to inform your program design process?
        ii. How would the energy efficiency program landscape more generally be affected by the absence of these BEM resources?
    c. Do you think it would have been feasible to evaluate the performance, adoption, and cost effectiveness of your program's ECMs without building energy modeling tools?
        i. If yes, what is the best alternative to BEM tools?
        ii. If no, what makes BEM tools so critical to this process?
    d. What would happen to prescriptive/prototypical building programs, energy efficiency programs, and your program specifically, without BEM tools?

C. We have heard that the following key factors (called "Rival Factors" by our evaluation team) also play a role in the energy efficiency program development process. What rival factors besides BEM tools guide program design?
    a. [If not already mentioned] How have you seen the following factors influence program activities you have participated in?
        i. Cost
        ii. Changes to statutory requirements
        iii. Program participation
    b. How has the role or influence of each rival factor changed over time? Did these rival factors become more or less influential with specific updates to your program?

D. We see that <PROGRAM> has changed in the following ways since XX <HIGH-LEVEL OBSERVATIONS FROM LITERATURE REVIEW>. What do you remember driving the key program updates during this time?
    a. How do building energy modeling tools support these types of updates?
    b. Are building energy modeling tools more or less impactful when analyzing certain ECMs or types of programs?
E. In your experience, how has the use of BEM tools like EnergyPlus, OpenStudio, Prototypical Buildings, and/or AEDGs to support the design of prescriptive programs changed over time?
    a. Have BEM tools become more or less influential on your program? If so, why?
    b. [IF BEM TOOLS ARE INFLUENTIAL ON ENERGY EFFICIENCY PROGRAM DEVELOPMENT] What distinguishes the utility of BEM tools when compared to other rival factors?
    c. [IF BEM TOOLS ARE NOT INFLUENTIAL ON ENERGY EFFICIENCY PROGRAM DEVELOPMENT] What barriers prevent ENERGY EFFICIENCY incentive and utility programs from using BEM tools to support their work to a greater degree?
F. Do you expect <PROGRAM> to leverage BEM tools to inform future requirements, ECMs, or other program elements?

AEDGs/Knowledge Impact Analysis:

G. Are you familiar with prescriptive design guides, like AEDGs, that include details on the types of measures and practices that can be used to create more efficient buildings?
H. Has <PROGRAM> used DOE-funded energy design/retrofit guides such as ASHRAE 30/60/90/Zero Energy AEDGs to support program development, implementation, or monitoring in the past?
    a. If yes, what guides and when? How were these guides used and to what extent?
    b. If no, why not?
        i. What alternative resources did <PROGRAM> use to design, implement, and promote new requirements, ECMs, or energy efficiency best practices?
I. Are you aware of other energy efficiency program administrators that may have used the AEDGs to develop a prescriptive path for a new construction program? (We have seen that Efficiency Vermont may have done so in the past, and that XCEL Energy "developed a quasi-prescriptive program for school and office.)[45]
    a. For programs that used these guides in the past, do you know roughly what time periods the programs using the AEDGs were active?
    b. Are you aware of any programs that have adopted certain prescriptive requirements of DOE-funded AEDGs?
    c. [If no programs are mentioned] Why do you think programs that have stopped using the AEDGs to inform their program requirements have done so?

Meta-Analysis (recommendations for programs to consider, secondary data to review)

J. Our team is conducting research into past evaluations of energy efficiency programs using DOE-funded BEM tools.
    a. Do you know of any reports that detail the energy savings associated with different iterations of your program that you are willing to share?
    b. Do you have any data or resources that describe how BEM tools supported the energy efficiency incentive program development process that you would be willing to share?

[45] In late March 2014, sets of measures corresponding to energy efficiency strategies as recommended by the 50% AEDGs for K-12 and offices were added to the Building Component Library (BCL). Xcel Energy intends to use these measures in a "quasi-prescriptive" fashion for school and office EDA projects [early design assistance, aka new construction].

   c. Could you recommend other utility or state programs that may have used DOE-funded BEM tools that our team can research further?

K. Do you have any recommendations for additional people or organizations to contact for this study that are knowledgeable of the energy efficiency incentive program development process, and role of BEM tools in supporting them?
   a. If so, would you be willing to share their contact information, or refer us to them?

L. Would you be willing to engage in future data collection efforts for this study?

Appendix C: Evidence Packet for ASHRAE 90.1 Code Change Development Process

Introduction

Thank you for agreeing to participate in this Delphi Panel exploring the factors that influenced the development of ASHRAE 90.1 code updates since 2007. We appreciate your time and contributions to this study. You have been selected to participate in this panel because of your expertise and knowledge of the ASHRAE 90.1 code change process. You are encouraged to note any comments or questions while reviewing the evidence packet and the accompanying survey will provide an opportunity at the end to provide feedback. Thank you for your participation.

Rationale for Conducting a Delphi Panel

From time-to-time the U.S. Department of Energy (DOE) engages independent evaluators to help them assess the impact of past R&D investments and activities. Corner Alliance, Inc. was engaged to evaluate the Building Technologies Office's Building Energy Modeling (BEM) program. The Delphi method employed here will leverage the expertise of a group of individuals involved in the development of ASHRAE 90.1 codes to develop a consensus on factors that influenced code development and the likely counterfactual results if DOE had not invested in BEM tool development. In short, the Delphi method is a series of sequential questionnaires (or 'rounds') interspersed by group feedback that seeks to gain the most reliable consensus of opinion from a panel of experts. Panelists will be asked to reflect on their experiences in ASHRAE committees and teams and to identify the factors that influenced decisions in designing ASHRAE code changes.

The intended findings from the Delphi panel include:

1. De-identified demographic information and experience of panelists
2. Consensus on the primary factors that influenced ASHRAE 90.1 code development
3. Consensus on potential impacts of alternative tools and approaches if DOE-funded BEM tools were not developed
4. Point estimates of DOE-funded BEM tools contribution to code development
5. Point estimates of the change in energy efficiency to codes if DOE-funded BEM tools were not developed by code iteration

Introduction to Building Energy Modeling

BEM is a physics-based software simulation of building energy use given a description of the building's physical assets (envelope, lighting systems, HVAC systems, water-heating systems), its operations (occupancy schedules, thermostat set points, lighting and plug-load schedules), and surrounding weather conditions. BEM is used to support a variety of use cases; this evaluation focuses on "prototypical" uses. Prototypical building models represent an entire class of buildings, e.g., offices, standalone retail stores, or schools, rather than any specific building and are used to analyze an entire building stock. Prototypical BEM use cases include development of energy efficiency codes, guidelines, and incentive programs, and the development of energy efficiency products. Prototypical use cases stand in contrast to "specific" use cases that look at individual specific existing or planned buildings and include new construction and retrofit design, performance calculations for code compliance, ratings, and energy efficiency incentives. DOE's Building Technologies Office (BTO) chose to focus on prototypical use cases because they are fewer, better defined, have smaller and more easily identifiable practitioner communities, and several—including both energy efficiency codes and utility programs—have been independently evaluated for energy savings. This last point further narrows the scope of this evaluation by allowing it to focus on the contribution of BEM—and specifically, BTO's BEM investments—to these use cases rather than additionally evaluating the use cases themselves.

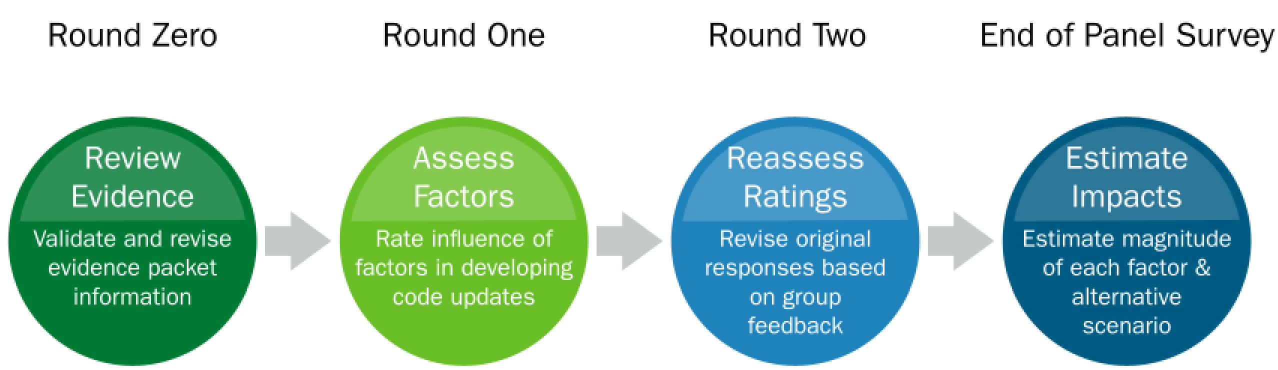
This part of the evaluation focuses on the energy efficiency code development use case and specifically on the ASHRAE Standard 90.1 "Energy Standard for Buildings Except Low Rise Residential Buildings" model code for commercial buildings. Various updates of this code are adopted in most states and the way in which BEM is used in its development is known. Other energy efficiency codes include California's Title 24 and the International Code Council's (ICC) International Energy Conservation Code (IECC). The former is similar to 90.1 in process but is used only in California. The latter has a different development process and is not heavily used for commercial buildings in the U.S.

To advance BEM use cases, BTO has supported efforts to improve the capabilities, accuracy, speed, and usability of BEM. It has done this by supporting BEM research and by developing open-source BEM software that embodies this research. The three BTO BEM products whose contributions are being evaluated here are:

- The EnergyPlus open-source BEM engine. EnergyPlus includes detailed physics-based models that can accurately simulate advanced envelopes, shading and daylighting, high-performance HVAC, refrigeration and water heating systems, and controls.
- ASHRAE Standard 140 "Standard Method of Test for BEM Computer Programs." A set of analytical and comparative tests for BEM engines along with reference results from multiple engines that promote increased and convergent accuracy in BEM engines and increase confidence in BEM.
- The commercial prototype building models. A set of models representing 16 commercial building types across 19 climate zones.

Delphi Method & Your Participation

The Delphi method is a research technique used to identify consensus on the opinions of experts. For this study, questions will be divided into three rounds. The graphic below outlines the overall process.



Round 0 will introduce evidence on factors that influenced code development and alternative scenarios if BEM tools had not been funded and asks panelists to validate the information and add any missing factors/scenarios. Round 0 will ask panelists to indicate their agreement with a series of statements about factors that influenced code development using Likert scale responses (e.g., 1 - Totally Disagree and 9 - Totally Agree) and describe their rationale for each rating in a short, written response (1–3 sentences). Round 2 will ask panelists to compare their Round 1 ratings and rationales with the aggregated results of other panelists. Panelists will review the group's ratings and various rationales for those ratings. Then, panelists will be given the opportunity to adjust their ratings and provide a rationale for any adjustments to their answers for the same questions asked in Round 1.

The panel will conclude with an End of Panel Survey. This survey will ask panelists to provide specific percentage point estimates (i.e., individual percentages that add up to 100%) for the impact of DOE-funded BEM activities and each factor identified on the development of ASHRAE 90.1 code changes. In addition, panelists will be asked to provide specific percentage point estimates on how energy efficiency would change (increase or decrease) in each alternative scenario presented if BEM tools were not developed (e.g., -10% or +5%).

Evidence Packet Structure

The Evidence Packet is divided into three main sections: Section 1 covers the ASHRAE 90.1 Development Process and Factors; Section 2 is the Summary of Major ASHRAE Code Changes; and Section 3 is Alternatives Without DOE-funded BEM Tools.

Under the development process and factor section, the packet proposes a list of factors that may have influenced ASHRAE 90.1 code updates. In the code change summary section, the packet details the number of code changes over time for a set of broad technology categories. The alternative to BEM tools section presents scenarios that may have happened in the absence of BEM tools.

ASHRAE 90.1 Development Process and Factors

Overview of ASHRAE 90.1 Code Update Process

ASHRAE Standard 90.1 advances by the continuous accretion of addenda. At regular three-year intervals, all addenda accrued in the previous three years are aggregated to define a new version of the standard. The most recent version of the Standard is the 2019 version, and the next version will be published in 2022.

Factors Influencing Development

DOE BTO's BEM investments and tools are only one contributor to the development of ASHRAE Standard 90.1. This panel aims to identify and differentiate the relative importance of various factors which influenced the development of ASHRAE 90.1. ASHRAE internal committee members who develop and approve code changes, as well as the external experts and stakeholders whose suggestions they may incorporate, make their decisions by leveraging various factors. Table C-1 lists the factors currently identified through research and discussion with relevant stakeholders that are believed to play a role in justifying ASHRAE 90.1 code changes. Together, all of the factors are intended to represent the total set of influences upon code development. In Round 0 of the panel, you will have an opportunity to validate this list, clarify the definitions of factors, and identify any missing factors based on your experience.

Table C-1. All Factors Influencing Development of ASHRAE 90.1

Factor	Definition	Example of Impact on Code Development	Relationship to DOE-Funded BEM Tools
DOE-Funded BEM Tools	ASHRAE leverages DOE-funded BEM tools to evaluate the cost and energy impacts of potential code updates	Analysis based on DOE-funded BEM prototypical buildings justifies requirements for the use of HVAC economizers in certain climates (90.1-2007, Addenda cy, co, dd, de, df)	N/A (this factor is the research subject)
Utility and Voluntary Program Specifications	ASHRAE updated the code by incorporating an above-code requirement	PG&E's Daylighting Initiative resources were used to justify the lighting control factors for different spaces in code (90.1-	Utility and voluntary programs sometimes use BEM as one of several tools to develop requirements

	developed by a utility program or a voluntary program like LEED or Energy Star	2007, Addendum ac); High-rise lighting requirements updates are justified by their similarity to ENERGY STAR (90.1-2013, Addendum do)	
Industry Standards	ASHRAE leverages other standards it developed or from other standards organizations (Cool Roof Rating Council, AHRI, ASTM, etc.)	ASTM standards E779 and 1827 are incorporated into the code as verification tools for determining compliance with air leakage control requirements (90.1-2013, Addendum l)	Standards bodies and voluntary programs sometimes use BEM to develop requirements and report compliance or verification of savings
Expert Opinion and External Stakeholders	ASHRAE approved a code update due to its recommendation by a stakeholder and/or subject matter expert (whether a committee member, third-party consultant, or an external organization), based on their own expertise and analysis, as well as market trends and interests	Skylighting requirements are added for certain space types, based on proposal by energy efficiency consultants at Heschong Mahone Group, Inc. (90.1-2007, Addendum al); Elevator working group (including industry members and the National Elevator Industry, Inc. trade association) develop a standard for elevator efficiency within the code (90.1-2013, Addendum de)	Subject matter experts use a variety of tools (including DOE-funded BEM tools on occasion) in their analyses; the external groups generally utilize standard engineering calculations and proprietary tools instead of BEM, with the potential exception of organizations representing builders or those interested in building-level impacts
New Federal or State Law	New law requires or justifies a code update	Baseline commercial refrigeration limits are based on California Energy Commission's Appliance Efficiency Regulations (90.1-2013, Addendum ek)	These laws are generally not based on BEM of any kind, as they usually relate to specific appliances rather than the whole building
Other DOE Program Guidance and Policy	ASHRAE relied upon resources from a non-BEM program within DOE (such as the Commercial Buildings Integration program) to develop or justify a code update	DOE statistics on the cost-effectiveness and efficiency of low voltage dry-type transformers were included in the code to help inform transformer specification and verification (90.1-2007, Addenda d, o, x, aa, ab, ae, at, au, ba)	Some of these DOE programs are based on DOE-funded BEM tools (like the Advanced Energy Design Guides)

<u>DOE-Funded BEM Tools</u>

ASHRAE and its technical assistance subcontractors, primarily the Pacific Northwest National Lab (PNNL) use prototypical BEM in two ways during the code development process. First, prototypical BEM is used to evaluate the cost-effectiveness (i.e., projected energy savings over capital cost) of proposed addenda. An addendum must pass a cost-effectiveness test in order to be accepted into the Standard. Second, for published versions of the standard (e.g., 2019 version), prototypical BEM is used to conduct a state-by-state level "determination" of the projected cost and energy-savings impact of adopting the new Standard relative to the previous version. Other factors influencing ASHRAE 90.1 development (listed below) may use BEM to add, modify, remove, justify and/or analyze changes to code. For the purposes of this panel, we ask participants to consider all the ways BEM is used as part of this factor—DOE-funded BEM Tools. For example, Utility and Voluntary programs such as LEED or EnergyStar may use DOE-funded BEM tools to design and monitor program requirements. Industry standards bodies such as IECC, AHRI, and others may use BEM to develop requirements and report compliance or verification of savings. Lastly, other DOE program guidance and policies that influence ASHRAE 90.1 development, such as the Advanced Energy Design Guides, are supported by BEM calculations and analysis.

Utility and Voluntary Program Specifications

ASHRAE committee members, and the experts that provide advice, may also use program specifications from state utility programs and voluntary national energy efficiency programs such as LEED or Energy Star. Program specifications can be used to justify changes in 90.1; for example, PG&E's Daylighting Initiative resources were used to justify the lighting control factors for different spaces in the 2007 90.1 update (Addendum ac). In addition, high-rise lighting requirements updates were justified using ENERGY STAR specifications in the 2013 update (Addendum do). As another example, committee members recommended that unmet load hour definitions specifying thermostat throttling range be updated in the ASHRAE 2007 update (Addenda cr, cs, cw, cz da, dc) to match LEED program specifications based on LEED's reported energy and cost savings from this requirement. DOE-funded BEM tools are sometimes used to develop the initial utility and voluntary program specifications that ASHRAE then leverages for 90.1 updates.

Industry Standards

ASHRAE code proponents and/or committee members may leverage or adapt building code specifications developed from other standards organizations to modify or clarify 90.1 requirements for emerging building technologies. For example, the Cooling Technology Institute adopted a certification standard that covers closed circuit cooling towers prior to the release of ASHRAE 90.1 2007. ASHRAE adopted this closed circuit cooling tower certification standard into 90.1 (Addenda a, b, c, g, h, i, j, k, l, m, n, p, q, s, t, u, w, y, ad, and aw) to specify different performance requirements for different fluid coolers and resolve confusion on how engineers should apply previous specifications to different cooling technologies. In addition, AHRI developed Standard 920 (I-P) to establish common rating conditions for dedicated outdoor air systems (DOAS). Despite DOAS technologies being used by commercial buildings as early as 1990, ASHRAE 90.1 had no minimum energy efficiency requirements for this equipment until they adopted AHRI's standard in 2013 (Addendum cd). Other standards bodies such as the Cool Roof Rating Council, ASTM, and other ASHRAE subcommittees may develop efficiency requirements for specific classes of new products or building equipment that ASHRAE 90.1 formally recognizes as 90.1 addenda.

Expert Opinion and External Stakeholders

ASHRAE 90.1 project committees consist of a diverse set of stakeholders that may recommend code updates based on expert opinion on a specific building technology or to promote technologies of interest to their field of study or organization. Previous evaluation interviews indicated that external stakeholders across a given building technology industry such as HVAC, envelope, lighting, or appliances may collectively negotiate changes to 90.1 through proposals and counter proposals that reflect the current energy efficiency levels and consumer demand for their products. Stakeholder interviews showed that private companies and trade associations advocating for changes to ASHRAE 90.1 predominantly utilize standard engineering calculations and their own proprietary modeling tools instead of DOE-funded BEM to analyze the energy efficiency and cost impacts of proposed code changes.

New Federal or State Law

ASHRAE participants may also propose or modify 90.1 requirements to accommodate current or future Federal and state law. For example, a code proponent proposed updates to 90.1 motor efficiency standards during 2013 committee hearings in anticipation of a new federal law going into effect in 2016 (Addendum cv). ASHRAE referenced California Title 24 and the International Energy Conservation Code requirement for air-cooled direct-expansion cooling units with economizers to have basic fault detection and diagnostic (FDD) systems in the 2013 release (Addendum el). ASHRAE also established baseline commercial refrigeration limits and prescribed minimum efficiency requirements for refrigerators and freezers to mirror California Energy Commission Appliance regulations in the 2013 release (Addendum ek). These laws are generally not based on BEM, as they usually relate to specific appliances rather than the whole building.

Other DOE Program Guidance and Policy

ASHRAE code proponents, committee members, and evaluators also rely on non-BEM DOE datasets and other resources to justify code updates. For example, data from the 2012 updates of DOE's Commercial Building Energy Consumption Survey indicated that baseline data illustrating consumer choices between gas or electric water heaters needed to be reexamined. DOE statistics on the cost-effectiveness and efficiency of low voltage dry-type transformers helped update transformer specifications added to 90.1 in 2007 (Addenda d, o, x, aa, ab, ae, at, au, ba).

Summary of Major ASHRAE Code Changes

ASHRAE 90.1 includes six broad technology categories under which the addenda for each code iteration are grouped. These categories are sections five through ten in ASHRAE 90.1 and include Building Envelope, HVAC, Service Hot Water, Power, Lighting, and Other Equipment. Table C-2 describes the number of code changes over time for each of these broad technology categories. For this study, addenda for each ASHRAE 90.1 iteration from 2007 to 2019 are only considered if they were included in PNNL's quantitative analyses measuring their impact on energy use and thus modeled on prototypical buildings. In most cases, the codes signify a positive impact on energy efficiency reflecting the change to a higher level of performance. Additionally, the data contained in this packet are relative to the building technology categories and thus questions will be related to BEM contribution by technology category rather than changes to BEM's functionality and its impact on code changes over the same time period. Major code changes for each technology category are summarized in the following section.

Table C-2. Addenda included in the quantitative analysis for each ASHRAE 90.1 iteration from 2007 to 2019 by technology category.

Year	Total Included in Quantitative Analysis	Building Envelope	HVAC	Service Hot Water	Power	Lighting	Other Equipment
2007	9	3	5	0	0	1	0
2010	34	7	16	0	2	9	0
2013	30	3	18	0	1	8	0
2016	21	5	9	1	0	6	0
2019	17	1	13	0	0	3	0

Technology Category Descriptions

The following subsections are the summary of the code changes separated by technology category. The following section should be referenced when answering Round 1 and Round 2 questions.

Section 5 – Building Envelope

Section 5 in ASHRAE Standard 90.1 details building envelope requirements, including minimum wall and roof insulation, roof albedo, and minimum performance of glazing. Many of the major updates to Section 5 – Building Envelope target opaque assembly requirements and fenestration requirements. A 2010 addendum set requirements for high-albedo roofs. In 2016, changes were made to some climate zone assignments and climate zone 0 was created. This change also impacts Section 6, HVAC. Since 2007, 19 addenda impacting Section 5 – Building Envelope have been included in the quantitative analysis for ASHRAE 90.1 iterations, including seven major changes highlighted in Table C-3.

Table C-3. Major Building Envelope code changes included in the quantitative analysis for each ASHRAE 90.1 iteration from 2007 to 2019.

Code Iteration	Addendum	Description of Changes
2007	as	Modifies the opaque assembly requirements in Tables 5.5-1 - 5.5-8.
2007	at	Modifies the fenestration requirements in Tables 5.5-1 - 5.5-8.
2010	f	This addendum sets requirements for high-albedo roofs.
2010	al	Adds skylight requirements in certain space types to promote daylighting energy savings.
2013	bb	Comprehensive envelope upgrade: Modifies the building envelope requirements for opaque assemblies and fenestration in tables 5.5.1 through 5.5.8. Adds and modifies text in Section 5. Adds new visible transmittance (VT) requirement through Section 5.5.4.5. Also updates the NFRC 301 reference, references in Section 11 and modifies two metal building roof assemblies in Table A2.3.
2016	w	Refers 90.1 to new climatic data based on Standard 169-2013 resulting in changes to climate zone assignments for some locations, the creation of a new climate zone 0, and the addition of criteria for climate zone 0. Adds method for rating the solar reflectance index of walls with glass spandrel area and adjusts criteria for minimum skylight area in climate zone 0.
2016	ai	Prescribes lower solar heat gain coefficient (SHGC) for vertical fenestration in climate zone 0 and lower U-factors for vertical fenestration in climate zones 4 through 8.

Section 6 – Heating, Ventilation, and Air-Conditioning

Section 6 in ASHRAE Standard 90.1 details heating, ventilation, and air-conditioning requirements, including minimum equipment features and efficiency, and limitations on reheat and fan power. Refrigeration is included in Section 6 for the 2019 iteration of ASHRAE Standard 90.1. Many of the major updates to Section 6 – HVAC target fan and ventilation controls, refines thresholds for energy recovery, and sets requirements for boilers and chillers. More code changes have been introduced and quantified for Section 6 – HVAC than for any other ASHRAE 90.1 technology category. Since 2007, 61 addenda impacting Section 6 – HVAC have been included in the quantitative analysis for ASHRAE 90.1 iterations, including 25 major changes highlighted in Table C-4.

Table C-4. Major HVAC code changes included in the quantitative analysis for each ASHRAE 90.1 iteration from 2007 to 2019.

Code Iteration	Addendum	Description of Change

2007	q	Removes Exception (a) to Section 6.4.3.2 for HVAC systems serving hotel/motel rooms and guest rooms.
2007	v	Modifies the provisions of Section 6.4.3.8 to allow for demand control ventilation.
2007	ac	Strengthens stringency in fan power limitations for simple systems with an easy-to-use format/structure. Expands application coverage to properly address complex exhaust fan systems associated with hospitals and laboratories. Improves compliance consistency by changing the fan power limitation structure based on a continuous curve and eliminates the nominal motor hp steps. Adds definitions for fan brake horsepower, fan system design conditions, fan system bhp, fan system motor nameplate hp, and nameplate horsepower.
2007	an	Modifies equipment efficiency requirements for commercial boilers in Table 6.8.1F.
2010	e	This addendum modifies the requirements for energy recovery by expanding them to cover the use of energy recovery by weather zone.
2010	m	This addendum establishes effective January 1, 2010, an additional path of compliance for water-cooled chillers and also combines all water-cooled positive displacement chillers into one category and adds a new size category for centrifugal chillers at or above 600 tons
2010	n	This addendum extends variable air volume fan control requirements to large single-zone units.
2010	ap	Modifies the requirements for demand control ventilation (DCV).
2010	bh	Provides requirements for multiple-zone HVAC systems (that include simultaneous heating and cooling) to include controls that automatically raise the supply-air temperature when the spaces served are not at peak load conditions
2010	cb	This addendum includes a number of changes to require simple systems to meet prescriptive outdoor air damper requirements, allow backdraft dampers only for exhaust and relief dampers in buildings less than three stories in height, require backdraft dampers on outdoor air intakes to be protected from wind, and limit windblown infiltration through the damper
2010	cy	This addendum makes several revisions to the economizer requirements in Section 6.5.1 and in Section 6.3.2. With increased envelope insulation levels and higher internal plug loads we are seeing commercial buildings operating in cooling at lower ambient temperatures. This allows for greater air and water economizers to be used instead of mechanical cooling.
2013	am	Boiler turndown requirements: Establishes minimum turndown for boilers and boiler plants of at least 1,000,000 Btu/h.
2013	aq	Fan control and DX staging: This addendum makes changes to the requirements for fan control for both constant volume and VAV units including extending the fan part load power requirements down to ¼ hp. In addition, it defines the requirements for integrated economizer control and defines direct expansion unit capacity staging requirements.

2016	bj	Establishes minimum chilled water coil selection delta T.
2016	ca	Reduces the threshold for variable flow heat rejection device fans from 7.5 to 5 hp. Eliminates the exception for climate zones 1 & 2.
2016	ce	Raises minimum threshold for energy recovery.
2016	cq	Bases variable speed thresholds for heat rejection fans on motor power, including service factor.
2016	dd	Reduces the threshold for variable flow pumping requirements for chilled water pumps; adds requirements for heating water pumps.
2016	j	Requires variable air volume system ventilation optimization even when energy recovery ventilator is installed.
2019	ap	Revises supply air temperature reset controls
2019	au	Eliminates the requirement that zones with direct digital control have air flow rates that are no more than 20% of the zone design peak flow rate.
2019	bd	Adds new chiller table for heat pump and heat recovery chillers.
2019	bq	Adds dry cooler efficiency requirements and slightly increases efficiency requirements for evaporative condensers.
2019	g	Provides definition of "occupied-standby mode" and adds new ventilation air requirements for zones served in occupied-standby mode.
2019	h	Clarifies that exhaust air ERVs should be sized to meet both heating and cooling design conditions unless one mode is not exempted by existing exceptions.

