PNNL-37133

Methodology for Evaluating Commercial Energy Code Updates

December 2024

Matthew Tyler
Michael Tillou
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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

This document lays out the Department of Energy's (DOE's) methodology for evaluating the cost-effectiveness of energy code and standard[1] proposals and editions. The evaluation is applied to new provisions or editions of ANSI/ASHRAE/IES[2] Standard 90.1 and the International Energy Conservation Code. The methodology follows standard lifecycle cost (LCC) economic analysis procedures. A cost-effectiveness evaluation requires three steps: 1) evaluating the energy and energy cost savings of code changes; 2) evaluating the incremental and replacement costs related to the changes; and 3) determining the cost-effectiveness of energy code changes based on those costs and savings over time.

Cost-effectiveness can be evaluated for an individual code change proposal or an entire edition-to-edition upgrade of an energy code. Multiple parties are interested in building energy codes, and they have different economic viewpoints. To account for this, and the fact that the ASHRAE Standing Standard Project Committee (SSPC), established in Standard 90.1, has developed an economic analysis procedure, three scenarios have been generated for the cost-effectiveness methodology:

1. **Scenario 1** (also referred to as the ***Publicly Owned Method***): LCC analysis method representing government or public ownership (without borrowing or taxes).
2. **Scenario 2** (also referred to as the ***Privately Owned Method***): LCC analysis method representing private or business ownership (includes loan impacts).
3. **Scenario 3** (also referred to as the ***ASHRAE 90.1 Scalar Method***): Represents a pre-tax private investment point of view, and uses economic inputs established by ASHRAE SSPC 90.1.

In evaluating code change proposals and assessing new editions of commercial building energy codes, DOE intends to calculate multiple metrics selected from the following: lifecycle cost net savings (net present value [NPV] of savings); savings-to-investment ratio (SIR); ASHRAE 90.1 scalar ratio; and simple payback period.

NPV of savings based on LCC is the primary metric DOE intends to use to evaluate whether a particular code change is cost-effective. Any code change that results in an NPV of savings greater than zero (i.e., monetary benefits exceed costs) will be considered cost-effective. The payback period, scalar ratio, and SIR analyses provide additional information DOE believes is helpful to other participants in code change processes and to states and jurisdictions considering adoption of a new code.

Parameters are chosen to represent the economic impact of a typical commercial building ownership or tenant situation. DOE's approach is to consult appropriate sources of publicly available information to establish assumptions for each financial, economic, and energy price

[1] Throughout this document, when referring to energy codes, energy standards are included, as they become adopted into code, and are evaluated for their impact as an adopted code.
[2] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating and Air- Conditioning Engineers; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010).

parameter, following the guidelines in this methodology. DOE intends to update parameters for future analyses to account for changing economic conditions and document the source of each parameter in the specific analysis.

Where this methodology is used to evaluate the cost-effectiveness of measures in an individual building, the actual utility rate tariffs should be used instead of representative national or regional energy costs.

Acknowledgments

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Acronyms and Abbreviations

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air- Conditioning Engineers
BECP	Building Energy Codes Program
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EISA	Energy Independence and Security Act of 2007
FEMP	Federal Energy Management Program
HVAC	heating, ventilating, and air-conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
LCC	lifecycle cost
MEP	mechanical, electrical, and plumbing
NIST	National Institute of Standards and Technology
NPV	net present value
PNNL	Pacific Northwest National Laboratory
PPI	Producer Price Index
SIR	savings-to-investment ratio
SSPC	Standing Standard Project Committee

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1.0 Introduction

The Department of Energy (DOE)[3] has developed and established a methodology for evaluating the energy and economic performance of commercial energy codes. This methodology serves two primary purposes. First, as participants in the codes and standards development processes, DOE will use the methodology described herein, where appropriate, to ensure proposals are both energy efficient and cost-effective. Second, when a new edition of ANSI/ASHRAE/IES[4] Standard 90.1 is published, DOE will evaluate the new standards and codes[5] to estimate expected energy savings and assess cost-effectiveness, which will help inform states and local jurisdictions interested in adopting the new codes. DOE may also evaluate the cost-effectiveness of new editions of the International Energy Conservation Code (IECC). DOE's measure of cost-effectiveness balances longer term energy savings against increases to initial costs through a lifecycle cost (LCC) perspective.