Section 7 – Service Hot Water

Section 7 in ASHRAE Standard 90.1 details service hot water requirements and includes minimum equipment features and efficiency. The only change to Section 7 – Service Hot Water came in 2016 with an addendum that requires insulation on the first eight feet of branch piping from recirculating service hot water systems as seen in Table C-5.

Table C-5. Major Service Hot Water code changes included in the quantitative analysis for each ASHRAE 90.1 iteration from 2007 to 2019.

Code Iteration	Addendum	Description of Change
2016	by	Requires insulation of the first 8 ft of branch piping from recirculating SWH systems.

Section 8 – Power

Section 8 in ASHRAE Standard 90.1 details power requirements around transformer efficiency, automatic receptacle controls, and energy monitoring. The only major change to Section 8 – Power came in 2010 with an addendum that modifies automatic receptacle control requirements and exemptions (see Table C-6). Only two other minor changes have been made to Section 8 – Power from 2007 to 2019, both of which also focus on receptacle control requirements.

Table C-6. Major Power code changes included in the quantitative analysis for each ASHRAE 90.1 iteration from 2007 to 2019.

Code Iteration	Addendum	Description of Change
2010	cs	Modifies automatic receptacle control requirements and exemptions to eliminate potential practical application issues.

Section 9 – Lighting

Section 9 in ASHRAE Standard 90.1 details lighting requirements, including maximum indoor lighting density, minimum lighting controls, and exterior and parking lighting. Many of the major updates to Section 9 – Lighting include reductions in lighting power density, increases in natural daylighting, and refinements to occupancy sensor applications. Since 2007, 27 addenda impacting Section 9 – Lighting have been included in the quantitative analysis for ASHRAE 90.1 iterations, including 12 major changes highlighted in Table C-7.

Table C-7. Major Lighting code changes included in the quantitative analysis for each ASHRAE 90.1 iteration from 2007 to 2019.

Code Iteration	Addendum	Description of Change
2010	d	This addendum modifies the daylighting requirements to allow the use of photocontrols combined with skylighting to reduce the electricity used for lighting.
2010	i	This addendum applies a four-zone lighting power density (LPD) approach to exterior lighting requirements.
2010	x	This revision updates the requirements for automatic lighting shutoffs, adds specific occupancy sensor applications, and provides additional clarification.
2010	ab	This change modifies skylighting and daylighting requirements from addendum “d” to 90.1-2007.
2010	by	Proposes new LPDs for both the whole building and space-by-space compliance methods. In addition, the Lighting Power Density may be re-calculated based on room geometry
2013	by	Requires the use of certain lighting controls in more space types. Reduces the amount of time after occupants vacate a space for lights to be automatically reduced or shut off. Establishes a table of lighting controls applicable to each space type.
2013	co	Comprehensive update of lighting power densities (LPDs) in Table 9.5.1 - Building Area Method
2016	ah	Clarifies that all lighting, including egress lighting on emergency circuits, shall be turned off when the space is unoccupied with 0.02 W/sf in exception.
2016	as	Requires luminaires in parking areas with input power greater than 78W and mounting height less than 24 ft to reduce power by 50% in response to occupancy.
2016	cg	Reduces exterior lighting power allowances.
2016	ch	Reduces interior lighting power allowances.

2019	bb	Changes interior LPD requirements for many space types.

Section 10 – Other Equipment

Section 10 in ASHRAE Standard 90.1 details other equipment requirements for electric motors, potable water booster pumps, elevators, and escalators. No changes to codes related to Section 10 – Other Equipment have been introduced and quantified in ASHRAE 90.1 iterations since 2007. Therefore, this section will not be included in the Delphi panel.

Alternatives Without DOE-Funded BEM Tools

While the above sections inform the evaluation of the role DOE-funded BEM tools and other factors had on the development of ASHRAE 90.1, this panel also needs to consider ***potential*** scenarios if DOE-funded BEM tools did not exist. Table C-8 below presents the postulated alternative scenarios which could have occurred. You will be asked for your estimate on the relative likelihood of these scenarios if DOE-funded BEM tools did not exist. During Round 0 of the panel, you will also be asked to identify any other alternative scenarios which you think could have happened and should be in the table. Table C-9 serves as a reference for Table C-8's alternative scenarios.

Table C-8. Alternative Scenarios

Alternative Scenario Name	Description
Independent Tool Development	New modeling tools equivalent to DOE-funded BEM tools would have been independently developed by the private sector, influencing the code in the same manner as DOE-funded BEM tools, and therefore the DOE-funded BEM tool-related code updates would have occurred anyway.
Alternative Tools Use	Code update committees would have used alternative tools such as DOE-2, Trane, and others outlined in the table below to develop and justify code updates. Without the same functionality of DOE-funded BEM tools, code updates would have less stringent/specific requirements, leading to changes in potential energy efficiency.
Energy-Related Updates Not Approved	Code updates that require energy modeling not available in other tools would not have been developed or approved. Therefore, ASHRAE 90.1 would have fewer code updates that impact energy savings.

Table C-9. Alternative Tools

Alternative Tool Use	Description
DOE-2	DOE-2 is a freeware building energy analysis program that can predict the energy use and cost for all types of buildings. DOE-2 uses a description of the building layout, constructions, operating schedules, conditioning systems (lighting, HVAC, etc.) and utility rates provided by the user, along with weather data, to perform an hourly simulation of the building and to estimate utility bills. DOE-2 was funded by DOE up until version DOE-2.1. Versions 2.2 and subsequent were funded by the California Public Utilities Commission (CPUC) and are therefore considered an "alternative tool".
CEC Simulation Engine (CSE)	A public domain, multi-zone, short-time step, detailed annual building simulation application developed to support the 2013 California Title 24 residential energy standards.

Carrier HAP	Proprietary HVAC software by Carrier which includes full-featured load calculation and system sizing for commercial buildings plus versatile hour-by-hour energy modeling.
Trane TRACE 700	Proprietary HVAC software by Trane which optimizes the design of a building's heating, ventilating and air-conditioning system based on energy utilization and life-cycle cost and built on the U.S. Department of Energy's EnergyPlus engine. The new version of TRACE (3D Plus) is based on EnergyPlus and would not make it an alternative tool.
IES Virtual Environment (VE)	A sub-hourly thermal simulation suite that can model new and existing buildings of varying sizes and complexity; it also allows cross-team collaboration from concept design to operation.
TRNSYS	A simulation program primarily used in the fields of renewable energy engineering and building simulation for passive as well as active solar design, developed at the University of Wisconsin.
ESPR	An open-sourced building performance energy modeling software that was created by the University of Strathclyde. It is primarily used in research, as a tool for consultants or as a teaching tool.
Standard engineering calculations	All other methods, including those not packaged within specific software tools, are used by analysts and engineers to perform building energy calculations at the level of DOE-funded BEM tools.

Appendix D: Delphi Panel Round Zero Summary Email

Thank you to all Panelists for completing Round 0 of the ASHRAE 90.1 Delphi Survey.

Prior to starting the Round 1 questions which will focus on developing a consensus among the panelists on the factors that influenced code development, the Round 0 responses will be summarized and presented with comments on how the feedback was incorporated into the survey. Since the number of panelists was limited to a small group, there is not a statistically relevant justification for including or excluding data. Where appropriate, feedback was used to add clarity to the descriptions of factors and scenarios.

The panel manager (PM) reviewed and captured all Round 0 input as appropriate and is summarized below.

Factors

Panelists suggested that one factor be removed. The rating questions in Round 1 will determine if the entire panel agrees that this factor should be removed. Panelists suggested potentially adding five additional factors. These suggestions helped the study team determine that greater clarification is needed to several factors. The evaluation team incorporated all suggested additions to the existing factor definitions. In addition, Panelists recommended clarifying several factor definitions and supporting examples. Those changes are highlighted in the revised Factors table.

Table D-1. Factors

Factor	Definition	Example of Impact on Code Development	Relationship to DOE-Funded BEM Tools
DOE-Funded BEM Tools	ASHRAE leverages DOE-funded BEM tools to evaluate the cost and energy impacts of potential code updates	Analysis based on DOE-funded BEM prototypical buildings justifies requirements for the use of HVAC economizers in certain climates (90.1-2007, Addenda cy, co, dd, de, df)	N/A (this factor is the research subject); Note: only EnergyPlus, ASHRAE Standard 140 and the commercial prototype building models are DOE-funded. Other tools like DOE-2 are not DOE-funded BEM products
Utility and Voluntary Program Specifications	ASHRAE updated the code by incorporating an above-code requirement developed by a utility program or a voluntary program like LEED or Energy Star as well as state stretch codes and ASHRAE 189.1	PG&E's Daylighting Initiative resources were used to justify the lighting control factors for different spaces in code (90.1-2007, Addendum ac); High-rise lighting requirements updates are justified by their similarity to ENERGY STAR (90.1-2013, Addendum do)	Utility and voluntary programs sometimes use BEM as one of several tools to develop requirements but cost-effectiveness is not a requirement for inclusion.

Industry Standards	ASHRAE leverages other standards it developed or from another standards organizations (Cool Roof Rating Council, AHRI, ASTM, etc.)	ASTM standards E779 and 1827 are incorporated into the code as verification tools for determining compliance with air leakage control requirements (90.1-2013, Addendum l)	Standards bodies and voluntary programs sometimes use BEM to develop requirements and report compliance or verification of savings
Expert Opinion and External Stakeholders	ASHRAE approved a code update due to its recommendation by a stakeholder and/or subject matter expert (whether a committee member, third-party consultant, or an external organization like NGOs), based on their own expertise and analysis, as well as market and manufacturer technology trends and interests	Skylighting requirements are added for certain space types, based on proposal by energy efficiency consultants at Heschong Mahone Group, Inc. (90.1-2007, Addendum al); Elevator working group (including industry members and the National Elevator Industry, Inc. trade association) develop a standard for elevator efficiency within the code (90.1-2013, Addendum de)	Subject matter experts use a variety of tools (including DOE-funded BEM tools on occasion) in their analyses; the external groups generally utilize standard engineering calculations and proprietary tools as well as the use of DOE-funded BEM in some cases, with the potential exception of organizations representing builders or those interested in building-level impacts
New Federal or State Law and Regulations	New law or regulations may require a code update when new information is available regarding an appliance or technology	Baseline commercial refrigeration limits are based on Energy Star; EPACT 2005 set standards for distribution transformers that were published in 90.1, and when DOE updated the efficiency requirements, the ASHRAE text and table were updated	These laws are generally not based on BEM of any kind, as they usually relate to specific appliances rather than the whole building
Other DOE Program Guidance and Policy	ASHRAE relied upon resources from a non-BEM program within DOE (such as the Commercial Buildings Integration program) to develop or justify a code update	DOE statistics on the cost-effectiveness and efficiency of low voltage dry-type transformers were included in the code to help inform transformer specification and verification (90.1-2007, Addenda d, o, x, aa, ab, ae, at, au, ba)	Some of these DOE programs are based on DOE-funded BEM tools (like the Advanced Energy Design Guides)

Alternative Scenarios

Panelists agreed that the three alternative scenarios provided in the evidence packet accurately represented the ways in which the ASHRAE 90.1 code may have evolved in the absence of DOE-funded BEM tools and that all three scenarios were distinct and should remain separate. Panelists recommended that the Industry Tool Use and Revision scenario be broadened to capture the presence of proprietary tools built in response to specific code proposals that would evaluate their cost-effectiveness in the absence of DOE-funded BEM tools. All changes to the alternative scenario descriptions used for the Round 1 instrument are highlighted in the table below:

Table D-2. Alternative Scenarios

Alternative Scenario Name	Description
Independent Tool Development	New modeling tools equivalent to DOE-funded BEM tools would have been independently developed by the private sector and/or ASHRAE committee members, influencing the code in the same manner as DOE-funded BEM tools, and therefore the DOE-funded BEM tool-related code updates would have occurred anyway.
Alternative Tools Use	Code update committees would have used alternative tools such as DOE-2, Trane, standard engineering calculations and others outlined in Evidence Packet Table 9 to develop and justify code updates. Without the same functionality of DOE-funded BEM tools, code updates could have less or more stringent/specific requirements, depending on the technology analyzed and the cost-effectiveness.
Energy-Related Updates Not Approved or Significantly Delayed	Code updates that require energy modeling not available in other tools may not have been developed or approved or faced significant delays in the approval process. Therefore, ASHRAE 90.1 would have fewer code updates that impact energy savings. In addition, BEM is not capable of modeling some of the approved code changes.

Appendix E: Delphi Panel Survey Instrument

ASHRAE 90.1 Delphi Panel Round 0

Introduction to ASHRAE 90.1 Code Change Development Process - Round 0

Greetings Panelist. Thank you for taking the time to complete this Round 0 survey.

Round 0 will ensure the data collection instrument fully captures all aspects of ASHRAE 90.1 code development to be rated by panelists in rounds 1-2. Panelists are asked to review the accompanying Evidence Packet and note any questions or comments. There will be a section at the end of the survey for capturing these notes.

Please review and accept the Consent to Participate on the next page.

Consent to Participate in Impact Evaluation of BEM Technology Study

Title of Research Study: Impact Evaluation of Building Energy Modeling Technology Research and Development Activities

Research Sponsor: Department of Energy Evaluation (DOE), Office of Energy Efficiency & Renewable Energy (EERE), Building Technologies Office (BTO)

Time Commitment: The time required is approximately 2-3 hours for each of the three surveys. Overall participation in the Delphi Study will take approximately 6-8 hours. The timeline for the Delphi Study will span a total of two months. Participants will be able to complete each survey at their leisure within the survey window period. Participants will not be required to be online at particular times and will provide responses asynchronously.

Participants' Rights: Your participation in this research study is entirely voluntary. If you decide not to participate, there will be no penalty to you, and you can decide to withdraw your consent and stop participating in the research at any time, without any penalty.

Payment for Participation: Delphi panelists will each be paid a $500 honorarium for their participation in panels unless your organization prohibits outside payments. Panelists will be paid at the conclusion of Round 2. Panelists who do not complete all rounds of the Delphi process will not be provided honoraria. Panelists are expected to provide "good faith responses" to each question in order to receive honorarium at the end of Round 2.

Consent to Participate: The informed consent form allows respondents to either consent to participate in the study or to not consent to participate in the study. If you click NO and choose not to participate in the study, you will be disqualified from continuing. If you click YES and consent to participate in the study, you will automatically continue to participate in the study.

1. Do you consent to participate in this research study? *

    Yes

    No

If you have selected "Yes", please continue to the next page.

If you do not consent to participate in this research study, thank you for your time.

Factors Influencing Development

Round 0 Questions

Introduction: Round 0 aims to expand on and clarify the factors and alternative scenarios described in the evidence packet. Panelists need to determine all factors that have influenced ASHRAE 90.1 code development. The factors listed in the table were developed through interviews with ASHRAE participants, reviewing ASHRAE code updates, and analyzing ASHRAE 90.1 committee minutes.

For the next series of questions, please reference Table 1 (Page 4 of accompanying Evidence Packet).

BTO's BEM investments and tools are only one contributor to the development of ASHRAE Standard 90.1. ASHRAE internal committee members who develop and approve code changes, as well as the external experts and stakeholders whose suggestions they may incorporate, make their decisions by leveraging various factors. Table 1 lists the factors currently identified through research and discussion with relevant stakeholders that are believed to play a role in justifying ASHRAE 90.1 code changes. Together, all of the factors are intended to represent the total set of influences upon code development. Below you will have an opportunity to validate this list, clarify the definitions of factors, and identify any missing factors based on your experience.

Panelists will indicate if the Factors described in Table 1 require modification, deletion, or addition of missing Factors.

2. Do any of the factors listed above fail to influence ASHRAE 90.1 code development and need to be removed from the table? *

Yes, one or more factors need to be removed.

No, all factors are relevant.

3. After reviewing Table 1, if a Factor is missing, please provide a name, a brief definition, its impact on code development, and any relationship to BEM tools if possible.

If the Factors list is complete, please proceed to the next question.

	Name	Definition	Impact	Relationship to DOE BEM
Additional Factor #1				
Additional Factor #2				

Comments

For each factor listed in Table 1 above, please indicate if any modifications are required to the Name, Definition, Impact, or Relationship to DOE-funded BEM.

4. DOE-funded BEM Tools *

Yes, modifications are needed

No, the descriptions are accurate

5. Utility and Voluntary Program Specifications *

Yes, modifications are needed

No, the descriptions are accurate

6. Industry Standards *

Yes, modifications are needed

No, the descriptions are accurate

7. Expert Opinions and External Stakeholders *

Yes, modifications are needed

No, the descriptions are accurate

8. New Federal or State Law *

Yes, modifications are needed

No, the descriptions are accurate

9. Other DOE Program Guidance and Policy *

Yes, modifications are needed

No, the descriptions are accurate

Modifications to Alternatives Without DOE-Funded BEM Tools

The following series of questions will address the potential role that other alternative factors could have played if DOE-funded BEM tools did not exist.

Alternative scenarios describe how ASHRAE 90.1 development would have changed if DOE-funded BEM tools were not available. Panelists are asked to validate, modify, or add to the following alternative scenarios for ASHRAE 90.1 development. While the previous questions evaluated the role DOE-funded BEM tools and other factors had on the development of ASHRAE 90.1, the next series of questions considers potential scenarios if DOE-funded BEM tools did not exist. Table 8 (Page 15 of accompanying Evidence Packet) presents the postulated alternative scenarios which could have occurred. Table 9 serves as a reference for Table 8's alternative scenarios. Please review the existing Alternative Scenarios table and identify any other alternative scenarios which you think could have happened and should be included in the table.

10. For the Alternative Scenarios, would it make more sense if the three scenarios were streamlined or condensed into a single scenario? If so, please describe how to best combine the scenarios.

11. After reviewing Table 8, if an Alternative Scenario is missing, please provide a name and a brief description if possible.

If the Alternative Scenario list is complete, please proceed to the next question.

	Alternative Scenario Name	Alternative Scenario Description
Additional Scenario 1		
Additional Scenario 2		

Comments

For each factor listed in Table 8, please indicate if any modifications are required to the Name or Description of the Alternative Scenario

12. Independent Tool Development *

Yes, modifications are needed

No, the descriptions are accurate

13. Alternative Tools Use *

Yes, modifications are needed

No, the descriptions are accurate

14. Energy-Related Updates Not Approved *

Yes, modifications are needed

No, the descriptions are accurate

Questions or Comments

To address any questions or comments not related to the previous questions, please indicate below in the provided text box. Your responses will be answered and aggregated with the other panelists for reference as part of Round 1.

As an example: "Each question needs more detail or context" or "The Evidence Packet was hard to follow or didn't make sense".

15. Please provide any comments or ask any questions below.

If no comments/questions, please indicate as "N/A".

Thank you

Your response is very important to us.

Upon completion of Round 0, the Corner Alliance team will review your responses and questions/comments and use these data to prepare the Round 1 survey.

In approximately 2 weeks, you will be sent by email a link to the next round of questions.

ASHRAE 90.1 Delphi Panel Round 1

Introduction to ASHRAE 90.1 Delphi Round 1

Welcome to Round 1! Thank you for completing Round 0. The evaluation team reviewed your responses, along with the rest of the panel's responses, and made improvements to Round 1 to better clarify key terms and descriptions. The major changes are described below along with a Q&A section. Please review this section before beginning Round 1.

In Round 1, you will leverage your expertise and information provided in the evidence packet to rate the relative importance of each of the factors that influenced the development of ASHRAE 90.1. Rating questions will be separated out by technology category as it is possible that certain factors played a varying role depending on the type of commercial code update. At the end of this round, you will also be asked to consider several potential alternative scenarios for code updates if DOE-funded BEM tools were not developed. Questions will focus on the likelihood of these scenarios to occur and their relative impact on energy savings achieved from the adoption of ASHRAE 90.1.

There will be an opportunity at the end of the survey to ask questions or leave comments. Thank you for your continued participation in the panel.

Round 0 Summary

Prior to starting the Round 1 questions which will focus on developing a consensus among the panelists on the factors that influenced code development, the Round 0 responses will be summarized and presented with comments on how the feedback was incorporated into the survey. Since the number of panelists was limited to a small group, there is not a statistically relevant justification for including or excluding data. Where appropriate, feedback was used to add clarity to the descriptions of factors and scenarios.

The panel manager (PM) reviewed and captured all Round 0 input as appropriate and is summarized below.

Factors

Panelists suggested that one factor be removed. The rating questions in Round 1 will determine if the entire panel agrees that this factor should be removed. Panelists also suggested potentially adding five additional factors. These suggestions helped the study team determine that greater clarification is needed to several factors. All suggested additions were incorporated into the existing factor definitions. In addition, Panelists recommended clarifying several factor definitions and supporting examples. Those changes are highlighted in the revised Factors table in the document emailed to you with the link to Round 1.

Alternative Scenarios

Panelists agreed that the three alternative scenarios provided in the evidence packet accurately represented the ways in which the ASHRAE 90.1 code may have evolved in the absence of DOE-funded BEM tools and that all three scenarios were distinct and should remain separate. Panelists recommended that the Industry Tool Use and Revision scenario be broadened to capture the presence of proprietary tools built in response to specific code proposals that would evaluate their cost-effectiveness in the absence of DOE-funded BEM tools. All changes to the alternative scenario descriptions used for the Round 1 instrument are highlighted in the table included in the email.

Panelist Comments

Panelists also offered several general comments and questions regarding the evidence packet and Delphi panel process. These have been incorporated into the panel as appropriate.

Factor Sorting

1. In Round 0, Panelists were asked to either add, delete, or modify the factors that may have influenced ASHRAE 90.1 code development. Based on the responses, the following question asks Panelists to "sort" the Round 0 factors into one of two groups: No Role In Code Development or Plays a Role in Code Development. Please refer to the updated Factors table provided via email.

For the Factors that were sorted into the "Plays a Role in Code Development" column, a series of questions will be asked to elucidate each Factor's potential role in code development based on ASHRAE's Building Technology Categories: Envelope, HVAC, Service Hot Water, Power and Lighting. *

Drag items from below into the appropriate categories.	No Role In Code Development	Plays a Role in Code Development
DOE BEM Tools		
Utility and Voluntary Program Specifications		
Industry Standards		
Expert Opinion and External Stakeholders		
New Federal or State Law		
Other DOE Program Guidance and Policy		

The following set of questions will ask Panelist to rate the influence DOE-FUNDED BEM TOOLS may have played in code development on a 1-9 scale (Not at all Influential to Extremely Influential) based on Building Technology Category. For reference, please refer to the original evidence packet for descriptions of the building technology categories.

2. Please indicate the influence of DOE-FUNDED BEM TOOLS in the development of Envelope code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

3. Please indicate the influence of DOE-FUNDED BEM TOOLS in the development of HVAC code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

4. Please indicate the influence of DOE-FUNDED BEM TOOLS in the development of Service Hot Water code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

5. Please indicate the influence of DOE-FUNDED BEM TOOLS in the development of Power code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

6. Please indicate the influence of DOE-FUNDED BEM TOOLS in the development of Lighting code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

The following set of questions will ask Panelist to rate the influence UTILITY AND VOLUNTARY PROGRAM SPECIFICATIONS may have played in code development on a 1-9 scale (Not at all Influential to Extremely Influential) based on Technology Category.

7. Please indicate the influence of UTILITY AND VOLUNTARY PROGRAM SPECIFICATIONS in the development of Envelope code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

8. Please indicate the influence of UTILITY AND VOLUNTARY PROGRAM SPECIFICATIONS in the development of HVAC code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

9. Please indicate the influence of UTILITY AND VOLUNTARY PROGRAM SPECIFICATIONS in the development of Service Hot Water code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

10. Please indicate the influence of UTILITY AND VOLUNTARY PROGRAM SPECIFICATIONS in the development of Power code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

11. Please indicate the influence of UTILITY AND VOLUNTARY PROGRAM SPECIFICATIONS in the development of Lighting code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

The following set of questions will ask Panelist to rate the influence INDUSTRY STANDARDS may have played in code development on a 1-9 scale (Not at all Influential to Extremely Influential) based on Technology Category.

12. Please indicate the influence of INDUSTRY STANDARDS in the development of Envelope code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

13. Please indicate the influence of INDUSTRY STANDARDS in the development of HVAC code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

14. Please indicate the influence of INDUSTRY STANDARDS in the development of Service Hot Water code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

15. Please indicate the influence of INDUSTRY STANDARDS in the development of Power code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

16. Please indicate the influence of INDUSTRY STANDARDS in the development of Lighting code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

The following set of questions will ask Panelist to rate the role EXPERT OPINIONS AND EXTERNAL STAKEHOLDERS may have played in code development on a 1-9 scale (Not at all Influential to Extremely Influential) based on Technology Category.

17. Please indicate the influence of EXPERT OPINION AND EXTERNAL STAKEHOLDERS in the development of Envelope code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

18. Please indicate the influence of EXPERT OPINION AND EXTERNAL STAKEHOLDERS in the development of HVAC code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

19. Please indicate the influence of EXPERT OPINION AND EXTERNAL STAKEHOLDERS in the development of Service Hot Water code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

20. Please indicate the influence of EXPERT OPINION AND EXTERNAL STAKEHOLDERS in the development of Power code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

21. Please indicate the influence of EXPERT OPINION AND EXTERNAL STAKEHOLDERS in the development of Lighting code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

The following set of questions will ask Panelist to rate the role NEW FEDERAL OR STATE LAW may have played in code development on a 1-9 scale (Not at all Influential to Extremely Influential) based on Technology Category.

22. Please indicate the influence of NEW FEDERAL OR STATE LAWS in the development of Envelope code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

23. Please indicate the influence of NEW FEDERAL OR STATE LAWS in the development of HVAC code updates.*

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

24. Please indicate the influence of NEW FEDERAL OR STATE LAWS in the development of Service Hot Water code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

25. Please indicate the influence of NEW FEDERAL OR STATE LAWS in the development of Power code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

26. Please indicate the influence of NEW FEDERAL OR STATE LAWS in the development of Lighting code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

The following set of questions will ask Panelist to rate the role OTHER DOE PROGRAM GUIDANCE AND POLICY may have played in code development on a 1-9 scale (Not at all Influential to Extremely Influential) based on Technology Category.

27. Please indicate the influence of OTHER DOE PROGRAM GUIDANCE AND POLICY in the development of Envelope code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

28. Please indicate the influence of OTHER DOE PROGRAM GUIDANCE AND POLICY in the development of HVAC code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

29. Please indicate the influence of OTHER DOE PROGRAM GUIDANCE AND POLICY in the development of Service Hot Water code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

30. Please indicate the influence of OTHER DOE PROGRAM GUIDANCE AND POLICY in the development of Power code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

31. Please indicate the influence of OTHER DOE PROGRAM GUIDANCE AND POLICY in the development of Lighting code updates. *

Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	○	○	○

Alternative Scenarios

The table below presents the postulated alternative scenarios which could have occurred in the absence of DOE-funded BEM tools. Panelists will be asked for their estimate on the relative likelihood of these scenarios happening if DOE-funded BEM tools did not exist.

Independent Tool Development	**New modeling tools equivalent to DOE-funded BEM tools would have been independently developed by the private sector and/or ASHRAE committee members in response to specific code proposals that would evaluate their cost-effectiveness, influencing the code in the same manner as DOE-funded BEM tools, and therefore the DOE-funded BEM tool related code updates would have occurred anyway.**

32. How likely INDEPENDENT TOOL DEVELOPMENT would have occurred if DOE-funded BEM tools were not developed? (Extremely Unlikely to Extremely Likely) *

Extremely Unlikely	2	3	4	5	6	7	8	Extremely Likely
○	○	○	○	○	○	○	○	○

33. Please provide a rationale for your above rating (1-3 sentences) *

34. What would be the impact on energy savings if INDEPENDENT TOOL DEVELOPMENT occurred compared to energy savings currently measured from adopting ASHRAE 90.1? *

1 - Extremely Negative	2	3	4	5 - No Change	6	7	8	9 - Extremely Positive
○	○	○	○	○	○	○	○	○

Alternative Tools Use	**Code update committees would have used alternative tools such as DOE-2, Trane, standard engineering calculations and others outlined in Evidence Packet Table 9 to develop and justify code updates. Without the same functionality of DOE-funded BEM tools, code updates could have less or more stringent/specific requirements, depending on the technology analyzed and the cost-effectiveness.**

35. How likely ALTERNATIVE TOOLS USE would have occurred if DOE-funded BEM tools were not developed? (Extremely Unlikely to Extremely Likely) *

Extremely Unlikely	2	3	4	5	6	7	8	Extremely Likely
○	○	○	○	○	○	○	○	○

36. Please provide a rationale for your above rating (1-3 sentences) *

37. What would be the impact on energy savings if ALTERNATIVE TOOL USE occurred compared to energy savings currently measured from adopting ASHRAE 90.1? *

1 - Extremely Negative	2	3	4	5 - No Change	6	7	8	9 - Extremely Positive
○	○	○	○	○	○	○	○	○

Energy-Related Updates Not Approved or Significantly Delayed	**Code updates that require energy modeling not available in other tools may not have been developed or approved or faced significant delays in the approval process. Therefore, ASHRAE 90.1 would have fewer code updates that impact energy savings. In addition, BEM is not capable of modeling some of the approved code changes.**

38. How likely ENERGY-RELATED UPDATES NOT APPROVED OR SIGNIFICANTLY DELAYED would have occurred if DOE-funded BEM tools were not developed? (Extremely Unlikely to Extremely Likely) *

Extremely Unlikely	2	3	4	5	6	7	8	Extremely Likely
○	○	○	○	○	○	○	○	○

39. Please provide a rationale for your above rating (1-3 sentences) *

40. What would be the impact on energy savings if ENERGY-RELATED UPDATES NOT APPROVED OR SIGNIFICANTLY DELAYED occurred compared to energy savings currently measured from adopting ASHRAE 90.1? *

1 - Extremely Negative	2	3	4	5 - No Change	6	7	8	9 - Extremely Positive
○	○	○	○	○	○	○	○	○

41. Please use the space below to add any comments or questions.

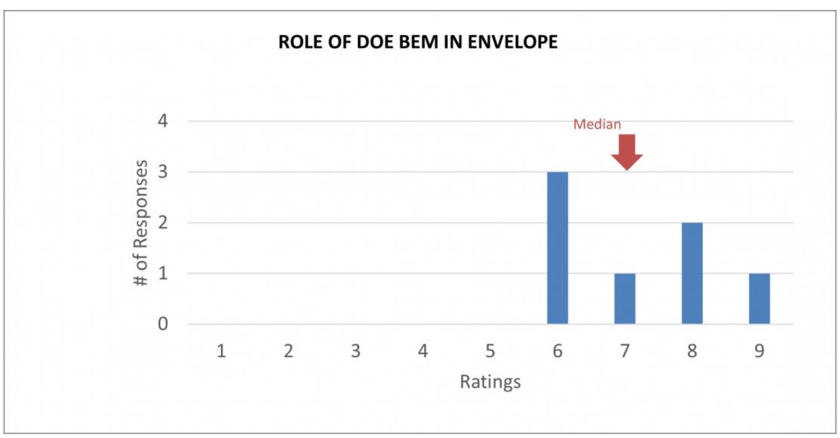
ASHRAE 90.1 Delphi Panel Round 2

Round 2 of the Delphi Panel featured customized surveys for each panelist. The questions asked in Round 1 were repeated, and panelists were shown their previous answer against the panel's aggregate response. Panelists were given the opportunity to change their responses and were asked to provide rationales for why they did or did not change their Round 1 answer.

See question 1 below for an example of how the survey was customized for each panelist.

1. Please indicate the influence of DOE-FUNDED BEM TOOLS in the development of ENVELOPE code updates.

Your Round 1 response was 7



Not at all Influential	2	3	4	5	6	7	8	Extremely Influential
○	○	○	○	○	○	◉	○	○

2. ENVELOPE - Please provide rationale for why you decided to change or keep your Round 1 answer below.

End of Panel Survey

Introduction

Purpose: DOE Building Technologies Office's (BTO) Building Energy Modeling (BEM) investments and tools are only one contributor to the development of ASHRAE Standard 90.1. ASHRAE internal committee members who develop and approve code changes, as well as the external experts and stakeholders whose suggestions they may incorporate, make their decisions by leveraging various factors. Table E-1 lists the factors currently identified through research and discussion with relevant stakeholders that are believed to play a role in justifying ASHRAE 90.1 code changes. Together, all of the factors are intended to represent the total set of influences upon code development.

This survey will ask respondents to provide point estimates for the impact of DOE-funded BEM tools and each factor identified on the development of ASHRAE 90.1 code updates. In addition, respondents will be asked to provide point estimates on how energy efficiency would change (increase or decrease) in each use case if BEM tools were not developed.

Table E-1. Factor Descriptions

Factor	Definition
DOE-Funded BEM Tools	ASHRAE leverages DOE-funded BEM tools to evaluate the cost and energy impacts of potential code updates
Utility and Voluntary Program Specifications	ASHRAE updated the code by incorporating an above-code requirement developed by a utility program or a voluntary program like LEED or Energy Star
Industry Standards	ASHRAE leverages other standards it developed or from other standards organizations (Cool Roof Rating Council, AHRI, ASTM, etc.)
Expert Opinion and External Stakeholders	ASHRAE approved a code update due to its recommendation by a stakeholder and/or subject matter expert (whether a committee member, third-party consultant, or an external organization), based on their own expertise and analysis, as well as market trends and interests
New Federal or State Law	New law requires or justifies a code update
Other DOE Program Guidance and Policy	ASHRAE relied upon resources from a non-BEM program within DOE (such as the Commercial Buildings Integration program) to develop or justify a code update

Factor Attribution to Code Technology - ENVELOPE

1. The six factors listed below have been identified as having influenced the development of code updates for ASHRAE 90.1 since 2007. For each factor, please provide an estimate for its relative importance in influencing ENVELOPE code changes.

Note: Percent estimates for all factors must sum to 100.

Background: Section 5 in ASHRAE Standard 90.1 details building envelope requirements, including minimum wall and roof insulation, roof albedo, and minimum performance of glazing.

[ ]	DOE BEM Tools
[ ]	Utility and Voluntary Program Specifications
[ ]	Industry Standards
[ ]	Expert Opinion and External Stakeholders
[ ]	New Federal or State Law
[ ]	Other DOE Program Guidance and Policy

0 out of 100 Total

Factor Attribution to Code Technology - HVAC

2. The six factors listed below have been identified as having influenced the development of code updates for ASHRAE 90.1 since 2007. For each factor below, please provide an estimate for its relative importance in influencing HVAC code changes.

Note: Percent estimates for all factors must sum to 100.

Background: Section 6 in ASHRAE Standard 90.1 details HVAC requirements, including minimum equipment features and efficiency, and limitations on reheat and fan power. Refrigeration is included in Section 6 for the 2019 iteration of ASHRAE Standard 90.1. Many of the major updates to Section 6 – HVAC target fan and ventilation controls, refines thresholds for energy recovery, and sets requirements for boilers and chillers.

[ ]	DOE BEM Tools
[ ]	Utility and Voluntary Program Specifications
[ ]	Industry Standards
[ ]	Expert Opinion and External Stakeholders
[ ]	New Federal or State Law
[ ]	Other DOE Program Guidance and Policy

0 out of 100 Total

Factor Attribution to Code Technology - SERVICE HOT WATER

3. The six factors listed below have been identified as having influenced the development of code updates for ASHRAE 90.1 since 2007. For each factor below, please provide an estimate for its relative importance in influencing SERVICE HOT WATER code changes.

Note: Percent estimates for all factors must sum to 100.

Background: Section 7 in ASHRAE Standard 90.1 details service hot water requirements and includes minimum equipment features and efficiency. The only change to Section 7 – Service Hot Water came in 2016 with an addendum that requires insulation on the first eight feet of branch piping from recirculating service hot water systems.

	DOE BEM Tools
	Utility and Voluntary Program Specifications
	Industry Standards
	Expert Opinion and External Stakeholders
	New Federal or State Law
	Other DOE Program Guidance and Policy
0 out of 100 Total	

Factor Attribution to Code Technology - POWER

4. The six factors listed below have been identified as having influenced the development of code updates for ASHRAE 90.1 since 2007. For each factor below, please provide an estimate for its relative importance in influencing POWER code changes.

Note: Percent estimates for all factors must sum to 100.

Background: Section 8 in ASHRAE Standard 90.1 details power requirements around transformer efficiency, automatic receptacle controls, and energy monitoring. The only major change to Section 8 – Power came in 2010 with an addendum that modifies automatic receptacle control requirements and exemptions. Only two other minor changes have been made to Section 8 – Power from 2007 to 2019, both of which also focus on receptacle control requirements.

[ ]	DOE BEM Tools
[ ]	Utility and Voluntary Program Specifications
[ ]	Industry Standards
[ ]	Expert Opinion and External Stakeholders
[ ]	New Federal or State Law
[ ]	Other DOE Program Guidance and Policy
0 out of 100 Total	

Factor Attribution to Code Technology - LIGHTING

5. The six factors listed below have been identified as having influenced the development of code updates for ASHRAE 90.1 since 2007. For each factor below, please provide an estimate for its relative importance in influencing LIGHTING code changes.

Note: Percent estimates for all factors must sum to 100.

Background: Section 9 in ASHRAE Standard 90.1 details lighting requirements, including maximum indoor lighting density, minimum lighting controls, and exterior and parking lighting. Many of the major updates to Section 9 – Lighting include reductions in lighting power density, increases in natural daylighting, and refinements to occupancy sensor applications.

[ ]	DOE BEM Tools
[ ]	Utility and Voluntary Program Specifications
[ ]	Industry Standards
[ ]	Expert Opinion and External Stakeholders
[ ]	New Federal or State Law
[ ]	Other DOE Program Guidance and Policy
0 out of 100 Total	

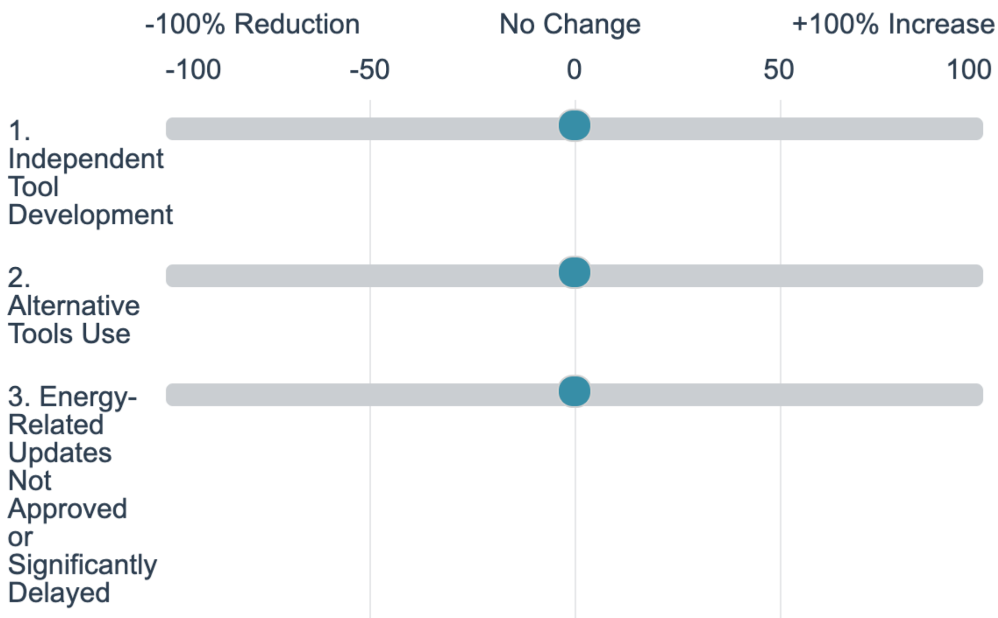
Alternative Scenarios

Question 2 - The following question will address the potential impact on energy savings that are achieved from ASHRAE 90.1 energy efficiency updates if DOE-funded BEM tools did not exist. Table E-2 describes Alternative scenarios and how ASHRAE 90.1 code development could have changed if DOE-funded BEM tools were not available.

Table E-2. Alternative Scenarios

Alternative Scenario Name	Description
Independent Tool Development	**New modeling tools equivalent to DOE-funded BEM tools would have been independently developed by the private sector, influencing the code in the same manner as DOE-funded BEM tools, and therefore the DOE-funded BEM tool-related code updates would have occurred anyway.**
Alternative Tools Use	**Code update committees would have used alternative tools such as DOE-2, Trane, and others to develop and justify code updates. Without the same functionality of DOE-funded BEM tools, code updates would have less stringent/specific requirements, leading to changes in potential energy efficiency.**
Energy-Related Updates Not Approved or Significantly Delayed	**Code updates that require energy modeling not available in other tools would not have been developed or approved, or faced significant delays. Therefore, ASHRAE 90.1 would have fewer code updates that impact energy savings.**

6. Based on the Alternative Scenarios listed in Table E-2 above, what would be the relative change in energy efficiency derived from ASHRAE 90.1 code updates if each alternative scenario were to happen? Use the sliding scale below the table to indicate your answers.



Appendix F: Energy and Emissions Savings Methods

Summary of Appendix F Tables

Table Number	Table Name	Description
Table F-1	PNNL Energy Savings by ASHRAE Standard 90.1 Update (EUI)	PNNL Energy Savings (by BEM End Use): Basis for Gross ASHRAE 90.1 energy savings, sourced from ***PNNL End-Use Opportunity Analysis Data Results Based on Standard 90.1-2016***.
Table F-2	Gross ASHRAE Energy Savings by ASHRAE Standard 90.1 Update (EUI)	Gross ASHRAE Energy Savings (by BEM End Use): Calculated as the sum of PNNL Energy Savings from current and all previous versions of the ASHRAE 90.1 standard since 2004.
Table F-3	Attribution Factors	Attribution Factors (by BEM End Use): Determined through the Delphi process. They are the product of the counterfactual and DOE-funded BEM attributions and vary according to BEM End Uses.
Table F-4	Attribution Energy Savings by ASHRAE Standard 90.1 Update (EUI)	Attribution Energy Savings (by BEM End Use): Calculated as the product of the Gross ASHRAE Energy Savings and Attribution Factors.
Table F-5	ASHRAE Standard 90.1 Code Adoption by State	ASHRAE Standard 90.1 Code Adoption (by state, by year): Determined to have happened (for a given state) within a given year if it was effective on or before July 1st of that year, per PNNL study methodology. Adoptions after the date of the 2016 PNNL study were obtained via DOE's Building Energy Codes Program.
Table F-6	ASHRAE Adoption Timeline	ASHRAE Adoption Timeline (by state, by year): Based on ASHRAE Standard 90.1 Code Adoption plus a two-year construction lag.
Table F-7	Commercial New Construction Weighting Factors	Commercial New Construction Weighting Factors (by state): Obtained from EIA state-level new construction data.
Table F-8	Commercial New Construction Floor Area (Square Feet)	Commercial New Construction Floor Area (by state, by year): Calculated as THE product of national new construction floor area and state New Construction Weighting Factors.

Table Number	Table Name	Description
Table F-9	Electric Gross Energy Savings (kWh)	Electric Gross Energy Savings (by state, by year): Calculated as the product of the Gross ASHRAE Energy Savings, ASHRAE Adoption Timeline, and Commercial New Construction Floor Area.
Table F-10	Electricity Net Energy Savings (kWh)	Electric Net Energy Savings: (by state, by year): Calculated as the product of Electric Gross Energy Savings and Attributions Factors.
Table F-11	Electricity CO2 Emission Rates (lbs. CO2e / MWh)	Electric CO2e Emission Rates (by state, by year): Obtained from EPA's eGRID.
Table F-12	Electricity Avoided CO2e Emissions (Lbs.)	Electric Avoided CO2e Emissions (by state, by year): Calculated as the product of Electric Net Energy Savings and corresponding Electric CO2e Emissions Rates.
Table F-13	Electricity Non-CO2 Emissions Rates (Lbs. / MWh)	Electric non-CO2 Emission Rates (by year): Obtained from EPA's AVERT.
Table F-14	Electricity Avoided non-CO2e Emissions (Lbs.)	Electric Avoided non-CO2e Emissions (by year): Calculated as the product of the national-level Electric Net Energy Savings and corresponding Electric non-CO2 Emissions Rates
Table F-15	Electricity Energy Price ($/kWh)	Electric Energy Price (by state, by year): Obtained from EIA.
Table F-16	Electricity Energy Cost Savings, Current Dollars	Electric Energy Cost Savings (by state, by year): Calculated as the product of Electric Net Energy Savings and Electric Energy Price.
Table F-17	Natural Gas Gross Energy Savings (Therms)	Natural Gas Gross Energy Saving (by state, by year): Calculated as the product of the Gross ASHRAE Energy Savings, ASHRAE Adoption Timeline, and New Construction Floor Areas.
Table F-18	Natural Gas Net Energy Savings (Therms)	Natural Gas Net Energy Savings (by state, by year): Calculated as the product of Natural Gas Gross Energy Savings and Attribution Factors.
Table F-19	Natural Gas Avoided CO2 Emissions (Lbs.)	Natural Gas Avoided CO2e Emissions (by state, by year): Calculated as the product of Natural Gas Net Energy Savings and natural gas emissions factor from EPA's GHG Emission Factors Hub.
Table F-20	Natural Gas Avoided NOx Emissions (Lbs.)	Natural Gas Avoided NOx Emissions (by state, by year): Calculated as the product of Natural Gas Net Energy Savings and natural gas emissions factor derived from EPA.

Table Number	Table Name	Description
Table F-21	Natural Gas Avoided PM2.5 Emissions (Lbs.)	Natural Gas Avoided PM2.5 Emissions (by state, by year): Calculated as the product of Natural Gas Net Energy Savings and natural gas emissions factor obtained from EPA.
Table F-22	Natural Gas Avoided SO2 Emissions (Lbs.)	Natural Gas Avoided SO2 Emissions (by state, by year): Calculated as the product of Natural Gas Net Energy Savings and natural gas emissions factor obtained from EPA.
Table F-23	Natural Gas Avoided VOC Emissions (Lbs.)	Natural Gas Avoided VOC Emissions (by state, by year): Calculated as the product of Natural Gas Net Energy Savings and a natural gas emissions factor obtained from EPA.
Table F-24	Natural Gas Avoided NH3 Emissions (Lbs.)	Natural Gas Avoided NH3 Emissions (by state, by year): Calculated as the product of Natural Gas Net Energy Savings and natural gas emissions factor obtained from EPA.
Table F-25	Natural Gas Energy Price ($/therm)	Natural Gas Energy Price (by state, by year): Obtained from EIA in $/thousand CF and converted to $/Therm.
Table F-26	Natural Gas Energy Cost Savings, Current Dollars	Natural Gas Energy Cost Savings (by state, by year): Calculated as the product of Natural Gas Net Energy Savings and Natural Gas Energy Price.
Table F-27	National Level Inputs for EPA's COBRA	National Level Inputs for EPA's COBRA (by year): Avoided energy and emissions inputs for EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).
Table F-28	Monetized Health Benefits, 3% Discount Factor	Monetized Health Benefits, 3% Discount Factor (by year): Environmental health benefits obtained from EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).
Table F-29	Monetized Health Benefits, 7% Discount Factor	Monetized Health Benefits, 7% Discount Factor (by year): Environmental health benefits obtained from EPA's CO-Benefits Risk Assessment Health Impacts Screening and Mapping Tool (COBRA).

Table F-1. PNNL Energy Savings by ASHRAE Standard 90.1 Update (EUI)

BEM End Use	Electric (kWh/SF/yr)				Natural Gas (therms/SF/yr)			
	2004-2007	2007-2010	2010-2013	2013-2016	2004-2007	2007-2010	2010-2013	2013-2016
Light.Int	-0.0340	0.7460	0.3920	0.6100	0	0	0	0
Light.Ext	0.0000	0.3790	0.0000	0.2000	0	0	0	0
SHW	0.0000	0.0060	0.0000	0.0000	0.00000348	0.00020186	0.00000090	0.00041325
Heat	0.0880	0.1390	0.0670	0.0130	0.02554170	0.03628089	0.00965156	0.00204328
Humidify	0.0120	0.0200	0.0370	-0.0310	0	0	0	0
Cool	0.2550	0.6930	0.3350	0.1240	0	0	0	0
Ht.Rej	0.0000	0.0220	0.0050	0.0050	0	0	0	0
Fans	0.2980	0.4650	0.2670	0.0840	0	0	0	0
Ht.Rcvy	0.0680	-0.0340	-0.0420	0.0110	0	0	0	0
Pumps	0.0050	0.0620	0.0090	0.0070	0	0	0	0
Refrig	0.0000	0.0000	0.0370	0.0000	0	0	0	0
Elevator	0.0000	0.0170	0.0020	0.0000	0	0	0	0
Txfmr	0.0000	0.0250	0.0010	0.0090	0	0	0	0
Cook	0.0000	0.0000	0.0000	0.0000	0	0	0	0

BEM End Use	Electric (kWh/SF/yr)				Natural Gas (therms/SF/yr)			
	2004-2007	2007-2010	2010-2013	2013-2016	2004-2007	2007-2010	2010-2013	2013-2016
IT	0.0000	0.0000	0.0000	0.0000	0	0	0	0
Equip	0.0000	0.0540	0.0730	0.0000	0	0	0	0
Total	0.6910	2.5950	1.1830	1.0330	0.02553822	0.03648275	0.00965246	0.00245653
Notes: Basis for energy savings calculation sourced from PNNL End-Use Opportunity Analysis Data Results Based on Standard 90.1-2016.								
Source: End-Use Opportunity Analysis Data Results Based on Standard 90.1-2016								

Table F-2. Gross ASHRAE Energy Savings by ASHRAE Standard 90.1 Update (EUI)

BEM End Use	Electric (kWh/SF/yr)				Natural Gas (therms/SF/yr)			
	2007	2010	2013	2016	2007	2010	2013	2016
Light.Int	-0.0340	0.7120	1.1040	1.7140	0	0	0	0
Light.Ext	0.0000	0.3790	0.3790	0.5790	0	0	0	0
SHW	0.0000	0.0060	0.0060	0.0060	0.00000348	0.00019838	0.00019928	0.00061252
Heat	0.0880	0.2270	0.2940	0.3070	0.02554170	0.06182260	0.07147416	0.07351744
Humidify	0.0120	0.0320	0.0690	0.0380	0	0	0	0
Cool	0.2550	0.9480	1.2830	1.4070	0	0	0	0

BEM End Use	Electric (kWh/SF/yr)				Natural Gas (therms/SF/yr)			
	2007	2010	2013	2016	2007	2010	2013	2016
Ht.Rej	0.0000	0.0220	0.0270	0.0320	0	0	0	0
Fans	0.2980	0.7630	1.0300	1.1140	0	0	0	0
Ht.Rcvy	0.0680	0.0340	-0.0080	0.0030	0	0	0	0
Pumps	0.0050	0.0670	0.0760	0.0830	0	0	0	0
Refrig	0.0000	0.0000	0.0370	0.0370	0	0	0	0
Elevator	0.0000	0.0170	0.0190	0.0190	0	0	0	0
Txfmr	0.0000	0.0250	0.0260	0.0350	0	0	0	0
Cook	0.0000	0.0000	0.0000	0.0000	0	0	0	0
IT	0.0000	0.0000	0.0000	0.0000	0	0	0	0
Equip	0.0000	0.0540	0.1270	0.1270	0	0	0	0
Total	0.6910	3.2860	4.4690	5.5020	0.02553822	0.06202098	0.07167344	0.07412996

Notes: Gross ASHRAE energy savings were calculated as the sum of PNNL Energy Savings from current and all previous versions of the ASHRAE standard.

Table F-3. Attribution Factors

BEM End Use**	ASHRAE Standard Technology Category	2004 – 2007*	2007 – 2010*	2010 – 2013*	2013 – 2016*
Light.Int	Lighting	7%	7%	7%	7%
Light.Ext	Lighting	7%	7%	7%	7%
SHW	Service Hot Water	4%	4%	4%	4%
Heat	Envelope	11%	11%	11%	11%
Humidify	HVAC	11%	11%	11%	11%
Cool	Envelope	11%	11%	11%	11%
Ht.Rej	HVAC	11%	11%	11%	11%
Fans	HVAC	11%	11%	11%	11%
Ht.Rcvy	HVAC	11%	11%	11%	11%
Pumps	HVAC	11%	11%	11%	11%
Refrig	HVAC	11%	11%	11%	11%
Elevator	Power	5%	5%	5%	5%
Txfmr	Power	5%	5%	5%	5%
Cook	Power	5%	5%	5%	5%
IT	Power	5%	5%	5%	5%

BEM End Use**	ASHRAE Standard Technology Category	2004 – 2007*	2007 – 2010*	2010 – 2013*	2013 – 2016*
Equip	Power	5%	5%	5%	5%

Notes:
*Attribution factors were determined through the Delphi process. They are the product of the counterfactual and DOE-funded BEM attributions and vary according to the BEM End Use type.
** BEM end uses were binned according to end use and mapped to corresponding ASHRAE Technology Categories. Building envelope and HVAC weightings of 38% and 62% were used to apportion attributions to space heating and space cooling per DOE's Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies.

Source: Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies (Figure 3 and Table 2)

Table F-4. Attribution Energy Savings by ASHRAE Standard 90.1 Update (EUI)

BEM End Use	Electric (kWh/SF/yr)				Natural Gas (therms/SF/yr)			
	2007	2010	2013	2016	2007	2010	2013	2016
Light.Int	-0.002380	0.049840	0.077280	0.119980	0	0	0	0
Light.Ext	0.000000	0.026530	0.026530	0.040530	0	0	0	0
SHW	0.000000	0.000210	0.000210	0.000210	0.00000012	0.00000694	0.00000697	0.00002144
Heat	0.009833	0.025363	0.032850	0.034302	0.00285386	0.00690765	0.00798605	0.00821436
Humidify	0.001260	0.003360	0.007245	0.003990	0	0	0	0

BEM End Use	Electric (kWh/SF/yr)				Natural Gas (therms/SF/yr)			
	2007	2010	2013	2016	2007	2010	2013	2016
Cool	0.028492	0.105923	0.143354	0.157209	0	0	0	0
Ht.Rej	0.000000	0.002310	0.002835	0.003360	0	0	0	0
Fans	0.031290	0.080115	0.108150	0.116970	0	0	0	0
Ht.Rcvy	0.007140	0.003570	-0.000840	0.000315	0	0	0	0
Pumps	0.000525	0.007035	0.007980	0.008715	0	0	0	0
Refrig	0.000000	0.000000	0.003885	0.003885	0	0	0	0
Elevator	0.000000	0.000893	0.000998	0.000998	0	0	0	0
Txfmr	0.000000	0.001313	0.001365	0.001838	0	0	0	0
Cook	0.000000	0.000000	0.000000	0.000000	0	0	0	0
IT	0.000000	0.000000	0.000000	0.000000	0	0	0	0
Equip	0.000000	0.002835	0.006668	0.006668	0	0	0	0
Total	0.076160	0.309297	0.418509	0.498969	0.00285374	0.00691459	0.00799303	0.00823579

Notes: Attribution energy savings were calculated as the product of the Gross ASHRAE Energy Savings and Attribution Factors.

Table F-5. ASHRAE Standard 90.1 Code Adoption by State

ASHRAE Version	2001	2004	2007	2010	2013	2016
State	Year Adopted					
Alabama	2010	2013	2013	2016	2016	
Alaska						
Arizona	2010	2013	2013	2013		
Arkansas	2005	2013	2013			
California						
Colorado	2007	2012	2012			
Connecticut	2005	2009	2012	2016		
Delaware	2004	2010	2010	2015		
Florida	2005	2007	2012	2015		
Georgia	2003	2008	2011	2016		
Hawaii						
Idaho	2005	2008	2011	2015		
Illinois	2006	2008	2010	2013	2016	
Indiana	2010	2010	2010			

ASHRAE Version	2001	2004	2007	2010	2013	2016
State	Year Adopted					
Iowa	2004	2007	2010	2014	2016	
Kansas						
Kentucky	2005	2007	2011	2014		
Louisiana	2005	2007	2012	2016		
Maine	2000	2005	2011	2016		
Maryland	2005	2007	2010	2012	2015	
Massachusetts	2001	2008	2010	2014	2016	
Michigan	2009	2011	2011	2016		
Minnesota	2009	2009	2015	2015		
Mississippi	2010	2013	2013	2013		
Missouri						
Montana	2005	2010	2010	2015		
Nebraska	2005	2012	2012			
Nevada	2005	2010	2012	2015		
New Hampshire	2002	2007	2010	2016		

ASHRAE Version	2001	2004	2007	2010	2013	2016
State	Year Adopted					
New Jersey	2002	2007	2011	2016	2016	2020
New Mexico	2004	2008	2012			
New York	2002	2008	2011	2015	2017	2020
North Carolina	2006	2009	2012	2016		
North Dakota						
Ohio	2005	2008	2012			
Oklahoma	2010	2012	2016			
Oregon						2020
Pennsylvania	2004	2007	2010	2016		
Rhode Island	2004	2007	2010	2013	2016	
South Carolina	2005	2008	2013	2016		
South Dakota						
Tennessee	2010	2011	2016			
Texas	2001	2011	2011	2016		
Utah	2002	2007	2010	2014	2016	

ASHRAE Version	2001	2004	2007	2010	2013	2016
State	Year Adopted					
Vermont	2001	2007	2012	2015	2015	
Virginia	2004	2006	2011	2015		
Washington						
West Virginia	2010	2014	2014			
Wisconsin	2008	2008	2012	2016		
Wyoming	2010	2011	2011	2016		
Washington, DC	2004	2010	2010	2014		
ASHRAE Version	2001	2004	2007	2010	2013	2016

Notes:
* U.S. territories not included due to lack of available data.
** Adoptions after the date of 2016 PNNL study were obtained via Building Energy Codes Program source (only where 90.1-2016 is in both adopted and equivalent columns)
*** Adoption is determined to happen within a year if it was effective on or before July 1st of that year, per PNNL study methodology.

Sources:

Impacts of Model Building Energy Codes

Status of State Energy Code Adoption - Commercial | Building Energy Codes Program

Table F-6. ASHRAE Adoption Timeline

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama													2001	2001	2001	2007	2007	2007	2013	2013	2013
Alaska																					
Arizona													2001	2001	2001	2010	2010	2010	2010	2010	2010
Arkansas								2001	2001	2001	2001	2001	2001	2001	2001	2007	2007	2007	2007	2007	2007
California																					
Colorado										2001	2001	2001	2001	2001	2007	2007	2007	2007	2007	2007	2007
Connecticut								2001	2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2010	2010	2010
Delaware							2001	2001	2001	2001	2001	2001	2007	2007	2007	2007	2007	2010	2010	2010	2010
Florida								2001	2001	2004	2004	2004	2004	2004	2007	2007	2007	2010	2010	2010	2010
Georgia						2001	2001	2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2007	2010	2010	2010
Hawaii																					
Idaho								2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2010	2010	2010	2010
Illinois									2001	2001	2004	2004	2007	2007	2007	2010	2010	2010	2013	2013	2013
Indiana													2007	2007	2007	2007	2007	2007	2007	2007	2007

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Iowa							2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2010	2010	2013	2013	2013
Kansas																					
Kentucky								2001	2001	2004	2004	2004	2004	2007	2007	2007	2010	2010	2010	2010	2010
Louisiana								2001	2001	2004	2004	2004	2004	2004	2007	2007	2007	2007	2010	2010	2010
Maine			2001	2001	2001	2001	2001	2004	2004	2004	2004	2004	2004	2007	2007	2007	2007	2007	2010	2010	2010
Maryland								2001	2001	2004	2004	2004	2007	2007	2010	2010	2010	2013	2013	2013	2013
Massachusetts				2001	2001	2001	2001	2001	2001	2001	2004	2004	2007	2007	2007	2007	2010	2010	2013	2013	2013
Michigan												2001	2001	2007	2007	2007	2007	2007	2010	2010	2010
Minnesota												2004	2004	2004	2004	2004	2004	2010	2010	2010	2010
Mississippi													2001	2001	2001	2010	2010	2010	2010	2010	2010
Missouri																					
Montana								2001	2001	2001	2001	2001	2007	2007	2007	2007	2007	2010	2010	2010	2010
Nebraska								2001	2001	2001	2001	2001	2001	2001	2007	2007	2007	2007	2007	2007	2007
Nevada								2001	2001	2001	2001	2001	2004	2004	2007	2007	2007	2010	2010	2010	2010
New Hampshire					2001	2001	2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2007	2007	2010	2010	2010
New Jersey					2001	2001	2001	2001	2001	2004	2004	2004	2004	2007	2007	2007	2007	2007	2013	2013	2013

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
New Mexico	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2001	2004	2004	2004	2004	2007	2007	2007	2007	2007	2007	2007
New York	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2010	2010	2013	2013
North Carolina	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2010	2010	2010
North Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ohio	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2004	2004	2004	2004	2007	2007	2007	2007	2007	2007	2007
Oklahoma	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2004	2004	2004	2004	2007	2007	2007
Oregon	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pennsylvania	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2007	2007	2010	2010	2010
Rhode Island	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2004	2004	2004	2007	2007	2007	2010	2010	2010	2013	2013	2013
South Carolina	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2004	2004	2004	2004	2004	2007	2007	2007	2010	2010	2010
South Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tennessee	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2004	2004	2004	2004	2004	2007	2007	2007
Texas	[redacted]	[redacted]	[redacted]	2001	2001	2001	2001	2001	2001	2001	2001	2001	2001	2007	2007	2007	2007	2007	2010	2010	2010
Utah	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2001	2001	2001	2004	2004	2004	2007	2007	2007	2007	2010	2010	2013	2013	2013
Vermont	[redacted]	[redacted]	[redacted]	2001	2001	2001	2001	2001	2001	2004	2004	2004	2004	2004	2007	2007	2007	2013	2013	2013	2013
Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2001	2001	2004	2004	2004	2004	2004	2007	2007	2007	2007	2010	2010	2010	2010

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Washington																					
West Virginia													2001	2001	2001	2001	2007	2007	2007	2007	2007
Wisconsin											2004	2004	2004	2004	2007	2007	2007	2007	2010	2010	2010
Wyoming													2001	2007	2007	2007	2007	2007	2010	2010	2010
Washington, DC							2001	2001	2001	2001	2001	2001	2007	2007	2007	2007	2010	2010	2010	2010	2010

Notes: Adoption timeline based on ASHRAE Code Adoption plus two year construction lag from report titled: Predicting Construction Duration of Building Projects, which can be found at https://www.fig.net/resources/proceedings/fig_proceedings/fig2006/papers/ts28/ts28_02_martin_etal_0831.pdf

Source: Impacts of Model Building Energy Codes

Table F-7. Commercial New Construction Weighting Factors

State	Abbreviation	Percent	State	Abbreviation	Percent
Alabama	AL	1.28%	Nebraska	NE	0.64%
Alaska	AK	0.17%	Nevada	NV	1.48%
Arizona	AZ	2.58%	New Hampshire	NH	0.32%
Arkansas	AR	0.70%	New Jersey	NJ	2.33%
California	CA	9.14%	New Mexico	NM	0.46%

State	Abbreviation	Percent	State	Abbreviation	Percent
Colorado	CO	2.36%	New York	NY	4.83%
Connecticut	CT	0.86%	North Carolina	NC	3.12%
Delaware	DE	0.22%	North Dakota	ND	0.28%
Florida	FL	8.98%	Ohio	OH	3.10%
Georgia	GA	4.12%	Oklahoma	OK	1.15%
Hawaii	HI	0.38%	Oregon	OR	1.15%
Idaho	ID	0.45%	Pennsylvania	PA	3.00%
Illinois	IL	3.79%	Rhode Island	RI	0.19%
Indiana	IN	2.23%	South Carolina	SC	1.68%
Iowa	IA	1.01%	South Dakota	SD	0.25%
Kansas	KS	0.94%	Tennessee	TN	2.19%
Kentucky	KY	1.29%	Texas	TX	11.67%
Louisiana	LA	1.18%	Utah	UT	1.26%
Maine	ME	0.28%	Vermont	VT	0.13%
Maryland	MD	2.25%	Virginia	VA	2.95%
Massachusetts	MA	2.01%	Washington	WA	2.80%

State	Abbreviation	Percent	State	Abbreviation	Percent
Michigan	MI	1.75%	West Virginia	WV	0.26%
Minnesota	MN	1.83%	Wisconsin	WI	1.60%
Mississippi	MS	0.71%	Wyoming	WY	0.17%
Missouri	MO	1.55%	Washington, DC	DC	0.74%
Montana	MT	0.16%			
Notes: Factors developed from new construction data provided by EIA.					
Source: Development of National New Construction Weighting Factors for the Commercial Building Prototype Analyses (2003-2018) (Table B.2)					

Table F-8. Commercial New Construction Floor Area (Million Square Feet)

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	1E+07	1E+07	1E+07	1E+07	1E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Alaska	1E+06	1E+06	1E+06	1E+06	1E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06
Arizona	2E+07	2E+07	2E+07	2E+07	2E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07
Arkansas	6E+06	6E+06	6E+06	6E+06	6E+06	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07
California	8E+07	8E+07	8E+07	8E+07	8E+07	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08
Colorado	2E+07	2E+07	2E+07	2E+07	2E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07
Connecticut	7E+06	7E+06	7E+06	7E+06	7E+06	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07
Delaware	2E+06	2E+06	2E+06	2E+06	2E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06
Florida	8E+07	8E+07	8E+07	8E+07	8E+07	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08	1E+08
Georgia	4E+07	4E+07	4E+07	4E+07	4E+07	8E+07	8E+07	8E+07	8E+07	8E+07	8E+07	8E+07	8E+07	7E+07	7E+07	7E+07	7E+07	7E+07	7E+07	7E+07	7E+07
Hawaii	3E+06	3E+06	3E+06	3E+06	3E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	6E+06	6E+06	6E+06	6E+06	6E+06	6E+06	6E+06	6E+06
Idaho	4E+06	4E+06	4E+06	4E+06	4E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06	7E+06

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Illinois	3E+07	3E+07	3E+07	3E+07	3E+07	7E+07	7E+07	7E+07	7E+07	7E+07	7E+07	7E+07	7E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07
Indiana	2E+07	2E+07	2E+07	2E+07	2E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07
Iowa	9E+06	9E+06	9E+06	9E+06	9E+06	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Kansas	8E+06	8E+06	8E+06	8E+06	8E+06	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Kentucky	1E+07	1E+07	1E+07	1E+07	1E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Louisiana	1E+07	1E+07	1E+07	1E+07	1E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Maine	2E+06	2E+06	2E+06	2E+06	2E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06
Maryland	2E+07	2E+07	2E+07	2E+07	2E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07
Massachusetts	2E+07	2E+07	2E+07	2E+07	2E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07
Michigan	2E+07	2E+07	2E+07	2E+07	2E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07
Minnesota	2E+07	2E+07	2E+07	2E+07	2E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07
Mississippi	6E+06	6E+06	6E+06	6E+06	6E+06	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07
Missouri	1E+07	1E+07	1E+07	1E+07	1E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07
Montana	1E+06	1E+06	1E+06	1E+06	1E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06
Nebraska	6E+06	6E+06	6E+06	6E+06	6E+06	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07
Nevada	1E+07	1E+07	1E+07	1E+07	1E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
New Hampshire	3E+06	3E+06	3E+06	3E+06	3E+06	6E+06	6E+06	6E+06	6E+06	6E+06	6E+06	6E+06	6E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06
New Jersey	2E+07	2E+07	2E+07	2E+07	2E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07
New Mexico	4E+06	4E+06	4E+06	4E+06	4E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	9E+06	8E+06	8E+06	8E+06	8E+06	8E+06	8E+06	8E+06	8E+06
New York	4E+07	4E+07	4E+07	4E+07	4E+07	9E+07	9E+07	9E+07	9E+07	9E+07	9E+07	9E+07	9E+07	8E+07	8E+07	8E+07	8E+07	8E+07	8E+07	8E+07	8E+07
North Carolina	3E+07	3E+07	3E+07	3E+07	3E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07
North Dakota	2E+06	2E+06	2E+06	2E+06	2E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06
Ohio	3E+07	3E+07	3E+07	3E+07	3E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07
Oklahoma	1E+07	1E+07	1E+07	1E+07	1E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Oregon	1E+07	1E+07	1E+07	1E+07	1E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Pennsylvania	3E+07	3E+07	3E+07	3E+07	3E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07
Rhode Island	2E+06	2E+06	2E+06	2E+06	2E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
South Carolina	1E+07	1E+07	1E+07	1E+07	1E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07
South Dakota	2E+06	2E+06	2E+06	2E+06	2E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06
Tennessee	2E+07	2E+07	2E+07	2E+07	2E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07	4E+07
Texas	1E+08	1E+08	1E+08	1E+08	1E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08	2E+08
Utah	1E+07	1E+07	1E+07	1E+07	1E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07	2E+07
Vermont	1E+06	1E+06	1E+06	1E+06	1E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	2E+06	2E+06	2E+06	2E+06	2E+06	2E+06	2E+06	2E+06
Virginia	3E+07	3E+07	3E+07	3E+07	3E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	6E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07
Washington	2E+07	2E+07	2E+07	2E+07	2E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07	5E+07
West Virginia	2E+06	2E+06	2E+06	2E+06	2E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	5E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06	4E+06
Wisconsin	1E+07	1E+07	1E+07	1E+07	1E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07	3E+07
Wyoming	1E+06	1E+06	1E+06	1E+06	1E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06	3E+06
Washington, DC	6E+06	6E+06	6E+06	6E+06	6E+06	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07	1E+07
TOTAL	9E+08	9E+08	9E+08	9E+08	9E+08	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09	2E+09

Notes: Square footage of new construction per state per year calculated as product of national new construction floor area and state New Construction Weighting Factors.

Source: Development of National New Construction Weighting Factors for the Commercial Building Prototype Analyses (2003-2018) (Table B.2)

Source: Commercial Buildings Energy Consumption Survey (interpolated)

Table F-9. Electric Gross Energy Savings (kWh)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	1.46E+07	2.93E+07	4.39E+07	1.38E+08	2.33E+08	3.28E+08
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	1.40E+08	2.80E+08	4.21E+08	5.61E+08	7.01E+08	8.41E+08
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	8.00E+06	1.60E+07	2.40E+07	3.20E+07	4.00E+07	4.80E+07
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	2.70E+07	5.39E+07	8.09E+07	1.08E+08	1.35E+08	1.62E+08	1.89E+08
Connecticut	[redacted]	[redacted]	[redacted]	9.83E+06	1.97E+07	2.95E+07	3.93E+07	8.60E+07	1.33E+08	1.80E+08
Delaware	[redacted]	2.93E+06	5.45E+06	7.96E+06	1.05E+07	1.30E+07	2.49E+07	3.69E+07	4.89E+07	6.08E+07
Florida	[redacted]	[redacted]	[redacted]	1.03E+08	2.05E+08	3.08E+08	7.96E+08	1.28E+09	1.77E+09	2.26E+09
Georgia	[redacted]	[redacted]	4.71E+07	9.42E+07	1.41E+08	1.88E+08	2.35E+08	4.59E+08	6.83E+08	9.07E+08
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	5.14E+06	1.03E+07	1.54E+07	2.06E+07	4.50E+07	6.95E+07	9.39E+07	1.18E+08
Illinois	[redacted]	5.05E+07	9.38E+07	1.37E+08	3.43E+08	5.49E+08	7.55E+08	1.04E+09	1.32E+09	1.60E+09
Indiana	[redacted]	2.97E+07	5.52E+07	8.07E+07	1.06E+08	1.32E+08	1.57E+08	1.83E+08	2.08E+08	2.34E+08
Iowa	[redacted]	1.35E+07	2.50E+07	3.65E+07	4.81E+07	1.03E+08	1.58E+08	2.33E+08	3.07E+08	3.82E+08
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	1.47E+07	2.95E+07	4.42E+07	1.14E+08	1.84E+08	2.55E+08	3.25E+08	3.95E+08
Louisiana	[redacted]	[redacted]	[redacted]	1.35E+07	2.70E+07	4.05E+07	5.39E+07	1.18E+08	1.82E+08	2.46E+08

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Maine	[redacted]	[redacted]	3.20E+06	6.40E+06	9.60E+06	1.28E+07	1.60E+07	3.12E+07	4.64E+07	6.16E+07
Maryland	[redacted]	3.00E+07	5.57E+07	1.78E+08	3.00E+08	4.23E+08	5.89E+08	7.55E+08	9.21E+08	1.09E+09
Massachusetts	[redacted]	2.68E+07	4.98E+07	7.27E+07	9.57E+07	2.05E+08	3.14E+08	4.63E+08	6.11E+08	7.60E+08
Michigan	[redacted]	[redacted]	2.00E+07	4.00E+07	6.00E+07	8.00E+07	1.00E+08	1.95E+08	2.90E+08	3.85E+08
Minnesota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	9.95E+07	1.99E+08	2.98E+08	3.98E+08
Mississippi	[redacted]	[redacted]	[redacted]	[redacted]	3.86E+07	7.72E+07	1.16E+08	1.54E+08	1.93E+08	2.32E+08
Missouri	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Montana	[redacted]	2.13E+06	3.96E+06	5.79E+06	7.62E+06	9.45E+06	1.81E+07	2.68E+07	3.55E+07	4.42E+07
Nebraska	[redacted]	[redacted]	[redacted]	7.31E+06	1.46E+07	2.19E+07	2.93E+07	3.66E+07	4.39E+07	5.12E+07
Nevada	[redacted]	[redacted]	[redacted]	1.69E+07	3.38E+07	5.07E+07	1.31E+08	2.12E+08	2.92E+08	3.72E+08
New Hampshire	[redacted]	4.27E+06	7.92E+06	1.16E+07	1.52E+07	1.89E+07	2.26E+07	3.99E+07	5.73E+07	7.47E+07
New Jersey	[redacted]	[redacted]	2.66E+07	5.33E+07	7.99E+07	1.07E+08	1.33E+08	3.05E+08	4.78E+08	6.50E+08
New Mexico	[redacted]	[redacted]	[redacted]	5.26E+06	1.05E+07	1.58E+07	2.10E+07	2.63E+07	3.15E+07	3.68E+07
New York	[redacted]	[redacted]	5.52E+07	1.10E+08	1.66E+08	2.21E+08	4.83E+08	7.46E+08	1.10E+09	1.46E+09
North Carolina	[redacted]	[redacted]	[redacted]	3.57E+07	7.13E+07	1.07E+08	1.43E+08	3.12E+08	4.82E+08	6.51E+08
North Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Ohio				3.54E+07	7.09E+07	1.06E+08	1.42E+08	1.77E+08	2.13E+08	2.48E+08
Oklahoma								1.31E+07	2.63E+07	3.94E+07
Oregon										
Pennsylvania		4.00E+07	7.43E+07	1.09E+08	1.43E+08	1.77E+08	2.11E+08	3.74E+08	5.37E+08	7.01E+08
Rhode Island		2.53E+06	4.70E+06	6.88E+06	1.72E+07	2.75E+07	3.79E+07	5.19E+07	6.59E+07	8.00E+07
South Carolina					1.92E+07	3.84E+07	5.76E+07	1.49E+08	2.40E+08	3.31E+08
South Dakota										
Tennessee								2.50E+07	5.01E+07	7.51E+07
Texas			1.33E+08	2.67E+08	4.00E+08	5.33E+08	6.67E+08	1.30E+09	1.94E+09	2.57E+09
Utah		1.68E+07	3.12E+07	4.56E+07	6.00E+07	1.28E+08	1.97E+08	2.90E+08	3.83E+08	4.76E+08
Vermont				1.49E+06	2.97E+06	4.46E+06	1.41E+07	2.37E+07	3.33E+07	4.29E+07
Virginia			3.37E+07	6.74E+07	1.01E+08	1.35E+08	2.95E+08	4.55E+08	6.16E+08	7.76E+08
Washington										
West Virginia						2.97E+06	5.94E+06	8.91E+06	1.19E+07	1.49E+07
Wisconsin				1.83E+07	3.66E+07	5.49E+07	7.31E+07	1.60E+08	2.47E+08	3.34E+08
Wyoming			1.94E+06	3.89E+06	5.83E+06	7.77E+06	9.71E+06	1.90E+07	2.82E+07	3.74E+07

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Washington, DC	[redacted]	9.87E+06	1.83E+07	2.68E+07	3.52E+07	7.55E+07	1.16E+08	1.56E+08	1.96E+08	2.36E+08
TOTAL	[redacted]	2.29E+08	7.66E+08	1.67E+09	2.97E+09	4.54E+09	7.09E+09	1.13E+10	1.57E+10	2.00E+10
Notes: Gross electric energy savings calculated as the product of the Gross ASHRAE Gross Energy Savings, ASHRAE Adoption Timeline, and New Construction Floor Areas.										

Table F-10. Electricity Net Energy Savings (kWh)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	1.61E+06	3.22E+06	4.84E+06	1.37E+07	2.26E+07	3.14E+07
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	1.32E+07	2.64E+07	3.96E+07	5.28E+07	6.60E+07	7.92E+07
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	8.82E+05	1.76E+06	2.65E+06	3.53E+06	4.41E+06	5.29E+06
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	2.97E+06	5.95E+06	8.92E+06	1.19E+07	1.49E+07	1.78E+07	2.08E+07
Connecticut	[redacted]	[redacted]	[redacted]	1.08E+06	2.17E+06	3.25E+06	4.33E+06	8.73E+06	1.31E+07	1.75E+07
Delaware	[redacted]	3.23E+05	6.00E+05	8.77E+05	1.15E+06	1.43E+06	2.56E+06	3.68E+06	4.81E+06	5.93E+06
Florida	[redacted]	[redacted]	[redacted]	1.13E+07	2.26E+07	3.39E+07	7.99E+07	1.26E+08	1.72E+08	2.18E+08
Georgia	[redacted]	[redacted]	5.19E+06	1.04E+07	1.56E+07	2.08E+07	2.59E+07	4.70E+07	6.81E+07	8.92E+07
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Idaho			5.67E+05	1.13E+06	1.70E+06	2.27E+06	4.57E+06	6.87E+06	9.17E+06	1.15E+07
Illinois		5.57E+06	1.03E+07	1.51E+07	3.45E+07	5.39E+07	7.33E+07	9.95E+07	1.26E+08	1.52E+08
Indiana		3.28E+06	6.09E+06	8.89E+06	1.17E+07	1.45E+07	1.73E+07	2.01E+07	2.29E+07	2.57E+07
Iowa		1.48E+06	2.76E+06	4.03E+06	5.30E+06	1.05E+07	1.56E+07	2.26E+07	2.96E+07	3.66E+07
Kansas										
Kentucky			1.62E+06	3.25E+06	4.87E+06	1.15E+07	1.81E+07	2.47E+07	3.13E+07	3.79E+07
Louisiana				1.49E+06	2.97E+06	4.46E+06	5.95E+06	1.20E+07	1.80E+07	2.41E+07
Maine			3.53E+05	7.05E+05	1.06E+06	1.41E+06	1.76E+06	3.20E+06	4.63E+06	6.06E+06
Maryland		3.31E+06	6.14E+06	1.76E+07	2.92E+07	4.07E+07	5.62E+07	7.18E+07	8.74E+07	1.03E+08
Massachusetts		2.95E+06	5.49E+06	8.02E+06	1.05E+07	2.08E+07	3.11E+07	4.50E+07	5.89E+07	7.28E+07
Michigan			2.20E+06	4.41E+06	6.61E+06	8.82E+06	1.10E+07	2.00E+07	2.89E+07	3.79E+07
Minnesota							9.36E+06	1.87E+07	2.81E+07	3.74E+07
Mississippi					3.63E+06	7.26E+06	1.09E+07	1.45E+07	1.82E+07	2.18E+07
Missouri										
Montana		2.35E+05	4.37E+05	6.38E+05	8.40E+05	1.04E+06	1.86E+06	2.68E+06	3.50E+06	4.31E+06
Nebraska				8.06E+05	1.61E+06	2.42E+06	3.22E+06	4.03E+06	4.84E+06	5.64E+06
Nevada				1.86E+06	3.73E+06	5.59E+06	1.32E+07	2.07E+07	2.83E+07	3.59E+07
New Hampshire		4.70E+05	8.73E+05	1.28E+06	1.68E+06	2.08E+06	2.49E+06	4.12E+06	5.76E+06	7.40E+06

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
New Jersey			2.93E+06	5.87E+06	8.80E+06	1.17E+07	1.47E+07	3.08E+07	4.69E+07	6.31E+07
New Mexico				5.79E+05	1.16E+06	1.74E+06	2.32E+06	2.90E+06	3.48E+06	4.06E+06
New York			6.08E+06	1.22E+07	1.83E+07	2.43E+07	4.90E+07	7.37E+07	1.07E+08	1.41E+08
North Carolina				3.93E+06	7.86E+06	1.18E+07	1.57E+07	3.17E+07	4.76E+07	6.36E+07
North Dakota										
Ohio				3.90E+06	7.81E+06	1.17E+07	1.56E+07	1.95E+07	2.34E+07	2.73E+07
Oklahoma								1.45E+06	2.90E+06	4.35E+06
Oregon										
Pennsylvania		4.41E+06	8.19E+06	1.20E+07	1.57E+07	1.95E+07	2.33E+07	3.86E+07	5.40E+07	6.93E+07
Rhode Island		2.79E+05	5.19E+05	7.58E+05	1.73E+06	2.70E+06	3.67E+06	4.99E+06	6.30E+06	7.62E+06
South Carolina					2.12E+06	4.23E+06	6.35E+06	1.49E+07	2.35E+07	3.21E+07
South Dakota										
Tennessee								2.76E+06	5.52E+06	8.28E+06
Texas			1.47E+07	2.94E+07	4.41E+07	5.88E+07	7.35E+07	1.33E+08	1.93E+08	2.53E+08
Utah		1.85E+06	3.44E+06	5.03E+06	6.61E+06	1.31E+07	1.95E+07	2.82E+07	3.69E+07	4.57E+07
Vermont				1.64E+05	3.27E+05	4.91E+05	1.39E+06	2.29E+06	3.19E+06	4.09E+06
Virginia			3.72E+06	7.43E+06	1.11E+07	1.49E+07	3.00E+07	4.50E+07	6.01E+07	7.52E+07
Washington										

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	3.27E+05	6.55E+05	9.82E+05	1.31E+06	1.64E+06
Wisconsin	[redacted]	[redacted]	[redacted]	2.02E+06	4.03E+06	6.05E+06	8.06E+06	1.62E+07	2.44E+07	3.26E+07
Wyoming	[redacted]	[redacted]	2.14E+05	4.28E+05	6.42E+05	8.56E+05	1.07E+06	1.94E+06	2.81E+06	3.68E+06
Washington, DC	[redacted]	1.09E+06	2.02E+06	2.95E+06	3.88E+06	7.67E+06	1.15E+07	1.52E+07	1.90E+07	2.28E+07
TOTAL	[redacted]	**2.52E+07**	**8.45E+07**	**1.82E+08**	**3.17E+08**	**4.77E+08**	**7.24E+08**	**1.13E+09**	**1.54E+09**	**1.95E+09**
Notes: Electric Net Energy Savings calculated as the product of Electric Gross Energy Savings and Attributions.										

Table F-11. Electricity CO2e Emission Rates (lbs. CO2e / MWh)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	917.47	917.47	917.47	917.47	917.47	917.47	892.88	868.30	785.57	785.57
Alaska	930.01	930.01	930.01	930.01	930.01	930.01	921.00	911.99	974.93	974.93
Arizona	937.07	937.07	937.07	937.07	937.07	937.07	954.66	972.25	873.32	873.32
Arkansas	1,122.59	1,122.59	1,122.59	1,122.59	1,122.59	1,122.59	1,170.87	1,219.14	1,127.94	1,127.94
California	454.06	454.06	454.06	454.06	454.06	454.06	438.04	422.03	387.18	387.18
Colorado	1,477.95	1,477.95	1,477.95	1,477.95	1,477.95	1,477.95	1,424.66	1,371.37	1,331.07	1,331.07
Connecticut	502.14	502.14	502.14	502.14	502.14	502.14	505.81	509.48	477.42	477.42

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Delaware	889.34	889.34	889.34	889.34	889.34	889.34	894.86	900.39	711.48	711.48
Florida	1,028.97	1,028.97	1,028.97	1,028.97	1,028.97	1,028.97	988.35	947.72	877.28	877.28
Georgia	1,007.45	1,007.45	1,007.45	1,007.45	1,007.45	1,007.45	969.65	931.86	880.95	880.95
Hawaii	1,532.88	1,532.88	1,532.88	1,532.88	1,532.88	1,532.88	1,528.83	1,524.78	1,562.72	1,562.72
Idaho	189.27	189.27	189.27	189.27	189.27	189.27	174.98	160.70	211.39	211.39
Illinois	816.04	816.04	816.04	816.04	816.04	816.04	817.29	818.54	725.78	725.78
Indiana	1,824.91	1,824.91	1,824.91	1,824.91	1,824.91	1,824.91	1,786.71	1,748.52	1,634.19	1,634.19
Iowa	1,003.87	1,003.87	1,003.87	1,003.87	1,003.87	1,003.87	1,040.62	1,077.36	861.46	861.46
Kansas	1,204.06	1,204.06	1,204.06	1,204.06	1,204.06	1,204.06	1,100.33	996.60	893.64	893.64
Kentucky	1,968.08	1,968.08	1,968.08	1,968.08	1,968.08	1,968.08	1,901.87	1,835.66	1,780.63	1,780.63
Louisiana	882.13	882.13	882.13	882.13	882.13	882.13	860.78	839.43	826.32	826.32
Maine	347.62	347.62	347.62	347.62	347.62	347.62	307.92	268.22	213.57	213.57
Maryland	1,019.45	1,019.45	1,019.45	1,019.45	1,019.45	1,019.45	930.31	841.16	738.70	738.70
Massachusetts	827.51	827.51	827.51	827.51	827.51	827.51	780.68	733.84	780.58	780.58
Michigan	1,106.02	1,106.02	1,106.02	1,106.02	1,106.02	1,106.02	1,110.89	1,115.76	1,013.43	1,013.43
Minnesota	1,020.28	1,020.28	1,020.28	1,020.28	1,020.28	1,020.28	1,011.70	1,003.11	880.93	880.93

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mississippi	943.03	943.03	943.03	943.03	943.03	943.03	931.27	919.52	837.36	837.36
Missouri	1,698.96	1,698.96	1,698.96	1,698.96	1,698.96	1,698.96	1,705.92	1,712.89	1,598.82	1,598.82
Montana	1,260.08	1,260.08	1,260.08	1,260.08	1,260.08	1,260.08	1,213.00	1,165.93	1,262.73	1,262.73
Nebraska	1,290.71	1,290.71	1,290.71	1,290.71	1,290.71	1,290.71	1,354.12	1,417.53	1,265.63	1,265.63
Nevada	771.54	771.54	771.54	771.54	771.54	771.54	759.08	746.62	739.33	739.33
New Hampshire	316.79	316.79	316.79	316.79	316.79	316.79	311.30	305.82	256.24	256.24
New Jersey	559.82	559.82	559.82	559.82	559.82	559.82	530.98	502.14	545.19	545.19
New Mexico	1,582.60	1,582.60	1,582.60	1,582.60	1,582.60	1,582.60	1,461.51	1,340.42	1,326.87	1,326.87
New York	465.88	465.88	465.88	465.88	465.88	465.88	442.28	418.68	378.25	378.25
North Carolina	872.66	872.66	872.66	872.66	872.66	872.66	838.37	804.07	779.54	779.54
North Dakota	1,674.82	1,674.82	1,674.82	1,674.82	1,674.82	1,674.82	1,595.84	1,516.85	1,447.49	1,447.49
Ohio	1,475.33	1,475.33	1,475.33	1,475.33	1,475.33	1,475.33	1,402.59	1,329.85	1,242.46	1,242.46
Oklahoma	1,048.31	1,048.31	1,048.31	1,048.31	1,048.31	1,048.31	970.85	893.38	734.25	734.25
Oregon	307.16	307.16	307.16	307.16	307.16	307.16	310.66	314.16	398.13	398.13
Pennsylvania	860.05	860.05	860.05	860.05	860.05	860.05	824.45	788.84	758.76	758.76
Rhode Island	871.69	871.69	871.69	871.69	871.69	871.69	870.23	868.78	852.28	852.28

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
South Carolina	632.80	632.80	632.80	632.80	632.80	632.80	633.68	634.56	538.39	538.39
South Dakota	516.56	516.56	516.56	516.56	516.56	516.56	518.27	519.99	492.12	492.12
Tennessee	998.41	998.41	998.41	998.41	998.41	998.41	873.38	748.36	704.38	704.38
Texas	1,054.60	1,054.60	1,054.60	1,054.60	1,054.60	1,054.60	1,019.13	983.66	913.42	913.42
Utah	1,638.38	1,638.38	1,638.38	1,638.38	1,638.38	1,638.38	1,623.87	1,609.35	1,601.82	1,601.82
Vermont	66.83	66.83	66.83	66.83	66.83	66.83	62.17	57.51	51.26	51.26
Virginia	818.98	818.98	818.98	818.98	818.98	818.98	780.91	742.84	635.85	635.85
Washington	187.93	187.93	187.93	187.93	187.93	187.93	193.99	200.04	299.10	299.10
West Virginia	1,990.56	1,990.56	1,990.56	1,990.56	1,990.56	1,990.56	1,976.01	1,961.46	1,945.24	1,945.24
Wisconsin	1,396.49	1,396.49	1,396.49	1,396.49	1,396.49	1,396.49	1,396.37	1,396.25	1,232.99	1,232.99
Wyoming	2,040.97	2,040.97	2,040.97	2,040.97	2,040.97	2,040.97	2,052.36	2,063.76	2,068.99	2,068.99
Washington, DC	483.04	483.04	483.04	483.04	483.04	483.04	461.56	440.07	797.69	797.69
Notes: Electric CO2 Emission Rates obtained from EPA's eGRID.										
Source: eGRID (2016, 2018, and 2019)										

Table F-12. Electricity Avoided CO2e Emissions (Lbs.)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama					1.48E+06	2.96E+06	4.32E+06	1.19E+07	1.77E+07	2.47E+07
Alaska										
Arizona					1.24E+07	2.47E+07	3.78E+07	5.13E+07	5.76E+07	6.92E+07
Arkansas					9.90E+05	1.98E+06	3.10E+06	4.30E+06	4.97E+06	5.97E+06
California										
Colorado				4.39E+06	8.79E+06	1.32E+07	1.69E+07	2.04E+07	2.37E+07	2.77E+07
Connecticut				5.44E+05	1.09E+06	1.63E+06	2.19E+06	4.45E+06	6.27E+06	8.37E+06
Delaware		2.87E+05	5.34E+05	7.80E+05	1.03E+06	1.27E+06	2.29E+06	3.32E+06	3.42E+06	4.22E+06
Florida				1.16E+07	2.33E+07	3.49E+07	7.89E+07	1.19E+08	1.51E+08	1.91E+08
Georgia			5.23E+06	1.05E+07	1.57E+07	2.09E+07	2.52E+07	4.38E+07	6.00E+07	7.86E+07
Hawaii										
Idaho			1.07E+05	2.15E+05	3.22E+05	4.29E+05	8.00E+05	1.10E+06	1.94E+06	2.43E+06
Illinois		4.54E+06	8.44E+06	1.23E+07	2.82E+07	4.40E+07	5.99E+07	8.15E+07	9.13E+07	1.10E+08
Indiana		5.98E+06	1.11E+07	1.62E+07	2.14E+07	2.65E+07	3.09E+07	3.52E+07	3.75E+07	4.21E+07
Iowa		1.49E+06	2.77E+06	4.04E+06	5.32E+06	1.05E+07	1.63E+07	2.44E+07	2.55E+07	3.15E+07
Kansas										
Kentucky			3.20E+06	6.40E+06	9.59E+06	2.26E+07	3.44E+07	4.53E+07	5.57E+07	6.74E+07
Louisiana				1.31E+06	2.62E+06	3.93E+06	5.12E+06	1.01E+07	1.49E+07	1.99E+07

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Maine			1.23E+05	2.45E+05	3.68E+05	4.90E+05	5.43E+05	8.57E+05	9.88E+05	1.29E+06
Maryland		3.37E+06	6.26E+06	1.80E+07	2.97E+07	4.15E+07	5.23E+07	6.04E+07	6.46E+07	7.61E+07
Massachusetts		2.44E+06	4.54E+06	6.63E+06	8.73E+06	1.72E+07	2.43E+07	3.30E+07	4.60E+07	5.69E+07
Michigan			2.44E+06	4.88E+06	7.31E+06	9.75E+06	1.22E+07	2.23E+07	2.93E+07	3.84E+07
Minnesota							9.47E+06	1.88E+07	2.47E+07	3.30E+07
Mississippi					3.42E+06	6.85E+06	1.01E+07	1.34E+07	1.52E+07	1.82E+07
Missouri										
Montana		2.96E+05	5.50E+05	8.04E+05	1.06E+06	1.31E+06	2.26E+06	3.12E+06	4.42E+06	5.45E+06
Nebraska				1.04E+06	2.08E+06	3.12E+06	4.37E+06	5.71E+06	6.12E+06	7.14E+06
Nevada				1.44E+06	2.88E+06	4.31E+06	9.99E+06	1.55E+07	2.09E+07	2.65E+07
New Hampshire		1.49E+05	2.77E+05	4.04E+05	5.32E+05	6.60E+05	7.74E+05	1.26E+06	1.48E+06	1.90E+06
New Jersey			1.64E+06	3.29E+06	4.93E+06	6.57E+06	7.79E+06	1.55E+07	2.56E+07	3.44E+07
New Mexico				9.17E+05	1.83E+06	2.75E+06	3.39E+06	3.88E+06	4.61E+06	5.38E+06
New York			2.83E+06	5.67E+06	8.50E+06	1.13E+07	2.17E+07	3.09E+07	4.05E+07	5.32E+07
North Carolina				3.43E+06	6.86E+06	1.03E+07	1.32E+07	2.55E+07	3.71E+07	4.96E+07
North Dakota										
Ohio				5.76E+06	1.15E+07	1.73E+07	2.19E+07	2.60E+07	2.91E+07	3.40E+07
Oklahoma								1.29E+06	2.13E+06	3.19E+06
Oregon										

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Pennsylvania	[redacted]	3.79E+06	7.04E+06	1.03E+07	1.35E+07	1.68E+07	1.92E+07	3.05E+07	4.10E+07	5.26E+07
Rhode Island	[redacted]	2.43E+05	4.52E+05	6.61E+05	1.51E+06	2.35E+06	3.20E+06	4.33E+06	5.37E+06	6.49E+06
South Carolina	[redacted]	[redacted]	[redacted]	[redacted]	1.34E+06	2.68E+06	4.02E+06	9.48E+06	1.27E+07	1.73E+07
South Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tennessee	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.06E+06	3.89E+06	5.83E+06
Texas	[redacted]	[redacted]	1.55E+07	3.10E+07	4.65E+07	6.20E+07	7.49E+07	1.31E+08	1.76E+08	2.31E+08
Utah	[redacted]	3.03E+06	5.63E+06	8.23E+06	1.08E+07	2.14E+07	3.17E+07	4.54E+07	5.92E+07	7.31E+07
Vermont	[redacted]	[redacted]	[redacted]	1.09E+04	2.19E+04	3.28E+04	8.65E+04	1.32E+05	1.64E+05	2.10E+05
Virginia	[redacted]	[redacted]	3.04E+06	6.09E+06	9.13E+06	1.22E+07	2.34E+07	3.35E+07	3.82E+07	4.78E+07
Washington	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	6.52E+05	1.29E+06	1.93E+06	2.55E+06	3.19E+06
Wisconsin	[redacted]	[redacted]	[redacted]	2.81E+06	5.63E+06	8.44E+06	1.13E+07	2.27E+07	3.01E+07	4.02E+07
Wyoming	[redacted]	[redacted]	4.37E+05	8.74E+05	1.31E+06	1.75E+06	2.20E+06	4.00E+06	5.81E+06	7.61E+06
Washington, DC	[redacted]	5.25E+05	9.75E+05	1.43E+06	1.88E+06	3.70E+06	5.29E+06	6.71E+06	1.52E+07	1.82E+07
TOTAL	0.00E+00	2.62E+07	8.31E+07	1.82E+08	3.14E+08	4.75E+08	6.89E+08	1.03E+09	1.29E+09	1.63E+09

Notes: Avoided electric emissions calculated as the product of Electric Net Savings and corresponding Electric CO2e Emissions Rates.

Table F-13. Electricity Non-CO2 Emissions Rates (Lbs. / MWh)

Avoided Pollutant Rate	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
NOX	1.56651	1.41764	1.32823	1.31438	1.21219	1.15920	0.92335	0.89084	0.85419	0.76397
SO2	3.57443	2.65899	2.44408	2.47261	2.16785	1.59563	1.12174	1.00662	0.91593	0.79861
PM2.5	0.15689	0.14138	0.12913	0.12419	0.12474	0.12129	0.09022	0.07656	0.08434	0.08487
VOC	0.02672	0.02672	0.02672	0.02672	0.02672	0.02672	0.02672	0.02663	0.02647	0.02572
NH3	0.02946	0.02946	0.02946	0.02946	0.02946	0.02946	0.02946	0.02837	0.02581	0.02718
Notes: Electric non-CO2 Emission Rates obtained from EPA's AVERT.										
Source (2017-2020):	AVERT Emissions Rates (October 2021), National weighted average of Uniform EE									
Source (2007-2017):	AVERT Emissions Rates (May 2019), National weighted average of Uniform EE, except for VOC and NH3, for which the 2017 number from the October 2021 file is used.									

Table F-14. Electricity Avoided non-CO2e Emissions (Lbs.)

Avoided Pollutant	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
NOX	[redacted]	3.58E+04	1.12E+05	2.40E+05	3.85E+05	5.53E+05	6.68E+05	1.00E+06	1.31E+06	1.49E+06
SO2	[redacted]	6.71E+04	2.06E+05	4.51E+05	6.88E+05	7.61E+05	8.12E+05	1.13E+06	1.41E+06	1.55E+06
PM2.5	[redacted]	3.57E+03	1.09E+04	2.27E+04	3.96E+04	5.78E+04	6.53E+04	8.62E+04	1.30E+05	1.65E+05

Avoided Pollutant	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
VOC	[redacted]	6.74E+02	2.26E+03	4.88E+03	8.48E+03	1.27E+04	1.93E+04	3.00E+04	4.06E+04	5.00E+04
NH3	[redacted]	7.44E+02	2.49E+03	5.38E+03	9.35E+03	1.40E+04	2.13E+04	3.19E+04	3.96E+04	5.29E+04
Notes: Avoided electric emissions calculated as the product of the national-level Electric Net Savings and corresponding Electric non-CO2e Emissions Rates.										

Table F-15. Electricity Energy Price ($ / kWh)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	0.1047	0.1063	0.1051	0.1079	0.1083	0.1111	0.1160	0.1124	0.1152	0.1155
Alaska	0.1510	0.1493	0.1558	0.1709	0.1744	0.1756	0.1889	0.1858	0.1980	0.1958
Arizona	0.0950	0.0953	0.0985	0.1013	0.1039	0.1041	0.1050	0.1064	0.1025	0.1011
Arkansas	0.0750	0.0771	0.0805	0.0805	0.0832	0.0823	0.0851	0.0775	0.0878	0.0861
California	0.1305	0.1341	0.1420	0.1562	0.1573	0.1507	0.1576	0.1634	0.1667	0.1753
Colorado	0.0944	0.0939	0.0986	0.1008	0.0988	0.0960	0.0989	0.1002	0.1043	0.1029
Connecticut	0.1557	0.1465	0.1463	0.1555	0.1597	0.1575	0.1606	0.1676	0.1675	0.1658
Delaware	0.1064	0.1013	0.1020	0.1050	0.1025	0.1007	0.0989	0.0965	0.0953	0.0918
Florida	0.0985	0.0966	0.0939	0.0987	0.0950	0.0890	0.0935	0.0919	0.0927	0.0885
Georgia	0.0987	0.0958	0.0999	0.1036	0.0989	0.0981	0.1009	0.0979	0.1002	0.1008

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hawaii	0.3237	0.3488	0.3405	0.3421	0.2693	0.2464	0.2677	0.2990	0.2923	0.2841
Idaho	0.0641	0.0686	0.0737	0.0778	0.0780	0.0776	0.0798	0.0793	0.0767	0.0775
Illinois	0.0864	0.0799	0.0814	0.0926	0.0902	0.0902	0.0909	0.0912	0.0908	0.0915
Indiana	0.0877	0.0914	0.0960	0.0996	0.0978	0.1001	0.1054	0.1060	0.1103	0.1121
Iowa	0.0785	0.0801	0.0844	0.0867	0.0892	0.0917	0.0946	0.0968	0.0999	0.0996
Kansas	0.0878	0.0924	0.0968	0.1013	0.1010	0.1047	0.1059	0.1066	0.1029	0.1040
Kentucky	0.0849	0.0873	0.0856	0.0944	0.0944	0.0957	0.0985	0.0974	0.1015	0.1034
Louisiana	0.0844	0.0775	0.0896	0.0910	0.0866	0.0859	0.0895	0.0885	0.0891	0.0885
Maine	0.1229	0.1153	0.1174	0.1270	0.1247	0.1208	0.1212	0.1251	0.1283	0.1256
Maryland	0.1128	0.1043	0.1068	0.1115	0.1100	0.1099	0.1075	0.1043	0.0997	0.0972
Massachusetts	0.1433	0.1384	0.1423	0.1468	0.1579	0.1560	0.1594	0.1717	0.1680	0.1603
Michigan	0.1033	0.1093	0.1106	0.1087	0.1055	0.1064	0.1100	0.1115	0.1139	0.1171
Minnesota	0.0863	0.0884	0.0942	0.0985	0.0944	0.0986	0.1048	0.1038	0.1034	0.1043
Mississippi	0.0948	0.0933	0.1010	0.1076	0.1055	0.0957	0.1017	0.1043	0.1052	0.1038
Missouri	0.0804	0.0820	0.0880	0.0890	0.0916	0.0926	0.0947	0.0940	0.0907	0.0893
Montana	0.0912	0.0913	0.0954	0.0964	0.1023	0.1019	0.1012	0.1011	0.1041	0.1051

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nebraska	0.0799	0.0838	0.0860	0.0873	0.0867	0.0880	0.0885	0.0883	0.0885	0.0889
Nevada	0.0905	0.0883	0.0901	0.0947	0.0925	0.0793	0.0796	0.0774	0.0804	0.0745
New Hampshire	0.1404	0.1336	0.1352	0.1434	0.1496	0.1443	0.1481	0.1581	0.1593	0.1541
New Jersey	0.1347	0.1278	0.1277	0.1315	0.1279	0.1226	0.1228	0.1221	0.1223	0.1235
New Mexico	0.0907	0.0932	0.0974	0.1027	0.1030	0.0975	0.1019	0.1002	0.0979	0.1028
New York	0.1581	0.1506	0.1535	0.1612	0.1531	0.1445	0.1475	0.1450	0.1406	0.1456
North Carolina	0.0813	0.0866	0.0876	0.0875	0.0873	0.0862	0.0844	0.0858	0.0881	0.0869
North Dakota	0.0761	0.0802	0.0839	0.0879	0.0883	0.0915	0.0919	0.0910	0.0901	0.0902
Ohio	0.0963	0.0947	0.0935	0.0983	0.1007	0.0997	0.1005	0.1011	0.0972	0.0953
Oklahoma	0.0760	0.0732	0.0777	0.0809	0.0768	0.0766	0.0811	0.0807	0.0798	0.0782
Oregon	0.0815	0.0831	0.0868	0.0875	0.0880	0.0891	0.0886	0.0891	0.0885	0.0900
Pennsylvania	0.1003	0.0944	0.0925	0.0973	0.0960	0.0922	0.0898	0.0894	0.0871	0.0850
Rhode Island	0.1237	0.1187	0.1292	0.1456	0.1578	0.1488	0.1520	0.1658	0.1638	0.1594
South Carolina	0.0930	0.0963	0.0988	0.1028	0.1021	0.1028	0.1057	0.1011	0.1058	0.1035
South Dakota	0.0776	0.0810	0.0851	0.0889	0.0916	0.0958	0.0974	0.0962	0.0959	0.0965
Tennessee	0.1027	0.1031	0.1000	0.1038	0.1016	0.1019	0.1055	0.1051	0.1065	0.1056

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Texas	0.0883	0.0816	0.0802	0.0816	0.0815	0.0826	0.0826	0.0816	0.0806	0.0760
Utah	0.0735	0.0806	0.0832	0.0853	0.0862	0.0875	0.0865	0.0823	0.0826	0.0827
Vermont	0.1400	0.1432	0.1466	0.1456	0.1454	0.1454	0.1461	0.1524	0.1598	0.1639
Virginia	0.0795	0.0808	0.0800	0.0815	0.0821	0.0793	0.0801	0.0832	0.0818	0.0763
Washington	0.0749	0.0768	0.0778	0.0797	0.0822	0.0843	0.0857	0.0872	0.0875	0.0892
West Virginia	0.0814	0.0842	0.0817	0.0799	0.0861	0.0935	0.0958	0.0924	0.0916	0.0940
Wisconsin	0.1042	0.1051	0.1075	0.1077	0.1089	0.1077	0.1087	0.1067	0.1072	0.1075
Wyoming	0.0772	0.0824	0.0857	0.0888	0.0912	0.0940	0.0970	0.0958	0.0964	0.0965
Washington, DC	0.1290	0.1202	0.1194	0.1219	0.1201	0.1172	0.1166	0.1197	0.1226	0.1185
Notes: Electricity prices obtained from EIA.										
Source: EIA (annual retail price by sector by state by provider)										

Table F-16. Electricity Energy Cost Savings, Current Dollars

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	$174,604	$358,237	$561,055	$1,539,444	$2,598,400	$3,628,432
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	$1,371,205	$2,747,689	$4,157,167	$5,616,794	$6,763,644	$8,005,515
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	$73,356	$145,126	$225,095	$273,323	$387,060	$455,479
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	$299,632	$587,375	$856,093	$1,175,938	$1,489,244	$1,860,218	$2,141,123
Connecticut	[redacted]	[redacted]	[redacted]	$168,440	$345,979	$511,819	$695,857	$1,463,480	$2,199,459	$2,906,510
Delaware	[redacted]	$32,747	$61,238	$92,135	$118,344	$144,170	$252,890	$355,350	$458,178	$544,658
Florida	[redacted]	[redacted]	[redacted]	$1,116,374	$2,149,048	$3,019,978	$7,467,594	$11,561,231	$15,920,045	$19,263,994
Georgia	[redacted]	[redacted]	$518,417	$1,075,235	$1,539,682	$2,036,303	$2,618,030	$4,603,417	$6,823,266	$8,988,468
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	$41,773	$88,194	$132,631	$175,934	$364,611	$544,864	$703,553	$889,285
Illinois	[redacted]	$444,966	$841,899	$1,399,783	$3,112,194	$4,860,884	$6,660,868	$9,075,232	$11,417,315	$13,905,584
Indiana	[redacted]	$299,497	$584,215	$885,880	$1,144,571	$1,452,649	$1,825,610	$2,133,736	$2,530,104	$2,886,259
Iowa	[redacted]	$118,876	$232,627	$349,262	$472,808	$959,819	$1,478,915	$2,190,004	$2,958,504	$3,645,888
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	$139,085	$306,767	$460,150	$1,097,980	$1,780,074	$2,402,907	$3,173,821	$3,915,536
Louisiana	[redacted]	[redacted]	[redacted]	$135,251	$257,422	$383,012	$532,085	$1,060,326	$1,605,322	$2,128,698
Maine	[redacted]	[redacted]	$41,404	$89,579	$131,936	$170,412	$213,721	$399,775	$593,762	$761,159

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Maryland	[redacted]	$344,832	$655,768	$1,967,916	$3,207,467	$4,469,426	$6,045,944	$7,490,260	$8,712,564	$10,007,812
Massachusetts	[redacted]	$408,765	$780,544	$1,176,881	$1,665,624	$3,249,521	$4,959,240	$7,730,622	$9,901,263	$11,677,563
Michigan	[redacted]	[redacted]	$243,786	$479,197	$697,635	$938,115	$1,212,319	$2,226,965	$3,294,497	$4,435,299
Minnesota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$981,024	$1,943,326	$2,903,756	$3,905,373
Mississippi	[redacted]	[redacted]	[redacted]	[redacted]	$383,158	$695,132	$1,108,071	$1,515,199	$1,910,343	$2,261,904
Missouri	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Montana	[redacted]	$21,465	$41,655	$61,519	$85,900	$106,100	$188,197	$270,756	$363,990	$453,504
Nebraska	[redacted]	[redacted]	[redacted]	$70,374	$139,780	$212,814	$285,364	$355,899	$428,046	$501,644
Nevada	[redacted]	[redacted]	[redacted]	$176,534	$344,865	$443,478	$1,047,774	$1,604,778	$2,275,653	$2,672,666
New Hampshire	[redacted]	$62,820	$118,066	$183,025	$251,235	$300,496	$368,102	$651,747	$917,449	$1,139,745
New Jersey	[redacted]	[redacted]	$374,768	$771,841	$1,126,066	$1,439,205	$1,801,941	$3,760,769	$5,739,255	$7,787,245
New Mexico	[redacted]	[redacted]	[redacted]	$59,504	$119,355	$169,473	$236,161	$290,276	$340,336	$416,932
New York	[redacted]	[redacted]	$933,838	$1,961,365	$2,794,215	$3,516,343	$7,233,581	$10,693,446	$15,069,288	$20,472,666
North Carolina	[redacted]	[redacted]	[redacted]	$343,858	$686,144	$1,016,247	$1,326,702	$2,718,041	$4,196,943	$5,526,665
North Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ohio	[redacted]	[redacted]	[redacted]	$383,823	$786,389	$1,167,870	$1,569,654	$1,973,782	$2,277,170	$2,604,767

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Oklahoma	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$116,893	$231,178	$339,815
Oregon	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pennsylvania	[redacted]	$416,135	$757,285	$1,164,246	$1,511,442	$1,800,006	$2,092,474	$3,455,065	$4,702,792	$5,893,796
Rhode Island	[redacted]	$33,139	$66,990	$110,338	$272,949	$402,000	$558,374	$827,107	$1,032,539	$1,214,425
South Carolina	[redacted]	[redacted]	[redacted]	[redacted]	$216,048	$435,059	$670,999	$1,510,613	$2,490,045	$3,325,354
South Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tennessee	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$289,910	$587,543	$873,867
Texas	[redacted]	[redacted]	$1,178,858	$2,398,873	$3,593,900	$4,856,542	$6,070,677	$10,868,295	$15,546,523	$19,196,073
Utah	[redacted]	$149,227	$286,082	$428,677	$570,002	$1,142,555	$1,687,009	$2,322,836	$3,051,658	$3,776,580
Vermont	[redacted]	[redacted]	[redacted]	$23,841	$47,616	$71,424	$203,227	$349,118	$509,856	$670,412
Virginia	[redacted]	[redacted]	$297,254	$605,656	$915,172	$1,178,614	$2,399,213	$3,747,554	$4,918,856	$5,739,493
Washington	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$30,620	$62,746	$90,778	$119,990	$153,917
Wisconsin	[redacted]	[redacted]	[redacted]	$217,046	$438,929	$651,138	$876,245	$1,733,399	$2,618,890	$3,506,043
Wyoming	[redacted]	[redacted]	$18,350	$38,028	$58,584	$80,511	$103,850	$185,872	$270,865	$355,062
Washington DC	[redacted]	$130,701	$241,120	$359,787	$466,416	$898,790	$1,335,553	$1,824,160	$2,332,430	$2,702,985

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
TOTAL	[redacted]	$2,463,170	$8,455,024	$18,988,858	$32,450,197	$48,191,582	$74,433,953	$115,256,590	$156,736,367	$195,678,198
Notes: Electric Energy Cost Savings calculated as the product of Electricity Net Savings and Electricity Energy Price.										

Table F-17. Natural Gas Gross Energy Savings (Therms)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	5.41E+05	1.08E+06	1.62E+06	3.14E+06	4.66E+06	6.17E+06
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	2.65E+06	5.29E+06	7.94E+06	1.06E+07	1.32E+07	1.59E+07
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	2.96E+05	5.91E+05	8.87E+05	1.18E+06	1.48E+06	1.77E+06
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	9.97E+05	1.99E+06	2.99E+06	3.99E+06	4.98E+06	5.98E+06	6.98E+06
Connecticut	[redacted]	[redacted]	[redacted]	3.63E+05	7.26E+05	1.09E+06	1.45E+06	2.34E+06	3.22E+06	4.10E+06
Delaware	[redacted]	1.08E+05	2.01E+05	2.94E+05	3.87E+05	4.80E+05	7.06E+05	9.31E+05	1.16E+06	1.38E+06
Florida	[redacted]	[redacted]	[redacted]	3.79E+06	7.59E+06	1.14E+07	2.06E+07	2.98E+07	3.90E+07	4.82E+07
Georgia	[redacted]	[redacted]	1.74E+06	3.48E+06	5.22E+06	6.96E+06	8.70E+06	1.29E+07	1.72E+07	2.14E+07
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Idaho			1.90E+05	3.80E+05	5.70E+05	7.60E+05	1.22E+06	1.68E+06	2.14E+06	2.61E+06
Illinois		1.87E+06	3.47E+06	5.07E+06	8.96E+06	1.28E+07	1.67E+07	2.12E+07	2.57E+07	3.02E+07
Indiana		1.10E+06	2.04E+06	2.98E+06	3.92E+06	4.87E+06	5.81E+06	6.75E+06	7.69E+06	8.63E+06
Iowa		4.98E+05	9.24E+05	1.35E+06	1.78E+06	2.81E+06	3.85E+06	5.05E+06	6.24E+06	7.44E+06
Kansas										
Kentucky			5.45E+05	1.09E+06	1.63E+06	2.96E+06	4.28E+06	5.60E+06	6.93E+06	8.25E+06
Louisiana				4.98E+05	9.97E+05	1.50E+06	1.99E+06	3.20E+06	4.41E+06	5.62E+06
Maine			1.18E+05	2.37E+05	3.55E+05	4.73E+05	5.91E+05	8.79E+05	1.17E+06	1.45E+06
Maryland		1.11E+06	2.06E+06	4.37E+06	6.67E+06	8.98E+06	1.16E+07	1.43E+07	1.70E+07	1.97E+07
Massachusetts		9.90E+05	1.84E+06	2.69E+06	3.54E+06	5.60E+06	7.66E+06	1.00E+07	1.24E+07	1.48E+07
Michigan			7.39E+05	1.48E+06	2.22E+06	2.96E+06	3.70E+06	5.49E+06	7.29E+06	9.08E+06
Minnesota							1.88E+06	3.75E+06	5.63E+06	7.51E+06
Mississippi					7.28E+05	1.46E+06	2.18E+06	2.91E+06	3.64E+06	4.37E+06
Missouri										
Montana		7.88E+04	1.46E+05	2.14E+05	2.82E+05	3.49E+05	5.13E+05	6.77E+05	8.41E+05	1.01E+06
Nebraska				2.70E+05	5.41E+05	8.11E+05	1.08E+06	1.35E+06	1.62E+06	1.89E+06

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nevada				6.25E+05	1.25E+06	1.88E+06	3.39E+06	4.91E+06	6.43E+06	7.95E+06
New Hampshire		1.58E+05	2.93E+05	4.28E+05	5.63E+05	6.98E+05	8.33E+05	1.16E+06	1.49E+06	1.82E+06
New Jersey			9.84E+05	1.97E+06	2.95E+06	3.94E+06	4.92E+06	7.68E+06	1.04E+07	1.32E+07
New Mexico				1.94E+05	3.89E+05	5.83E+05	7.77E+05	9.71E+05	1.17E+06	1.36E+06
New York			2.04E+06	4.08E+06	6.12E+06	8.16E+06	1.31E+07	1.81E+07	2.38E+07	2.95E+07
North Carolina				1.32E+06	2.64E+06	3.95E+06	5.27E+06	8.47E+06	1.17E+07	1.49E+07
North Dakota										
Ohio				1.31E+06	2.62E+06	3.93E+06	5.24E+06	6.55E+06	7.86E+06	9.17E+06
Oklahoma								4.86E+05	9.71E+05	1.46E+06
Oregon										
Pennsylvania		1.48E+06	2.75E+06	4.01E+06	5.28E+06	6.55E+06	7.81E+06	1.09E+07	1.40E+07	1.70E+07
Rhode Island		9.36E+04	1.74E+05	2.54E+05	4.49E+05	6.44E+05	8.39E+05	1.06E+06	1.29E+06	1.51E+06
South Carolina					7.10E+05	1.42E+06	2.13E+06	3.85E+06	5.58E+06	7.30E+06
South Dakota										
Tennessee								9.25E+05	1.85E+06	2.77E+06
Texas			4.93E+06	9.86E+06	1.48E+07	1.97E+07	2.46E+07	3.66E+07	4.86E+07	6.06E+07

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Utah		6.21E+05	1.15E+06	1.69E+06	2.22E+06	3.51E+06	4.80E+06	6.30E+06	7.79E+06	9.28E+06
Vermont				5.49E+04	1.10E+05	1.65E+05	3.19E+05	4.73E+05	6.27E+05	7.81E+05
Virginia			1.25E+06	2.49E+06	3.74E+06	4.98E+06	8.01E+06	1.10E+07	1.41E+07	1.71E+07
Washington										
West Virginia						1.10E+05	2.20E+05	3.29E+05	4.39E+05	5.49E+05
Wisconsin				6.76E+05	1.35E+06	2.03E+06	2.70E+06	4.34E+06	5.99E+06	7.63E+06
Wyoming			7.18E+04	1.44E+05	2.15E+05	2.87E+05	3.59E+05	5.33E+05	7.08E+05	8.82E+05
Washington, DC		3.65E+05	6.77E+05	9.90E+05	1.30E+06	2.06E+06	2.82E+06	3.58E+06	4.34E+06	5.10E+06
TOTAL		8.47E+06	2.83E+07	5.96E+07	9.83E+07	1.41E+08	1.97E+08	2.77E+08	3.58E+08	4.38E+08

Notes: Gross natural gas energy savings calculated as the product of the Gross ASHRAE Energy Savings, ASHRAE Adoption Timeline, and New Construction Floor Areas.

Table F-18. Natural Gas Net Energy Savings (Therms)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama					6.04E+04	1.21E+05	1.81E+05	3.50E+05	5.20E+05	6.89E+05
Alaska										
Arizona					2.95E+05	5.90E+05	8.85E+05	1.18E+06	1.48E+06	1.77E+06
Arkansas					3.30E+04	6.61E+04	9.91E+04	1.32E+05	1.65E+05	1.98E+05

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	1.11E+05	2.23E+05	3.34E+05	4.46E+05	5.57E+05	6.68E+05	7.80E+05
Connecticut	[redacted]	[redacted]	[redacted]	4.06E+04	8.12E+04	1.22E+05	1.62E+05	2.61E+05	3.59E+05	4.57E+05
Delaware	[redacted]	1.21E+04	2.25E+04	3.29E+04	4.33E+04	5.36E+04	7.88E+04	1.04E+05	1.29E+05	1.54E+05
Florida	[redacted]	[redacted]	[redacted]	4.24E+05	8.48E+05	1.27E+06	2.30E+06	3.33E+06	4.35E+06	5.38E+06
Georgia	[redacted]	[redacted]	1.94E+05	3.89E+05	5.83E+05	7.78E+05	9.72E+05	1.44E+06	1.91E+06	2.39E+06
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	2.12E+04	4.25E+04	6.37E+04	8.50E+04	1.36E+05	1.88E+05	2.39E+05	2.91E+05
Illinois	[redacted]	2.09E+05	3.88E+05	5.66E+05	1.00E+06	1.43E+06	1.87E+06	2.37E+06	2.87E+06	3.37E+06
Indiana	[redacted]	1.23E+05	2.28E+05	3.33E+05	4.39E+05	5.44E+05	6.49E+05	7.54E+05	8.60E+05	9.65E+05
Iowa	[redacted]	5.56E+04	1.03E+05	1.51E+05	1.99E+05	3.14E+05	4.30E+05	5.63E+05	6.97E+05	8.30E+05
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	6.09E+04	1.22E+05	1.83E+05	3.30E+05	4.78E+05	6.25E+05	7.73E+05	9.20E+05
Louisiana	[redacted]	[redacted]	[redacted]	5.57E+04	1.11E+05	1.67E+05	2.23E+05	3.58E+05	4.93E+05	6.28E+05
Maine	[redacted]	[redacted]	1.32E+04	2.64E+04	3.96E+04	5.29E+04	6.61E+04	9.81E+04	1.30E+05	1.62E+05
Maryland	[redacted]	1.24E+05	2.30E+05	4.87E+05	7.45E+05	1.00E+06	1.30E+06	1.60E+06	1.89E+06	2.19E+06
Massachusetts	[redacted]	1.11E+05	2.06E+05	3.00E+05	3.95E+05	6.25E+05	8.55E+05	1.12E+06	1.39E+06	1.65E+06
Michigan	[redacted]	[redacted]	8.26E+04	1.65E+05	2.48E+05	3.30E+05	4.13E+05	6.13E+05	8.13E+05	1.01E+06
Minnesota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.09E+05	4.19E+05	6.28E+05	8.37E+05

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mississippi	[redacted]	[redacted]	[redacted]	[redacted]	8.12E+04	1.62E+05	2.44E+05	3.25E+05	4.06E+05	4.87E+05
Missouri	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Montana	[redacted]	8.81E+03	1.64E+04	2.39E+04	3.15E+04	3.90E+04	5.73E+04	7.56E+04	9.39E+04	1.12E+05
Nebraska	[redacted]	[redacted]	[redacted]	3.02E+04	6.04E+04	9.06E+04	1.21E+05	1.51E+05	1.81E+05	2.11E+05
Nevada	[redacted]	[redacted]	[redacted]	6.99E+04	1.40E+05	2.10E+05	3.79E+05	5.48E+05	7.17E+05	8.87E+05
New Hampshire	[redacted]	1.76E+04	3.27E+04	4.78E+04	6.29E+04	7.80E+04	9.31E+04	1.30E+05	1.66E+05	2.03E+05
New Jersey	[redacted]	[redacted]	1.10E+05	2.20E+05	3.30E+05	4.40E+05	5.50E+05	8.58E+05	1.17E+06	1.47E+06
New Mexico	[redacted]	[redacted]	[redacted]	2.17E+04	4.34E+04	6.51E+04	8.68E+04	1.09E+05	1.30E+05	1.52E+05
New York	[redacted]	[redacted]	2.28E+05	4.56E+05	6.84E+05	9.12E+05	1.46E+06	2.02E+06	2.65E+06	3.29E+06
North Carolina	[redacted]	[redacted]	[redacted]	1.47E+05	2.95E+05	4.42E+05	5.89E+05	9.46E+05	1.30E+06	1.66E+06
North Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ohio	[redacted]	[redacted]	[redacted]	1.46E+05	2.93E+05	4.39E+05	5.85E+05	7.32E+05	8.78E+05	1.02E+06
Oklahoma	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	5.43E+04	1.09E+05	1.63E+05
Oregon	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pennsylvania	[redacted]	1.65E+05	3.07E+05	4.48E+05	5.90E+05	7.32E+05	8.73E+05	1.22E+06	1.56E+06	1.90E+06
Rhode Island	[redacted]	1.05E+04	1.94E+04	2.84E+04	5.01E+04	7.19E+04	9.36E+04	1.19E+05	1.44E+05	1.69E+05
South Carolina	[redacted]	[redacted]	[redacted]	[redacted]	7.93E+04	1.59E+05	2.38E+05	4.30E+05	6.22E+05	8.14E+05
South Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tennessee	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.03E+05	2.07E+05	3.10E+05

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Texas	[redacted]	[redacted]	5.51E+05	1.10E+06	1.65E+06	2.20E+06	2.75E+06	4.09E+06	5.42E+06	6.76E+06
Utah	[redacted]	6.94E+04	1.29E+05	1.88E+05	2.48E+05	3.92E+05	5.36E+05	7.03E+05	8.69E+05	1.04E+06
Vermont	[redacted]	[redacted]	[redacted]	6.14E+03	1.23E+04	1.84E+04	3.56E+04	5.28E+04	7.00E+04	8.71E+04
Virginia	[redacted]	[redacted]	1.39E+05	2.78E+05	4.18E+05	5.57E+05	8.94E+05	1.23E+06	1.57E+06	1.91E+06
Washington	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.23E+04	2.45E+04	3.68E+04	4.91E+04	6.14E+04
Wisconsin	[redacted]	[redacted]	[redacted]	7.55E+04	1.51E+05	2.27E+05	3.02E+05	4.85E+05	6.68E+05	8.51E+05
Wyoming	[redacted]	[redacted]	8.02E+03	1.60E+04	2.41E+04	3.21E+04	4.01E+04	5.96E+04	7.90E+04	9.84E+04
Washington, DC	[redacted]	4.07E+04	7.57E+04	1.11E+05	1.46E+05	2.30E+05	3.15E+05	3.99E+05	4.84E+05	5.69E+05
TOTAL	[redacted]	9.46E+05	3.17E+06	6.66E+06	1.10E+07	1.57E+07	2.20E+07	3.09E+07	3.99E+07	4.89E+07

Notes: Natural Gas Net Electric Energy Savings calculated as the product of Natural Gas Gross Electric Energy Savings and Attributions.

Table F-19. Natural Gas Avoided CO2e Emissions (Lbs.)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	1.44E+06	2.87E+06	4.31E+06	8.33E+06	1.24E+07	1.64E+07
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	7.02E+06	1.40E+07	2.10E+07	2.81E+07	3.51E+07	4.21E+07
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	7.86E+05	1.57E+06	2.36E+06	3.14E+06	3.93E+06	4.71E+06

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	2.65E+06	5.30E+06	7.95E+06	1.06E+07	1.32E+07	1.59E+07	1.85E+07
Connecticut	[redacted]	[redacted]	[redacted]	9.65E+05	1.93E+06	2.90E+06	3.86E+06	6.20E+06	8.54E+06	1.09E+07
Delaware	[redacted]	2.88E+05	5.35E+05	7.82E+05	1.03E+06	1.28E+06	1.87E+06	2.47E+06	3.07E+06	3.67E+06
Florida	[redacted]	[redacted]	[redacted]	1.01E+07	2.02E+07	3.02E+07	5.47E+07	7.91E+07	1.03E+08	1.28E+08
Georgia	[redacted]	[redacted]	4.62E+06	9.25E+06	1.39E+07	1.85E+07	2.31E+07	3.43E+07	4.55E+07	5.67E+07
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	5.05E+05	1.01E+06	1.52E+06	2.02E+06	3.24E+06	4.47E+06	5.69E+06	6.91E+06
Illinois	[redacted]	4.96E+06	9.22E+06	1.35E+07	2.38E+07	3.41E+07	4.44E+07	5.63E+07	6.82E+07	8.01E+07
Indiana	[redacted]	2.92E+06	5.42E+06	7.93E+06	1.04E+07	1.29E+07	1.54E+07	1.79E+07	2.04E+07	2.29E+07
Iowa	[redacted]	1.32E+06	2.46E+06	3.59E+06	4.72E+06	7.47E+06	1.02E+07	1.34E+07	1.66E+07	1.97E+07
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	1.45E+06	2.90E+06	4.34E+06	7.85E+06	1.14E+07	1.49E+07	1.84E+07	2.19E+07
Louisiana	[redacted]	[redacted]	[redacted]	1.32E+06	2.65E+06	3.97E+06	5.30E+06	8.51E+06	1.17E+07	1.49E+07
Maine	[redacted]	[redacted]	3.14E+05	6.28E+05	9.43E+05	1.26E+06	1.57E+06	2.33E+06	3.09E+06	3.86E+06
Maryland	[redacted]	2.95E+06	5.47E+06	1.16E+07	1.77E+07	2.38E+07	3.09E+07	3.80E+07	4.50E+07	5.21E+07
Massachusetts	[redacted]	2.63E+06	4.89E+06	7.14E+06	9.40E+06	1.49E+07	2.03E+07	2.66E+07	3.30E+07	3.93E+07
Michigan	[redacted]	[redacted]	1.96E+06	3.93E+06	5.89E+06	7.86E+06	9.82E+06	1.46E+07	1.93E+07	2.41E+07
Minnesota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	4.98E+06	9.95E+06	1.49E+07	1.99E+07

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mississippi					1.93E+06	3.86E+06	5.79E+06	7.72E+06	9.65E+06	1.16E+07
Missouri										
Montana		2.09E+05	3.89E+05	5.69E+05	7.48E+05	9.28E+05	1.36E+06	1.80E+06	2.23E+06	2.67E+06
Nebraska				7.18E+05	1.44E+06	2.15E+06	2.87E+06	3.59E+06	4.31E+06	5.03E+06
Nevada				1.66E+06	3.32E+06	4.98E+06	9.01E+06	1.30E+07	1.71E+07	2.11E+07
New Hampshire		4.19E+05	7.78E+05	1.14E+06	1.50E+06	1.86E+06	2.21E+06	3.08E+06	3.95E+06	4.83E+06
New Jersey			2.61E+06	5.23E+06	7.84E+06	1.05E+07	1.31E+07	2.04E+07	2.77E+07	3.50E+07
New Mexico				5.16E+05	1.03E+06	1.55E+06	2.06E+06	2.58E+06	3.10E+06	3.61E+06
New York			5.42E+06	1.08E+07	1.63E+07	2.17E+07	3.48E+07	4.80E+07	6.31E+07	7.83E+07
North Carolina				3.50E+06	7.00E+06	1.05E+07	1.40E+07	2.25E+07	3.10E+07	3.95E+07
North Dakota										
Ohio				3.48E+06	6.96E+06	1.04E+07	1.39E+07	1.74E+07	2.09E+07	2.44E+07
Oklahoma								1.29E+06	2.58E+06	3.87E+06
Oregon										
Pennsylvania		3.93E+06	7.29E+06	1.07E+07	1.40E+07	1.74E+07	2.08E+07	2.89E+07	3.71E+07	4.52E+07
Rhode Island		2.49E+05	4.62E+05	6.75E+05	1.19E+06	1.71E+06	2.23E+06	2.82E+06	3.42E+06	4.02E+06
South Carolina					1.89E+06	3.77E+06	5.66E+06	1.02E+07	1.48E+07	1.94E+07
South Dakota										
Tennessee								2.46E+06	4.92E+06	7.37E+06

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Texas	[redacted]	[redacted]	1.31E+07	2.62E+07	3.93E+07	5.24E+07	6.55E+07	9.72E+07	1.29E+08	1.61E+08
Utah	[redacted]	1.65E+06	3.06E+06	4.48E+06	5.89E+06	9.32E+06	1.27E+07	1.67E+07	2.07E+07	2.46E+07
Vermont	[redacted]	[redacted]	[redacted]	1.46E+05	2.92E+05	4.38E+05	8.46E+05	1.25E+06	1.66E+06	2.07E+06
Virginia	[redacted]	[redacted]	3.31E+06	6.62E+06	9.93E+06	1.32E+07	2.13E+07	2.93E+07	3.73E+07	4.53E+07
Washington	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	2.92E+05	5.84E+05	8.75E+05	1.17E+06	1.46E+06
Wisconsin	[redacted]	[redacted]	[redacted]	1.80E+06	3.59E+06	5.39E+06	7.18E+06	1.15E+07	1.59E+07	2.02E+07
Wyoming	[redacted]	[redacted]	1.91E+05	3.82E+05	5.72E+05	7.63E+05	9.54E+05	1.42E+06	1.88E+06	2.34E+06
Washington, DC	[redacted]	9.69E+05	1.80E+06	2.63E+06	3.46E+06	5.47E+06	7.48E+06	9.50E+06	1.15E+07	1.35E+07
TOTAL	[redacted]	2.25E+07	7.53E+07	1.58E+08	2.61E+08	3.74E+08	5.24E+08	7.35E+08	9.49E+08	1.16E+09

Notes: Avoided natural gas emissions calculated as the product of Net Natural Gas Savings and natural gas emissions factor of 23.7790596 from EPA's GHG Emission Factors Hub.

Source: GHG Emission Factors Hub

Table F-20. Natural Gas Avoided NOx Emissions (Lbs.)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	3.27E+02	6.54E+02	9.81E+02	1.31E+03	1.64E+03	1.96E+03
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	2.21E+03	3.31E+03	4.41E+03	5.51E+03	6.62E+03	7.72E+03
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	8.04E+02	1.21E+03	1.61E+03	2.58E+03	3.55E+03	4.53E+03
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	4.20E+03	8.39E+03	1.26E+04	2.28E+04	3.29E+04	4.31E+04	5.33E+04
Connecticut	[redacted]	[redacted]	[redacted]	3.85E+03	5.78E+03	7.70E+03	9.63E+03	1.43E+04	1.90E+04	2.36E+04
Delaware	[redacted]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Florida	[redacted]	[redacted]	[redacted]	4.21E+02	6.31E+02	8.41E+02	1.35E+03	1.86E+03	2.37E+03	2.88E+03
Georgia	[redacted]	[redacted]	3.84E+03	5.61E+03	9.90E+03	1.42E+04	1.85E+04	2.34E+04	2.84E+04	3.34E+04
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	1.02E+03	1.49E+03	1.97E+03	3.11E+03	4.25E+03	5.58E+03	6.90E+03	8.22E+03
Illinois	[redacted]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Indiana	[redacted]	0.00E+00	6.03E+02	1.21E+03	1.81E+03	3.27E+03	4.73E+03	6.19E+03	7.65E+03	9.11E+03
Iowa	[redacted]	0.00E+00	0.00E+00	5.51E+02	1.10E+03	1.65E+03	2.21E+03	3.54E+03	4.88E+03	6.21E+03
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	2.28E+03	4.83E+03	7.37E+03	9.92E+03	1.29E+04	1.58E+04	1.88E+04	2.17E+04
Louisiana	[redacted]	[redacted]	[redacted]	2.97E+03	3.91E+03	6.19E+03	8.46E+03	1.11E+04	1.37E+04	1.64E+04

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Maine			8.18E+02	1.64E+03	2.45E+03	3.27E+03	4.09E+03	6.07E+03	8.05E+03	1.00E+04
Maryland		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.07E+03	4.14E+03	6.22E+03	8.29E+03
Massachusetts		0.00E+00	0.00E+00	0.00E+00	8.04E+02	1.61E+03	2.41E+03	3.22E+03	4.02E+03	4.82E+03
Michigan			0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Minnesota							5.67E+02	7.49E+02	9.30E+02	1.11E+03
Mississippi					5.98E+02	8.97E+02	1.20E+03	1.50E+03	1.79E+03	2.09E+03
Missouri										
Montana		1.74E+02	3.24E+02	4.73E+02	6.23E+02	7.73E+02	9.22E+02	1.28E+03	1.65E+03	2.01E+03
Nebraska				2.18E+03	3.27E+03	4.35E+03	5.44E+03	8.49E+03	1.15E+04	1.46E+04
Nevada				2.15E+02	4.30E+02	6.45E+02	8.60E+02	1.07E+03	1.29E+03	1.50E+03
New Hampshire		0.00E+00	2.26E+03	4.51E+03	6.77E+03	9.03E+03	1.45E+04	2.00E+04	2.63E+04	3.26E+04
New Jersey			0.00E+00	1.46E+03	2.92E+03	4.37E+03	5.83E+03	9.36E+03	1.29E+04	1.64E+04
New Mexico				0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
New York			0.00E+00	1.45E+03	2.90E+03	4.35E+03	5.79E+03	7.24E+03	8.69E+03	1.01E+04
North Carolina				0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.37E+02	1.07E+03	1.61E+03
North Dakota										

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Ohio				4.44E+03	5.84E+03	7.24E+03	8.64E+03	1.20E+04	1.54E+04	1.88E+04
Oklahoma								1.18E+03	1.42E+03	1.67E+03
Oregon										
Pennsylvania		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rhode Island		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.02E+03	2.05E+03	3.07E+03
South Carolina					1.64E+04	2.18E+04	2.73E+04	4.05E+04	5.37E+04	6.69E+04
South Dakota										
Tennessee								5.22E+02	6.93E+02	8.63E+02
Texas			1.38E+03	2.76E+03	4.14E+03	5.51E+03	8.85E+03	1.22E+04	1.55E+04	1.89E+04
Utah		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Vermont				0.00E+00	0.00E+00	1.21E+02	2.43E+02	3.64E+02	4.86E+02	6.07E+02
Virginia			0.00E+00	7.48E+02	1.50E+03	2.24E+03	2.99E+03	4.80E+03	6.61E+03	8.42E+03
Washington										
West Virginia						2.28E+03	3.12E+03	3.95E+03	4.79E+03	5.63E+03
Wisconsin				6.60E+04	1.09E+05	1.56E+05	2.18E+05	3.06E+05	3.95E+05	4.84E+05
Wyoming			0.00E+00	0.00E+00	3.27E+02	6.54E+02	9.81E+02	1.31E+03	1.64E+03	1.96E+03

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Washington, DC	[redacted]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
TOTAL	[redacted]	0.00E+00	0.00E+00	1.10E+03	2.21E+03	3.31E+03	4.41E+03	5.51E+03	6.62E+03	7.72E+03

Notes: Avoided natural gas emissions calculated as the product of Natural Gas Net Energy Savings and a weighted natural gas emissions factor of 0.009900148 lbs./therm derived from C&I Nationwide Inventory and Emission Factors for Large Wall-Fired Boilers (>100) and Small Boilers (<100).

Source: Characterization of the U.S. Industrial/Commercial Boiler Population (Table ES-1)

Table F-21. Natural Gas Avoided PM2.5 Emissions (Lbs.)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	4.43E+01	8.85E+01	1.33E+02	2.57E+02	3.81E+02	5.05E+02
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	2.16E+02	4.32E+02	6.49E+02	8.65E+02	1.08E+03	1.30E+03
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	2.42E+01	4.84E+01	7.26E+01	9.68E+01	1.21E+02	1.45E+02
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	8.16E+01	1.63E+02	2.45E+02	3.27E+02	4.08E+02	4.90E+02	5.71E+02
Connecticut	[redacted]	[redacted]	[redacted]	2.97E+01	5.95E+01	8.92E+01	1.19E+02	1.91E+02	2.63E+02	3.35E+02
Delaware	[redacted]	8.88E+00	1.65E+01	2.41E+01	3.17E+01	3.93E+01	5.78E+01	7.62E+01	9.46E+01	1.13E+02
Florida	[redacted]	[redacted]	[redacted]	3.11E+02	6.21E+02	9.32E+02	1.68E+03	2.44E+03	3.19E+03	3.94E+03
Georgia	[redacted]	[redacted]	1.43E+02	2.85E+02	4.28E+02	5.70E+02	7.13E+02	1.06E+03	1.40E+03	1.75E+03

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	1.56E+01	3.11E+01	4.67E+01	6.23E+01	1.00E+02	1.38E+02	1.75E+02	2.13E+02
Illinois	[redacted]	1.53E+02	2.84E+02	4.15E+02	7.33E+02	1.05E+03	1.37E+03	1.74E+03	2.10E+03	2.47E+03
Indiana	[redacted]	9.00E+01	1.67E+02	2.44E+02	3.21E+02	3.99E+02	4.76E+02	5.53E+02	6.30E+02	7.07E+02
Iowa	[redacted]	4.08E+01	7.57E+01	1.11E+02	1.46E+02	2.30E+02	3.15E+02	4.13E+02	5.11E+02	6.08E+02
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	4.46E+01	8.92E+01	1.34E+02	2.42E+02	3.50E+02	4.58E+02	5.66E+02	6.74E+02
Louisiana	[redacted]	[redacted]	[redacted]	4.08E+01	8.16E+01	1.22E+02	1.63E+02	2.62E+02	3.61E+02	4.60E+02
Maine	[redacted]	[redacted]	9.68E+00	1.94E+01	2.91E+01	3.87E+01	4.84E+01	7.19E+01	9.54E+01	1.19E+02
Maryland	[redacted]	9.08E+01	1.69E+02	3.57E+02	5.46E+02	7.34E+02	9.52E+02	1.17E+03	1.39E+03	1.61E+03
Massachusetts	[redacted]	8.11E+01	1.51E+02	2.20E+02	2.90E+02	4.58E+02	6.27E+02	8.21E+02	1.02E+03	1.21E+03
Michigan	[redacted]	[redacted]	6.05E+01	1.21E+02	1.82E+02	2.42E+02	3.03E+02	4.49E+02	5.96E+02	7.43E+02
Minnesota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.53E+02	3.07E+02	4.60E+02	6.13E+02
Mississippi	[redacted]	[redacted]	[redacted]	[redacted]	5.95E+01	1.19E+02	1.79E+02	2.38E+02	2.98E+02	3.57E+02
Missouri	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Montana	[redacted]	6.46E+00	1.20E+01	1.75E+01	2.31E+01	2.86E+01	4.20E+01	5.54E+01	6.88E+01	8.22E+01
Nebraska	[redacted]	[redacted]	[redacted]	2.21E+01	4.43E+01	6.64E+01	8.85E+01	1.11E+02	1.33E+02	1.55E+02
Nevada	[redacted]	[redacted]	[redacted]	5.12E+01	1.02E+02	1.54E+02	2.78E+02	4.02E+02	5.26E+02	6.50E+02
New Hampshire	[redacted]	1.29E+01	2.40E+01	3.50E+01	4.61E+01	5.72E+01	6.83E+01	9.51E+01	1.22E+02	1.49E+02

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
New Jersey	[redacted]	[redacted]	8.06E+01	1.61E+02	2.42E+02	3.22E+02	4.03E+02	6.29E+02	8.54E+02	1.08E+03
New Mexico	[redacted]	[redacted]	[redacted]	1.59E+01	3.18E+01	4.77E+01	6.36E+01	7.96E+01	9.55E+01	1.11E+02
New York	[redacted]	[redacted]	1.67E+02	3.34E+02	5.01E+02	6.68E+02	1.07E+03	1.48E+03	1.95E+03	2.41E+03
North Carolina	[redacted]	[redacted]	[redacted]	1.08E+02	2.16E+02	3.24E+02	4.32E+02	6.93E+02	9.55E+02	1.22E+03
North Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ohio	[redacted]	[redacted]	[redacted]	1.07E+02	2.14E+02	3.22E+02	4.29E+02	5.36E+02	6.43E+02	7.51E+02
Oklahoma	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	3.98E+01	7.96E+01	1.19E+02
Oregon	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pennsylvania	[redacted]	1.21E+02	2.25E+02	3.29E+02	4.32E+02	5.36E+02	6.40E+02	8.91E+02	1.14E+03	1.39E+03
Rhode Island	[redacted]	7.67E+00	1.42E+01	2.08E+01	3.67E+01	5.27E+01	6.86E+01	8.70E+01	1.05E+02	1.24E+02
South Carolina	[redacted]	[redacted]	[redacted]	[redacted]	5.81E+01	1.16E+02	1.74E+02	3.15E+02	4.56E+02	5.97E+02
South Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tennessee	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	7.58E+01	1.52E+02	2.27E+02
Texas	[redacted]	[redacted]	4.04E+02	8.07E+02	1.21E+03	1.61E+03	2.02E+03	3.00E+03	3.97E+03	4.95E+03
Utah	[redacted]	5.08E+01	9.44E+01	1.38E+02	1.82E+02	2.87E+02	3.93E+02	5.15E+02	6.37E+02	7.59E+02
Vermont	[redacted]	[redacted]	[redacted]	4.50E+00	8.99E+00	1.35E+01	2.61E+01	3.87E+01	5.13E+01	6.39E+01
Virginia	[redacted]	[redacted]	1.02E+02	2.04E+02	3.06E+02	4.08E+02	6.55E+02	9.03E+02	1.15E+03	1.40E+03
Washington	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	8.99E+00	1.80E+01	2.70E+01	3.60E+01	4.50E+01

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Wisconsin	[redacted]	[redacted]	[redacted]	5.53E+01	1.11E+02	1.66E+02	2.21E+02	3.55E+02	4.90E+02	6.24E+02
Wyoming	[redacted]	[redacted]	5.88E+00	1.18E+01	1.76E+01	2.35E+01	2.94E+01	4.36E+01	5.79E+01	7.21E+01
Washington, DC	[redacted]	2.99E+01	5.55E+01	8.11E+01	1.07E+02	1.69E+02	2.31E+02	2.93E+02	3.55E+02	4.17E+02
TOTAL	[redacted]	6.93E+02	2.32E+03	4.88E+03	8.05E+03	1.15E+04	1.61E+04	2.27E+04	2.93E+04	3.58E+04
Notes: Avoided natural gas emissions calculated as the product of Natural Gas Net Energy Savings and a natural gas emissions factor of 0.000732883 lbs./therm obtained from EPA.										
Source: AP-42 (Chapter 1.4, Table 1.4-2)										

Table F-22. Natural Gas Avoided SO2 Emissions (Lbs.)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	3.50E+00	6.99E+00	1.05E+01	2.03E+01	3.01E+01	3.99E+01
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	1.71E+01	3.41E+01	5.12E+01	6.83E+01	8.54E+01	1.02E+02
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	1.91E+00	3.82E+00	5.73E+00	7.65E+00	9.56E+00	1.15E+01
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	6.44E+00	1.29E+01	1.93E+01	2.58E+01	3.22E+01	3.87E+01	4.51E+01
Connecticut	[redacted]	[redacted]	[redacted]	2.35E+00	4.70E+00	7.05E+00	9.39E+00	1.51E+01	2.08E+01	2.65E+01

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Delaware	[redacted]	7.01E-01	1.30E+00	1.90E+00	2.50E+00	3.10E+00	4.56E+00	6.02E+00	7.47E+00	8.93E+00
Florida	[redacted]	[redacted]	[redacted]	2.45E+01	4.90E+01	7.36E+01	1.33E+02	1.92E+02	2.52E+02	3.11E+02
Georgia	[redacted]	[redacted]	1.13E+01	2.25E+01	3.38E+01	4.50E+01	5.63E+01	8.35E+01	1.11E+02	1.38E+02
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	1.23E+00	2.46E+00	3.69E+00	4.92E+00	7.89E+00	1.09E+01	1.38E+01	1.68E+01
Illinois	[redacted]	1.21E+01	2.24E+01	3.28E+01	5.78E+01	8.29E+01	1.08E+02	1.37E+02	1.66E+02	1.95E+02
Indiana	[redacted]	7.10E+00	1.32E+01	1.93E+01	2.54E+01	3.15E+01	3.76E+01	4.36E+01	4.97E+01	5.58E+01
Iowa	[redacted]	3.22E+00	5.98E+00	8.73E+00	1.15E+01	1.82E+01	2.49E+01	3.26E+01	4.03E+01	4.80E+01
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	3.52E+00	7.05E+00	1.06E+01	1.91E+01	2.76E+01	3.62E+01	4.47E+01	5.32E+01
Louisiana	[redacted]	[redacted]	[redacted]	3.22E+00	6.44E+00	9.67E+00	1.29E+01	2.07E+01	2.85E+01	3.63E+01
Maine	[redacted]	[redacted]	7.65E-01	1.53E+00	2.29E+00	3.06E+00	3.82E+00	5.68E+00	7.53E+00	9.38E+00
Maryland	[redacted]	7.17E+00	1.33E+01	2.82E+01	4.31E+01	5.80E+01	7.52E+01	9.24E+01	1.10E+02	1.27E+02
Massachusetts	[redacted]	6.40E+00	1.19E+01	1.74E+01	2.29E+01	3.62E+01	4.95E+01	6.48E+01	8.02E+01	9.56E+01
Michigan	[redacted]	[redacted]	4.78E+00	9.56E+00	1.43E+01	1.91E+01	2.39E+01	3.55E+01	4.71E+01	5.86E+01
Minnesota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	1.21E+01	2.42E+01	3.63E+01	4.84E+01
Mississippi	[redacted]	[redacted]	[redacted]	[redacted]	4.70E+00	9.40E+00	1.41E+01	1.88E+01	2.35E+01	2.82E+01
Missouri	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Montana	[redacted]	5.10E-01	9.47E-01	1.38E+00	1.82E+00	2.26E+00	3.32E+00	4.37E+00	5.43E+00	6.49E+00

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nebraska	[redacted]	[redacted]	[redacted]	1.75E+00	3.50E+00	5.24E+00	6.99E+00	8.74E+00	1.05E+01	1.22E+01
Nevada	[redacted]	[redacted]	[redacted]	4.04E+00	8.08E+00	1.21E+01	2.19E+01	3.17E+01	4.15E+01	5.13E+01
New Hampshire	[redacted]	1.02E+00	1.89E+00	2.77E+00	3.64E+00	4.51E+00	5.39E+00	7.51E+00	9.62E+00	1.17E+01
New Jersey	[redacted]	[redacted]	6.36E+00	1.27E+01	1.91E+01	2.55E+01	3.18E+01	4.96E+01	6.75E+01	8.53E+01
New Mexico	[redacted]	[redacted]	[redacted]	1.26E+00	2.51E+00	3.77E+00	5.02E+00	6.28E+00	7.54E+00	8.79E+00
New York	[redacted]	[redacted]	1.32E+01	2.64E+01	3.96E+01	5.28E+01	8.47E+01	1.17E+02	1.54E+02	1.91E+02
North Carolina	[redacted]	[redacted]	[redacted]	8.52E+00	1.70E+01	2.56E+01	3.41E+01	5.47E+01	7.54E+01	9.60E+01
North Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ohio	[redacted]	[redacted]	[redacted]	8.47E+00	1.69E+01	2.54E+01	3.39E+01	4.23E+01	5.08E+01	5.93E+01
Oklahoma	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	3.14E+00	6.28E+00	9.42E+00
Oregon	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pennsylvania	[redacted]	9.56E+00	1.77E+01	2.59E+01	3.41E+01	4.23E+01	5.05E+01	7.04E+01	9.02E+01	1.10E+02
Rhode Island	[redacted]	6.05E-01	1.12E+00	1.64E+00	2.90E+00	4.16E+00	5.41E+00	6.87E+00	8.32E+00	9.77E+00
South Carolina	[redacted]	[redacted]	[redacted]	[redacted]	4.59E+00	9.18E+00	1.38E+01	2.49E+01	3.60E+01	4.71E+01
South Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tennessee	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	5.98E+00	1.20E+01	1.79E+01
Texas	[redacted]	[redacted]	3.19E+01	6.37E+01	9.56E+01	1.27E+02	1.59E+02	2.37E+02	3.14E+02	3.91E+02
Utah	[redacted]	4.01E+00	7.45E+00	1.09E+01	1.43E+01	2.27E+01	3.10E+01	4.06E+01	5.03E+01	5.99E+01
Vermont	[redacted]	[redacted]	[redacted]	3.55E-01	7.10E-01	1.06E+00	2.06E+00	3.05E+00	4.05E+00	5.04E+00

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Virginia	[redacted]	[redacted]	8.06E+00	1.61E+01	2.42E+01	3.22E+01	5.17E+01	7.13E+01	9.08E+01	1.10E+02
Washington	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	7.10E-01	1.42E+00	2.13E+00	2.84E+00	3.55E+00
Wisconsin	[redacted]	[redacted]	[redacted]	4.37E+00	8.74E+00	1.31E+01	1.75E+01	2.81E+01	3.86E+01	4.92E+01
Wyoming	[redacted]	[redacted]	4.64E-01	9.28E-01	1.39E+00	1.86E+00	2.32E+00	3.45E+00	4.57E+00	5.70E+00
Washington, DC	[redacted]	2.36E+00	4.38E+00	6.40E+00	8.42E+00	1.33E+01	1.82E+01	2.31E+01	2.80E+01	3.29E+01
TOTAL	[redacted]	5.47E+01	1.83E+02	3.86E+02	6.35E+02	9.10E+02	1.27E+03	1.79E+03	2.31E+03	2.83E+03

Notes: Avoided natural gas emissions calculated as the product of Natural Gas Net Energy Savings and a natural gas emissions factor of 0.0000578592092574735 lbs./therm obtained from EPA.

Source: AP-42 (Chapter 1.4, Table 1.4-2)

Table F-23. Natural Gas Avoided VOC Emissions (Lbs.)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	3.20E+01	6.41E+01	9.61E+01	1.86E+02	2.76E+02	3.65E+02
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	1.56E+02	3.13E+02	4.69E+02	6.26E+02	7.82E+02	9.39E+02
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	1.75E+01	3.50E+01	5.26E+01	7.01E+01	8.76E+01	1.05E+02
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Colorado				5.91E+01	1.18E+02	1.77E+02	2.36E+02	2.95E+02	3.54E+02	4.14E+02
Connecticut				2.15E+01	4.31E+01	6.46E+01	8.61E+01	1.38E+02	1.90E+02	2.43E+02
Delaware		6.42E+00	1.19E+01	1.74E+01	2.29E+01	2.85E+01	4.18E+01	5.51E+01	6.85E+01	8.18E+01
Florida				2.25E+02	4.50E+02	6.74E+02	1.22E+03	1.76E+03	2.31E+03	2.85E+03
Georgia			1.03E+02	2.06E+02	3.09E+02	4.13E+02	5.16E+02	7.66E+02	1.02E+03	1.27E+03
Hawaii										
Idaho			1.13E+01	2.25E+01	3.38E+01	4.51E+01	7.24E+01	9.96E+01	1.27E+02	1.54E+02
Illinois		1.11E+02	2.06E+02	3.00E+02	5.30E+02	7.60E+02	9.90E+02	1.26E+03	1.52E+03	1.79E+03
Indiana		6.51E+01	1.21E+02	1.77E+02	2.33E+02	2.88E+02	3.44E+02	4.00E+02	4.56E+02	5.12E+02
Iowa		2.95E+01	5.48E+01	8.01E+01	1.05E+02	1.67E+02	2.28E+02	2.99E+02	3.69E+02	4.40E+02
Kansas										
Kentucky			3.23E+01	6.46E+01	9.69E+01	1.75E+02	2.53E+02	3.32E+02	4.10E+02	4.88E+02
Louisiana				2.95E+01	5.91E+01	8.86E+01	1.18E+02	1.90E+02	2.61E+02	3.33E+02
Maine			7.01E+00	1.40E+01	2.10E+01	2.80E+01	3.50E+01	5.20E+01	6.90E+01	8.60E+01
Maryland		6.57E+01	1.22E+02	2.58E+02	3.95E+02	5.31E+02	6.89E+02	8.47E+02	1.00E+03	1.16E+03
Massachusetts		5.87E+01	1.09E+02	1.59E+02	2.10E+02	3.32E+02	4.53E+02	5.94E+02	7.35E+02	8.76E+02
Michigan			4.38E+01	8.76E+01	1.31E+02	1.75E+02	2.19E+02	3.25E+02	4.31E+02	5.37E+02
Minnesota							1.11E+02	2.22E+02	3.33E+02	4.44E+02
Mississippi					4.31E+01	8.61E+01	1.29E+02	1.72E+02	2.15E+02	2.58E+02

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Missouri										
Montana		4.67E+00	8.68E+00	1.27E+01	1.67E+01	2.07E+01	3.04E+01	4.01E+01	4.98E+01	5.95E+01
Nebraska				1.60E+01	3.20E+01	4.81E+01	6.41E+01	8.01E+01	9.61E+01	1.12E+02
Nevada				3.70E+01	7.41E+01	1.11E+02	2.01E+02	2.91E+02	3.80E+02	4.70E+02
New Hampshire		9.34E+00	1.74E+01	2.54E+01	3.34E+01	4.14E+01	4.94E+01	6.88E+01	8.82E+01	1.08E+02
New Jersey			5.83E+01	1.17E+02	1.75E+02	2.33E+02	2.92E+02	4.55E+02	6.18E+02	7.82E+02
New Mexico				1.15E+01	2.30E+01	3.45E+01	4.61E+01	5.76E+01	6.91E+01	8.06E+01
New York			1.21E+02	2.42E+02	3.63E+02	4.84E+02	7.77E+02	1.07E+03	1.41E+03	1.75E+03
North Carolina				7.81E+01	1.56E+02	2.34E+02	3.12E+02	5.02E+02	6.91E+02	8.80E+02
North Dakota										
Ohio				7.76E+01	1.55E+02	2.33E+02	3.10E+02	3.88E+02	4.66E+02	5.43E+02
Oklahoma								2.88E+01	5.76E+01	8.64E+01
Oregon										
Pennsylvania		8.76E+01	1.63E+02	2.38E+02	3.13E+02	3.88E+02	4.63E+02	6.45E+02	8.27E+02	1.01E+03
Rhode Island		5.55E+00	1.03E+01	1.51E+01	2.66E+01	3.81E+01	4.96E+01	6.30E+01	7.63E+01	8.96E+01
South Carolina					4.21E+01	8.41E+01	1.26E+02	2.28E+02	3.30E+02	4.32E+02
South Dakota										
Tennessee								5.48E+01	1.10E+02	1.64E+02
Texas			2.92E+02	5.84E+02	8.76E+02	1.17E+03	1.46E+03	2.17E+03	2.88E+03	3.58E+03

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Utah		3.68E+01	6.83E+01	9.99E+01	1.31E+02	2.08E+02	2.84E+02	3.73E+02	4.61E+02	5.49E+02
Vermont				3.25E+00	6.51E+00	9.76E+00	1.89E+01	2.80E+01	3.71E+01	4.62E+01
Virginia			7.38E+01	1.48E+02	2.22E+02	2.95E+02	4.74E+02	6.53E+02	8.32E+02	1.01E+03
Washington										
West Virginia						6.51E+00	1.30E+01	1.95E+01	2.60E+01	3.25E+01
Wisconsin				4.01E+01	8.01E+01	1.20E+02	1.60E+02	2.57E+02	3.54E+02	4.51E+02
Wyoming			4.26E+00	8.51E+00	1.28E+01	1.70E+01	2.13E+01	3.16E+01	4.19E+01	5.22E+01
Washington, DC		2.16E+01	4.01E+01	5.87E+01	7.72E+01	1.22E+02	1.67E+02	2.12E+02	2.57E+02	3.02E+02
TOTAL		5.02E+02	1.68E+03	3.53E+03	5.82E+03	8.34E+03	1.17E+04	1.64E+04	2.12E+04	2.59E+04

Notes: Avoided natural gas emissions calculated as the product of Natural Gas Net Energy Savings and a natural gas emissions factor of 0.0000578592092574735 lbs./therm obtained from EPA.

Source: AP-42 (Chapter 1.4, Table 1.4-2)

Table F-24. Natural Gas Avoided NH3 Emissions (Lbs.)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama					2.85E+00	5.71E+00	8.56E+00	1.66E+01	2.46E+01	3.25E+01
Alaska										
Arizona					1.39E+01	2.79E+01	4.18E+01	5.58E+01	6.97E+01	8.36E+01

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	1.56E+00	3.12E+00	4.68E+00	6.24E+00	7.81E+00	9.37E+00
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	5.26E+00	1.05E+01	1.58E+01	2.11E+01	2.63E+01	3.16E+01	3.68E+01
Connecticut	[redacted]	[redacted]	[redacted]	1.92E+00	3.84E+00	5.75E+00	7.67E+00	1.23E+01	1.70E+01	2.16E+01
Delaware	[redacted]	5.72E-01	1.06E+00	1.55E+00	2.04E+00	2.53E+00	3.72E+00	4.91E+00	6.10E+00	7.29E+00
Florida	[redacted]	[redacted]	[redacted]	2.00E+01	4.01E+01	6.01E+01	1.09E+02	1.57E+02	2.06E+02	2.54E+02
Georgia	[redacted]	[redacted]	9.19E+00	1.84E+01	2.76E+01	3.68E+01	4.59E+01	6.82E+01	9.05E+01	1.13E+02
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	1.00E+00	2.01E+00	3.01E+00	4.01E+00	6.45E+00	8.88E+00	1.13E+01	1.37E+01
Illinois	[redacted]	9.86E+00	1.83E+01	2.68E+01	4.72E+01	6.77E+01	8.82E+01	1.12E+02	1.36E+02	1.59E+02
Indiana	[redacted]	5.80E+00	1.08E+01	1.57E+01	2.07E+01	2.57E+01	3.07E+01	3.56E+01	4.06E+01	4.56E+01
Iowa	[redacted]	2.63E+00	4.88E+00	7.13E+00	9.38E+00	1.48E+01	2.03E+01	2.66E+01	3.29E+01	3.92E+01
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	2.88E+00	5.75E+00	8.63E+00	1.56E+01	2.26E+01	2.95E+01	3.65E+01	4.35E+01
Louisiana	[redacted]	[redacted]	[redacted]	2.63E+00	5.26E+00	7.89E+00	1.05E+01	1.69E+01	2.33E+01	2.97E+01
Maine	[redacted]	[redacted]	6.24E-01	1.25E+00	1.87E+00	2.50E+00	3.12E+00	4.64E+00	6.15E+00	7.66E+00
Maryland	[redacted]	5.85E+00	1.09E+01	2.30E+01	3.52E+01	4.73E+01	6.14E+01	7.55E+01	8.95E+01	1.04E+02
Massachusetts	[redacted]	5.23E+00	9.71E+00	1.42E+01	1.87E+01	2.95E+01	4.04E+01	5.30E+01	6.55E+01	7.81E+01
Michigan	[redacted]	[redacted]	3.90E+00	7.81E+00	1.17E+01	1.56E+01	1.95E+01	2.90E+01	3.84E+01	4.79E+01

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Minnesota							9.89E+00	1.98E+01	2.97E+01	3.96E+01
Mississippi					3.84E+00	7.67E+00	1.15E+01	1.53E+01	1.92E+01	2.30E+01
Missouri										
Montana		4.16E-01	7.73E-01	1.13E+00	1.49E+00	1.84E+00	2.71E+00	3.57E+00	4.44E+00	5.30E+00
Nebraska				1.43E+00	2.85E+00	4.28E+00	5.71E+00	7.14E+00	8.56E+00	9.99E+00
Nevada				3.30E+00	6.60E+00	9.90E+00	1.79E+01	2.59E+01	3.39E+01	4.19E+01
New Hampshire		8.33E-01	1.55E+00	2.26E+00	2.97E+00	3.69E+00	4.40E+00	6.13E+00	7.86E+00	9.59E+00
New Jersey			5.20E+00	1.04E+01	1.56E+01	2.08E+01	2.60E+01	4.05E+01	5.51E+01	6.96E+01
New Mexico				1.03E+00	2.05E+00	3.08E+00	4.10E+00	5.13E+00	6.16E+00	7.18E+00
New York			1.08E+01	2.15E+01	3.23E+01	4.31E+01	6.92E+01	9.53E+01	1.25E+02	1.56E+02
North Carolina				6.96E+00	1.39E+01	2.09E+01	2.78E+01	4.47E+01	6.15E+01	7.84E+01
North Dakota										
Ohio				6.91E+00	1.38E+01	2.07E+01	2.77E+01	3.46E+01	4.15E+01	4.84E+01
Oklahoma								2.56E+00	5.13E+00	7.69E+00
Oregon										
Pennsylvania		7.80E+00	1.45E+01	2.12E+01	2.79E+01	3.46E+01	4.13E+01	5.75E+01	7.37E+01	8.99E+01
Rhode Island		4.94E-01	9.18E-01	1.34E+00	2.37E+00	3.40E+00	4.42E+00	5.61E+00	6.80E+00	7.98E+00
South Carolina					3.75E+00	7.49E+00	1.12E+01	2.03E+01	2.94E+01	3.85E+01
South Dakota										

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Tennessee								4.88E+00	9.77E+00	1.47E+01
Texas			2.60E+01	5.21E+01	7.81E+01	1.04E+02	1.30E+02	1.93E+02	2.56E+02	3.19E+02
Utah		3.28E+00	6.09E+00	8.90E+00	1.17E+01	1.85E+01	2.53E+01	3.32E+01	4.11E+01	4.89E+01
Vermont				2.90E-01	5.80E-01	8.70E-01	1.68E+00	2.49E+00	3.31E+00	4.12E+00
Virginia			6.58E+00	1.32E+01	1.97E+01	2.63E+01	4.23E+01	5.82E+01	7.41E+01	9.01E+01
Washington										
West Virginia						5.80E-01	1.16E+00	1.74E+00	2.32E+00	2.90E+00
Wisconsin				3.57E+00	7.14E+00	1.07E+01	1.43E+01	2.29E+01	3.16E+01	4.02E+01
Wyoming			3.79E-01	7.58E-01	1.14E+00	1.52E+00	1.90E+00	2.81E+00	3.73E+00	4.65E+00
Washington, DC		1.93E+00	3.58E+00	5.23E+00	6.88E+00	1.09E+01	1.49E+01	1.89E+01	2.29E+01	2.69E+01
TOTAL		4.47E+01	1.50E+02	3.15E+02	5.19E+02	7.43E+02	1.04E+03	1.46E+03	1.89E+03	2.31E+03

Notes: Avoided natural gas emissions calculated as the product of Natural Gas Net Energy Savings and a natural gas emissions factor of 0.00004725168756027 lbs./therm obtained from EPA.

Source: Development and Selection of Ammonia Emission Factors (Table 5-2)

Table F-25. Natural Gas Energy Price ($/therm)

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	$1.1919	$1.2112	$1.1909	$1.1553	$1.0781	$1.0280	$1.1610	$1.1466	$1.1446	$1.1504

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alaska	$0.7801	$0.7801	$0.8042	$0.8004	$0.7724	$0.8042	$0.9441	$0.9634	$0.9537	$0.9556
Arizona	$0.9634	$0.9016	$0.8447	$0.9971	$1.0154	$0.8515	$0.8650	$0.8380	$0.7030	$0.6663
Arkansas	$0.8582	$0.7705	$0.7406	$0.7599	$0.8129	$0.6885	$0.8042	$0.7666	$0.7406	$0.7377
California	$0.7994	$0.6798	$0.7531	$0.8727	$0.7753	$0.8120	$0.8447	$0.8264	$0.9074	$0.9431
Colorado	$0.7560	$0.7310	$0.7001	$0.7859	$0.7203	$0.6191	$0.6914	$0.6596	$0.6673	$0.6008
Connecticut	$0.8177	$0.8100	$0.8872	$0.9875	$0.8293	$0.8476	$0.8968	$0.8901	$0.9402	$0.9045
Delaware	$1.3095	$1.2835	$1.1360	$1.1013	$1.0318	$0.9238	$1.0000	$1.0116	$0.9682	$1.0395
Florida	$1.0743	$1.0039	$1.0482	$1.1013	$1.0492	$1.0048	$1.0579	$1.0800	$1.1051	$1.1099
Georgia	$1.0135	$0.9402	$0.9045	$0.9508	$0.8274	$0.7637	$0.8467	$0.7878	$0.7917	$0.7435
Hawaii	$4.3954	$4.5352	$4.0424	$3.8978	$3.0058	$2.3896	$2.6432	$2.9855	$2.9180	$2.5612
Idaho	$0.7801	$0.7088	$0.7030	$0.7425	$0.7319	$0.6866	$0.6384	$0.5815	$0.5246	$0.5391
Illinois	$0.7975	$0.7502	$0.7300	$0.8544	$0.7030	$0.6885	$0.7502	$0.6982	$0.6770	$0.6596
Indiana	$0.7753	$0.7416	$0.7319	$0.7898	$0.7338	$0.6316	$0.7252	$0.7107	$0.6721	$0.6615
Iowa	$0.7281	$0.6876	$0.6721	$0.7859	$0.6278	$0.5776	$0.6625	$0.6596	$0.5738	$0.5641
Kansas	$0.8573	$0.8505	$0.8746	$0.9267	$0.8554	$0.8110	$0.8968	$0.8322	$0.7406	$0.7223
Kentucky	$0.8476	$0.7985	$0.8023	$0.8737	$0.8438	$0.7608	$0.8737	$0.8129	$0.8293	$0.8332

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Louisiana	$0.9026	$0.8139	$0.8284	$0.8689	$0.7724	$0.7637	$0.8669	$0.8399	$0.8129	$0.8071
Maine	$1.1273	$1.1784	$1.2334	$1.4590	$1.3655	$1.0251	$1.0926	$1.2546	$1.2170	$1.0955
Maryland	$0.9923	$0.9643	$0.9701	$1.0145	$0.9450	$0.8621	$0.9904	$0.9229	$0.9778	$1.0241
Massachusetts	$1.1263	$1.0299	$1.0849	$1.2035	$1.0424	$0.9142	$0.9797	$1.2382	$1.0916	$1.0800
Michigan	$0.8814	$0.8052	$0.7541	$0.7985	$0.7242	$0.6654	$0.6770	$0.6663	$0.6567	$0.6615
Minnesota	$0.7194	$0.6133	$0.6615	$0.8351	$0.7049	$0.6210	$0.6557	$0.6827	$0.6393	$0.6162
Mississippi	$0.7705	$0.7107	$0.7338	$0.8062	$0.7589	$0.7522	$0.8505	$0.8197	$0.8197	$0.8361
Missouri	$0.9634	$0.9200	$0.8679	$0.8640	$0.8814	$0.7608	$0.8139	$0.7676	$0.7396	$0.7088
Montana	$0.8351	$0.7695	$0.7801	$0.8457	$0.7792	$0.6876	$0.7155	$0.6837	$0.6644	$0.6731
Nebraska	$0.6451	$0.5969	$0.6258	$0.7011	$0.6172	$0.5256	$0.6143	$0.6056	$0.5622	$0.5265
Nevada	$0.7782	$0.7165	$0.6374	$0.7917	$0.8351	$0.6596	$0.5506	$0.6114	$0.6258	$0.6991
New Hampshire	$1.1051	$1.1524	$1.1697	$1.4426	$1.3144	$1.0955	$1.1292	$1.2266	$1.2035	$1.0887
New Jersey	$0.9171	$0.8197	$0.9209	$0.9720	$0.8197	$0.7647	$0.8814	$0.8689	$0.8727	$0.8476
New Mexico	$0.6731	$0.6085	$0.6528	$0.7589	$0.6095	$0.5477	$0.6355	$0.5371	$0.4397	$0.4590
New York	$0.8987	$0.7560	$0.7715	$0.8014	$0.6615	$0.5969	$0.6625	$0.7097	$0.6953	$0.6635
North Carolina	$0.9296	$0.8312	$0.8496	$0.8795	$0.7975	$0.7435	$0.8602	$0.8177	$0.8447	$0.8689

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
North Dakota	$0.6750	$0.5824	$0.6095	$0.7464	$0.6384	$0.5256	$0.5786	$0.5689	$0.5468	$0.5072
Ohio	$0.8245	$0.6856	$0.5988	$0.7541	$0.6249	$0.5535	$0.5892	$0.5709	$0.5757	$0.5429
Oklahoma	$0.8621	$0.8631	$0.7763	$0.7956	$0.7830	$0.7445	$0.8139	$0.6837	$0.7020	$0.6683
Oregon	$0.9257	$0.8592	$0.8293	$0.9103	$0.9797	$0.8968	$0.8428	$0.8177	$0.7599	$0.7956
Pennsylvania	$1.0048	$0.9875	$0.9749	$0.9769	$0.8987	$0.7859	$0.8833	$0.9036	$0.9151	$0.8775
Rhode Island	$1.2854	$1.1871	$1.1929	$1.2430	$1.1562	$1.0762	$1.0897	$1.2517	$1.2411	$1.1871
South Carolina	$0.9335	$0.8361	$0.8775	$0.9209	$0.8216	$0.8120	$0.8987	$0.9036	$0.8322	$0.8303
South Dakota	$0.6731	$0.6220	$0.6355	$0.7377	$0.5998	$0.5439	$0.6037	$0.5699	$0.5304	$0.5082
Tennessee	$0.8717	$0.8062	$0.8110	$0.8968	$0.8158	$0.7522	$0.8428	$0.8110	$0.7811	$0.7454
Texas	$0.6818	$0.6393	$0.6991	$0.7965	$0.6673	$0.6644	$0.7435	$0.6316	$0.5959	$0.6287
Utah	$0.6798	$0.6750	$0.6876	$0.7435	$0.7686	$0.7165	$0.7136	$0.7107	$0.6123	$0.6326
Vermont	$1.1475	$1.1659	$0.7300	$0.8804	$0.7608	$0.6393	$0.6789	$0.6528	$0.5796	$0.5217
Virginia	$0.9344	$0.8457	$0.8515	$0.8843	$0.7840	$0.6972	$0.7705	$0.7792	$0.8226	$0.7830
Washington	$1.0029	$0.9470	$0.8881	$0.8708	$0.9431	$0.8187	$0.8004	$0.7618	$0.7223	$0.8447
West Virginia	$0.9306	$0.9016	$0.8303	$0.8602	$0.8631	$0.7473	$0.7377	$0.7821	$0.7734	$0.7869
Wisconsin	$0.7743	$0.7078	$0.6692	$0.8428	$0.6538	$0.6066	$0.6365	$0.6210	$0.5921	$0.5535

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Wyoming	$0.7030	$0.6480	$0.6567	$0.7416	$0.7165	$0.6307	$0.6673	$0.6374	$0.6075	$0.6345
Washington, DC	$1.1803	$1.0791	$1.1225	$1.1745	$1.0675	$0.9527	$1.0482	$1.0048	$1.0829	$1.0203
Notes: Natural gas prices obtained from EIA in $/thousand CF and converted to $/Therm										
Source: EIA										

Table F-26. Natural Gas Energy Cost Savings, Current Dollars

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Alabama	[redacted]	[redacted]	[redacted]	[redacted]	$65,130	$124,201	$210,419	$401,804	$594,808	$792,474
Alaska	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Arizona	[redacted]	[redacted]	[redacted]	[redacted]	$299,590	$502,447	$765,620	$988,961	$1,037,043	$1,179,584
Arkansas	[redacted]	[redacted]	[redacted]	[redacted]	$26,857	$45,494	$79,710	$101,310	$122,337	$146,231
California	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Colorado	[redacted]	[redacted]	[redacted]	$87,538	$160,469	$206,869	$308,048	$367,338	$445,961	$468,409
Connecticut	[redacted]	[redacted]	[redacted]	$40,080	$67,322	$103,213	$145,603	$232,041	$337,580	$413,727
Delaware	[redacted]	$15,547	$25,555	$36,209	$44,639	$49,559	$78,804	$105,165	$125,012	$160,379
Florida	[redacted]	[redacted]	[redacted]	$466,735	$889,330	$1,277,594	$2,431,362	$3,591,447	$4,809,675	$5,970,467
Georgia	[redacted]	[redacted]	$175,884	$369,770	$482,651	$594,032	$823,169	$1,137,171	$1,515,748	$1,773,730

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hawaii	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Idaho	[redacted]	[redacted]	$14,930	$31,540	$46,634	$58,328	$87,083	$109,246	$125,552	$156,754
Illinois	[redacted]	$156,557	$282,906	$483,944	$702,870	$986,820	$1,400,436	$1,653,019	$1,941,946	$2,222,613
Indiana	[redacted]	$91,051	$166,899	$263,215	$321,810	$343,462	$470,648	$536,060	$577,706	$638,212
Iowa	[redacted]	$38,235	$69,416	$118,632	$124,685	$181,441	$284,613	$371,435	$399,711	$468,312
Kansas	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Kentucky	[redacted]	[redacted]	$48,847	$106,384	$154,116	$251,208	$417,343	$508,244	$640,833	$766,722
Louisiana	[redacted]	[redacted]	[redacted]	$48,388	$86,034	$127,602	$193,121	$300,445	$400,482	$506,547
Maine	[redacted]	[redacted]	$16,299	$38,562	$54,134	$54,185	$72,191	$123,067	$158,345	$177,612
Maryland	[redacted]	$119,463	$223,197	$494,425	$703,744	$863,807	$1,286,877	$1,473,649	$1,852,255	$2,244,537
Massachusetts	[redacted]	$113,978	$222,975	$361,520	$412,033	$571,467	$837,659	$1,387,608	$1,513,389	$1,784,317
Michigan	[redacted]	[redacted]	$62,283	$131,894	$179,443	$219,824	$279,558	$408,529	$534,038	$670,345
Minnesota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$137,227	$285,755	$401,389	$515,812
Mississippi	[redacted]	[redacted]	[redacted]	[redacted]	$61,619	$122,141	$207,171	$266,205	$332,757	$407,294
Missouri	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Montana	[redacted]	$6,779	$12,764	$20,223	$24,516	$26,825	$41,008	$51,694	$62,393	$75,523

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Nebraska	[redacted]	[redacted]	[redacted]	$21,176	$37,284	$47,624	$74,218	$91,461	$101,889	$111,326
Nevada	[redacted]	[redacted]	[redacted]	$55,301	$116,664	$138,219	$208,576	$335,063	$448,912	$619,807
New Hampshire	[redacted]	$20,303	$38,275	$68,993	$82,710	$85,479	$105,167	$159,125	$200,162	$220,916
New Jersey	[redacted]	[redacted]	$101,271	$213,783	$270,411	$336,369	$484,618	$745,337	$1,017,446	$1,249,292
New Mexico	[redacted]	[redacted]	[redacted]	$16,476	$26,463	$35,674	$55,186	$58,306	$57,280	$69,757
New York	[redacted]	[redacted]	$175,859	$365,347	$452,397	$544,284	$969,994	$1,431,195	$1,845,948	$2,185,064
North Carolina	[redacted]	[redacted]	[redacted]	$129,502	$234,865	$328,441	$506,649	$773,420	$1,100,354	$1,441,755
North Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Ohio	[redacted]	[redacted]	[redacted]	$110,331	$182,850	$242,953	$344,818	$417,620	$505,376	$556,027
Oklahoma	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$37,108	$76,206	$108,813
Oregon	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Pennsylvania	[redacted]	$163,107	$299,075	$437,978	$530,209	$574,926	$771,242	$1,098,908	$1,426,936	$1,669,348
Rhode Island	[redacted]	$12,418	$23,176	$35,296	$57,954	$77,325	$101,971	$148,569	$178,481	$200,530
South Carolina	[redacted]	[redacted]	[redacted]	[redacted]	$65,144	$128,759	$213,783	$388,522	$517,720	$676,032
South Dakota	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Tennessee	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$83,824	$161,468	$231,139

State	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Texas	[redacted]	[redacted]	$385,067	$877,422	$1,102,620	$1,463,786	$2,047,494	$2,582,372	$3,231,812	$4,248,684
Utah	[redacted]	$46,830	$88,587	$140,006	$190,432	$280,767	$382,454	$499,280	$532,172	$655,137
Vermont	[redacted]	[redacted]	[redacted]	$5,402	$9,336	$11,768	$24,162	$34,455	$40,546	$45,464
Virginia	[redacted]	[redacted]	$118,552	$246,234	$327,462	$388,282	$689,023	$959,637	$1,290,575	$1,492,697
Washington	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
West Virginia	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$9,171	$18,105	$28,790	$37,961	$48,279
Wisconsin	[redacted]	[redacted]	[redacted]	$63,644	$98,743	$137,410	$192,243	$301,211	$395,514	$471,025
Wyoming	[redacted]	[redacted]	$5,269	$11,900	$17,246	$20,240	$26,770	$37,963	$47,993	$62,461
Washington, DC	[redacted]	$43,966	$84,936	$129,898	$155,342	$219,268	$329,943	$401,315	$524,153	$580,151
TOTAL	[redacted]	$828,235	$2,642,025	$6,027,745	$8,865,754	$11,781,265	$18,104,088	$25,013,673	$31,667,866	$38,483,306
Notes: Natural Gas Energy Cost Savings calculated as the product of Natural Gas Net Energy Savings and Natural Gas Energy Price.										

Table F-27. National Level Inputs for EPA's COBRA

Metric	2012	2013	2014	2015	2016	2017	2018	2019	2020
Electricity Savings (kWh)	25,244,356	84,468,509	182,483,886	317,284,100	476,741,272	723,887,532	1,125,306,267	1,535,448,859	1,945,591,452
Electricity C02e Emissions (lbs)	26,154,697	83,126,530	182,240,058	313,516,839	474,894,783	688,986,515	1,025,152,969	1,294,333,305	1,631,088,826

Metric	2012	2013	2014	2015	2016	2017	2018	2019	2020
Electricity PM2.5 Emissions (lbs)	3,569	10,908	22,662	39,579	57,826	65,312	86,158	129,505	165,127
Electricity SO2 Emissions (lbs)	67,124	206,448	451,212	687,824	760,702	812,011	1,132,759	1,406,362	1,553,768
Electricity NOx Emissions (tons)	35,787	112,194	239,852	384,608	552,639	668,404	1,002,471	1,311,560	1,486,372
Electricity NH3 Emissions (lbs)	744	2,489	5,377	9,348	14,047	21,328	31,922	39,626	52,875
Electricity VOC Emissions (lbs)	674	2,257	4,875	8,477	12,737	19,340	29,969	40,640	50,038
Natural Gas Savings (Therms)	945,920	3,165,081	6,663,811	10,978,806	15,729,849	22,022,080	30,924,102	39,912,270	48,900,438
Natural Gas C02e Emissions (lbs)	22,493,084	75,262,654	158,459,162	261,065,671	374,041,017	523,664,344	735,346,070	949,076,254	1,162,806,437
Natural Gas PM2.5 Emissions (lbs)	693	2,320	4,884	8,046	11,528	16,140	22,664	29,251	35,838
Natural Gas S02 Emissions (lbs)	55	183	386	635	910	1,274	1,789	2,309	2,829
Natural Gas NOx Emissions (lbs)	9,365	31,335	65,973	108,692	155,728	218,022	306,153	395,137	484,122
Natural Gas NH3 Emissions (lbs)	45	150	315	519	743	1,041	1,461	1,886	2,311
Natural Gas VOC Emissions (lbs)	502	1,679	3,534	5,823	8,343	11,680	16,401	21,169	25,936
Total C02e Emissions (lbs)	48,647,781	158,389,184	340,699,220	574,582,510	848,935,800	1,212,650,859	1,760,499,039	2,243,409,559	2,793,895,263
Total PM2.5 Emissions (lbs)	4,262	13,227	27,546	47,625	69,354	81,451	108,822	158,756	200,965
Total SO2 Emissions (lbs)	67,179	206,631	451,598	688,459	761,612	813,285	1,134,548	1,408,671	1,556,598
Total NOx Emissions (lbs)	45,152	143,528	305,825	493,299	708,367	886,426	1,308,624	1,706,697	1,970,494
Total NH3 Emissions (lbs)	788	2,638	5,692	9,867	14,790	22,369	33,383	41,512	55,186
Total VOC Emissions (lbs)	1,176	3,935	8,410	14,300	21,080	31,020	46,370	61,809	75,973

Metric	2012	2013	2014	2015	2016	2017	2018	2019	2020
Electricity Savings (kWh)	23,733,828	79,414,230	172,351,913	302,416,828	457,870,919	703,467,084	1,107,483,931	1,520,397,657	1,933,311,384
Electricity C02e Emissions (tons)	13,077	41,563	91,120	156,758	237,447	344,493	512,576	647,167	815,544
Electricity PM2.5 Emissions (tons)	1.78	5.45	11.33	19.79	28.91	32.66	43.08	64.75	82.56
Electricity SO2 Emissions (tons)	33.56	103.22	225.61	343.91	380.35	406.01	566.38	703.18	776.88
Electricity NOx Emissions (tons)	17.89	56.10	119.93	192.30	276.32	334.20	501.24	655.78	743.19
Electricity NH3 Emissions (tons)	0.37	1.24	2.69	4.67	7.02	10.66	15.96	19.81	26.44
Electricity VOC Emissions (tons)	0.34	1.13	2.44	4.24	6.37	9.67	14.98	20.32	25.02
Natural Gas Savings (Therms)	926,557	3,100,293	6,527,592	10,755,055	15,410,167	21,576,676	30,302,351	39,112,412	47,922,473
Natural Gas C02e Emissions (tons)	11,247	37,631	79,230	130,533	187,021	261,832	367,673	474,538	581,403
Natural Gas PM2.5 Emissions (tons)	0.35	1.16	2.44	4.02	5.76	8.07	11.33	14.63	17.92
Natural Gas SO2 Emissions (tons)	0.03	0.09	0.19	0.32	0.46	0.64	0.89	1.15	1.41
Natural Gas NOx Emissions (tons)	4.68	15.67	32.99	54.35	77.86	109.01	153.08	197.57	242.06
Natural Gas NH3 Emissions (tons)	0.02	0.07	0.16	0.26	0.37	0.52	0.73	0.94	1.16

Metric	2012	2013	2014	2015	2016	2017	2018	2019	2020
Natural Gas VOC Emissions (tons)	0.25	0.84	1.77	2.91	4.17	5.84	8.20	10.58	12.97
Total C02e Emissions (tons)	24,324	79,195	170,350	287,291	424,468	606,325	880,250	1,121,705	1,396,948
Total PM2.5 Emissions (tons)	2.13	6.61	13.77	23.81	34.68	40.73	54.41	79.38	100.48
Total SO2 Emissions (tons)	33.59	103.32	225.80	344.23	380.81	406.64	567.27	704.34	778.30
Total NOx Emissions (tons)	22.58	71.76	152.91	246.65	354.18	443.21	654.31	853.35	985.25
Total NH3 Emissions (tons)	0.39	1.32	2.85	4.93	7.39	11.18	16.69	20.76	27.59
Total VOC Emissions (tons)	0.59	1.97	4.20	7.15	10.54	15.51	23.19	30.90	37.99

Table F-28. Monetized Health Benefits, 3% Discount Factor

Health Benefits (Current$) - Total	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mortality (average estimate)	0	1	1	2	3	3	4	5	6
$ Mortality (average estimate)	1,935,326	6,173,407	13,641,486	21,925,942	27,654,210	32,566,671	46,786,033	62,426,618	73,998,930
Infant Mortality	0	0	0	0	0	0	0	0	0
$ Infant Mortality	7,037	22,439	49,596	79,670	100,330	117,989	169,538	226,101	267,788
Nonfatal Heart Attacks (average estimate)	0	0	0	1	1	1	1	2	2

Health Benefits (Current$) - Total	2012	2013	2014	2015	2016	2017	2018	2019	2020
$ Nonfatal Heart Attacks (average estimate)	9,635	30,709	67,896	108,997	136,956	160,698	230,873	307,794	364,237
Hospital Admits, All Respiratory	0	0	0	0	0	0	1	1	1
Hospital Admits, All Respiratory Direct	0	0	0	0	0	0	0	1	1
Hospital Admits, Asthma	0	0	0	0	0	0	0	0	0
Hospital Admits, Chronic Lung Disease	0	0	0	0	0	0	0	0	0
$ Hospital Admits, All Respiratory	999	3,186	7,040	11,315	14,265	16,792	24,121	32,185	38,149
Hospital Admits, Cardiovascular (except heart attacks)	0	0	0	0	0	0	1	1	1
$ Hospital Admits, Cardiovascular (except heart attacks)	1,374	4,382	9,684	15,561	19,611	23,069	33,137	44,217	52,401
Acute Bronchitis	0	0	1	2	2	2	3	4	5
$ Acute Bronchitis	87	278	613	987	1,251	1,480	2,127	2,841	3,375
Upper Respiratory Symptoms	3	9	19	30	37	43	61	80	94
$ Upper Respiratory Symptoms	109	347	767	1,235	1,566	1,853	2,662	3,556	4,225
Lower Respiratory Symptoms	2	6	13	21	26	31	43	56	66
$ Lower Respiratory Symptoms	48	154	341	549	696	824	1,183	1,581	1,878
Emergency Room Visits, Asthma	0	0	0	1	1	1	1	2	2

Health Benefits (Current$) - Total	2012	2013	2014	2015	2016	2017	2018	2019	2020
$ Emergency Room Visits, Asthma	31	100	220	354	449	531	762	1,018	1,209
Minor Restricted Activity Days	82	257	558	890	1,119	1,302	1,826	2,398	2,818
$ Minor Restricted Activity Days	6,670	21,312	47,042	75,787	96,256	114,139	163,943	219,087	260,532
Work Loss Days	14	44	94	151	189	220	309	406	477
$ Work Loss Days	2,576	8,232	18,170	29,274	37,188	44,106	63,351	84,663	100,688
Asthma Exacerbation	3	9	20	31	39	45	64	83	98
Asthma Exacerbation, Cough	1	2	4	7	9	10	14	19	22
Asthma Exacerbation, Shortness of Breath	1	3	6	10	12	14	19	26	30
Asthma Exacerbation, Wheeze	1	4	9	15	18	21	30	39	46
$ Asthma Exacerbation	198	631	1,393	2,243	2,843	3,364	4,833	6,456	7,670
Total	1,964,090	6,265,176	13,844,249	22,251,914	28,065,622	33,051,517	47,482,563	63,356,117	75,101,082

Table F-29. Monetized Health Benefits, 7% Discount Factor

Health Benefits (Current$)	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mortality (average estimate)	0	1	1	2	3	3	4	5	6
$ Mortality (average estimate)	1,723,948	5,498,555	12,150,255	19,529,088	24,631,165	29,006,616	41,671,575	55,602,395	65,909,670

Health Benefits (Current$)	2012	2013	2014	2015	2016	2017	2018	2019	2020
Infant Mortality	0	0	0	0	0	0	0	0	0
$ Infant Mortality	7,037	22,439	49,596	79,670	100,330	117,989	169,538	226,101	267,788
Nonfatal Heart Attacks (average estimate)	0	0	0	1	1	1	1	2	2
$ Nonfatal Heart Attacks (average estimate)	9,028	28,770	63,611	102,118	128,319	150,569	216,321	288,398	341,292
Hospital Admits, All Respiratory	0	0	0	0	0	0	1	1	1
Hospital Admits, All Respiratory Direct	0	0	0	0	0	0	0	1	1
Hospital Admits, Asthma	0	0	0	0	0	0	0	0	0
Hospital Admits, Chronic Lung Disease	0	0	0	0	0	0	0	0	0
$ Hospital Admits, All Respiratory	999	3,186	7,040	11,315	14,265	16,792	24,121	32,185	38,149
Hospital Admits, Cardiovascular (except heart attacks)	0	0	0	0	0	0	1	1	1
$ Hospital Admits, Cardiovascular (except heart attacks)	1,374	4,382	9,684	15,561	19,611	23,069	33,137	44,217	52,401
Acute Bronchitis	0	0	1	2	2	2	3	4	5
$ Acute Bronchitis	87	278	613	987	1,251	1,480	2,127	2,841	3,375
Upper Respiratory Symptoms	3	9	19	30	37	43	61	80	94
$ Upper Respiratory Symptoms	109	347	767	1,235	1,566	1,853	2,662	3,556	4,225

Health Benefits (Current$)	2012	2013	2014	2015	2016	2017	2018	2019	2020
Lower Respiratory Symptoms	2	6	13	21	26	31	43	56	66
$ Lower Respiratory Symptoms	48	154	341	549	696	824	1,183	1,581	1,878
Emergency Room Visits, Asthma	0	0	0	1	1	1	1	2	2
$ Emergency Room Visits, Asthma	31	100	220	354	449	531	762	1,018	1,209
Minor Restricted Activity Days	82	257	558	890	1,119	1,302	1,826	2,398	2,818
$ Minor Restricted Activity Days	6,671	21,312	47,042	75,787	96,256	114,139	163,943	219,087	260,532
Work Loss Days	14	44	94	151	189	220	309	406	477
$ Work Loss Days	2,576	8,232	18,170	29,274	37,188	44,106	63,351	84,663	100,688
Asthma Exacerbation	3	9	20	31	39	45	64	83	98
Asthma Exacerbation, Cough	1	2	4	7	9	10	14	19	22
Asthma Exacerbation, Shortness of Breath	1	3	6	10	12	14	19	26	30
Asthma Exacerbation, Wheeze	1	4	9	15	18	21	30	39	46
$ Asthma Exacerbation	198	631	1,393	2,243	2,843	3,364	4,833	6,456	7,670
Total	1,752,106	5,588,386	12,348,731	19,848,181	25,033,940	29,481,333	42,353,553	56,512,498	66,988,876

Appendix G: Economic Calculations

Measure	Formulation for Calculating Performance Measures[46]
Total Investment Cost (I)	A simple summation of year-by-year constant dollar portfolio investment costs over the evaluation study period, i.e., $I = \sum_{y=1}^{N} I_y$, where I_y is an undiscounted constant dollar portfolio investment cost in year y and N is the number of years in the study period.
Gross Benefits (GB)	A simple summation of total benefits measured in dollars. This computation excludes both the EERE investment cost (I) and the required rate of return, as indicated by using an implied 0% discount rate; hence, it is only a partial measure of economic performance, i.e., $GB = \sum_{y=1}^{N} B_y$, where B_y is an undiscounted constant dollar benefit in year y (computed net of non-investment costs in that year), and N is the number of years in the study period.
Present Value (PV) of Investment Costs	Present value of investment costs, i.e., PV-investment = $\sum_{y=0}^{N-1} I_y/(1+d)^y$, where I_y is an undiscounted constant dollar portfolio investment cost in year y, N is the number of years in the study period, ***d is the discount rate,*** and investment costs are assumed to occur at the beginning of each year.
Present Value (PV) of Benefits	Present value of benefits, i.e., PV-benefits = $\sum_{y=1}^{N} B_y/(1+d)^y$, where B_y is an undiscounted constant dollar benefit in year y (computed net of non-investment costs in that year), N is the number of years in the study period, ***d is the discount rate,*** and benefits are assumed to occur at the end of each year.
Net Present Value (NPV)	Net present value of benefits less Investment costs, i.e., NPV = $\{\sum_{y=1}^{N} B_y/(1+d)^y\} - \{\sum_{y=0}^{N-1} I_y/(1+d)^y\}$, where all terms are as previously defined.
Benefit-to-Cost Ratio (BCR)	Ratio of PV-benefits to PV-investment, i.e., BCR= $\{\sum_{y=1}^{N} B_y/(1+d)^y\} / \{\sum_{y=0}^{N-1} I_y/(1+d)^y\}$, where all terms are as previously defined.

[46] Table extracted from Table 11.7.1, page 87 of DOE Evaluating Realized Impacts of DOE/EERE R&D Programs (energy.gov).

Internal Rate of Return (IRR)	The real interest rate solution value (i) for which PV-benefits = PV-investment, NPV = 0 and BCR = 1, when inserted in the following equality: $\{\sum_{y=1}^{N} By/(1+i)^{y}\} - \{\sum_{y=0}^{N-1} Iy/(1+i)^{y}\} = 0$, where all terms are previously defined.

Appendix H: Present Value Multipliers

Year	3% Discount Rate (Beginning of Year)*	3% Discount Rate (End of Year)**	7% Discount Rate (Beginning of Year)*	7% Discount Rate (End of Year)**
2000	1.0000	0.9709	1.0000	0.9346
2001	0.9709	0.9426	0.9346	0.8734
2002	0.9426	0.9151	0.8734	0.8163
2003	0.9151	0.8885	0.8163	0.7629
2004	0.8885	0.8626	0.7629	0.7130
2005	0.8626	0.8375	0.7130	0.6663
2006	0.8375	0.8131	0.6663	0.6227
2007	0.8131	0.7894	0.6227	0.5820
2008	0.7894	0.7664	0.5820	0.5439
2009	0.7664	0.7441	0.5439	0.5083
2010	0.7441	0.7224	0.5083	0.4751
2011	0.7224	0.7014	0.4751	0.4440
2012	0.7014	0.6810	0.4440	0.4150
2013	0.6810	0.6611	0.4150	0.3878
2014	0.6611	0.6419	0.3878	0.3624
2015	0.6419	0.6232	0.3624	0.3387
2016	0.6232	0.6050	0.3387	0.3166
2017	0.6050	0.5874	0.3166	0.2959
2018	0.5874	0.5703	0.2959	0.2765
2019	0.5703	0.5537	0.2765	0.2584
2020	0.5537	0.5375	0.2584	0.2415

Notes:
* Beginning of year Present Value multipliers used for Program Investment Costs, per DOE Guide.
** End of year Present Value multipliers used for Program benefits, per DOE Guide.