1.1 Need for Cost-effectiveness Analysis

Section 307 of the Energy Conservation and Production Act, as amended, directs DOE to support voluntary building energy codes by providing "assistance in determining the cost-effectiveness and the technical feasibility of the energy efficiency measures included in such standards and codes" (42 U.S.C. 6836(a)(3)), periodically reviewing the technical and economic basis of the voluntary building energy codes, seeking adoption of all technologically feasible and economically justified energy efficiency measures, and otherwise participating in any industry process for review and modification of such codes (42 U.S.C. 6836(b)(2) and (3)).

The methodology described here supports DOE in fulfilling its charge to evaluate energy codes and energy code proposals. Where evaluation of the cost-effectiveness of codes is required, DOE intends to follow the procedures and use the parameters presented here. In some cases, DOE may rely on extant cost-effectiveness studies, directly addressing the building elements involved in a proposed change, if such can be identified. When evaluating code changes proposed by entities other than DOE,[6] DOE may rely on energy savings estimates, cost estimates, or cost-effectiveness analyses provided by the proponent(s) or others if DOE deems the estimates and calculations credible.

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[3] Throughout this document, DOE is identified as the primary actor in developing and applying the discussed cost-effectiveness methodology. In this activity, DOE has and will use outside resources, including the work of other parties, such as the national laboratories, to achieve its goal of evaluating cost effectiveness of code proposals. DOE engages in this activity through the Buildings Technology Office, and uses resources from other divisions in DOE, including the Federal Energy Management Program (FEMP) and the Energy Information Administration (EIA).

[4] ANSI – American National Standards Institute; ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers; IES – Illuminating Engineering Society; IESNA – Illuminating Engineering Society of North America (IESNA rather than IES was identified with Standard 90.1 prior to 90.1-2010).

[5] Throughout this document, when referring to energy codes, energy standards are included, as they become adopted into code, and are evaluated for their impact as an adopted code.

[6] All code change proposals for ASHRAE Standard 90.1 are publicly available and published by ASHRAE as addenda for public review so that public comments can be considered by the committee in a consensus process that follows ANSI procedures. The consensus process determines whether the code changes are approved for addition to the next published edition of Standard 90.1.

Incremental first cost or cost-effectiveness information is requested by code development bodies for proposals to energy codes. For example, the International Code Council (ICC) Code Development Procedures (ICC 2020) require the following:

> 3.3.5.6 Cost Impact: The proponent shall indicate one of the following regarding the cost impact of the code change proposal: 1) the code change proposal will increase the cost of construction; 2) the code change proposal will decrease the cost of construction; or 3) the code change proposal will not increase or decrease the cost of construction. The proponent shall submit information which substantiates such assertion. This information will be considered by the code development committee and will be included in the published code change proposal. Supporting documentation may be provided via a link to a website provided by the proponent and included in the cost substantiation statement. The cost substantiation statement shall include the date the link was created. Any proposal submitted which does not include the requisite cost impact information shall be considered incomplete and shall not be processed.

The ASHRAE 90.1 Standing Standard Project Committee (hereafter ASHRAE SSPC 90.1) discusses cost-effectiveness analysis related to the ANSI consensus process on pages 1 and 4 of its work plan:[7]

> The main goal and primary responsibility are to publish a consensus standard in mandatory language: That sets practical, technically feasible, and **cost-effective** minimum energy efficiency requirements for commercial buildings, except for low-rise residential buildings, on a consistent time schedule. *[Emphasis added]*
>
> …Thus, neither ASHRAE nor ANSI has an overt requirement for economic analysis, nor for any other analysis for that matter, except that the SSPC must reach “consensus” before a new standard will be approved by ANSI.
>
> That said, the Committee has often used economic analysis in its decision-making process, and it continues to believe that economics play an important role in establishing the requirements for a minimum national building energy efficiency standard. Sometimes the Committee may desire a rigorous and detailed level of economic analysis, while at other times intuitive professional judgment as to the economic impact of a proposed new measure—*without rigorous analysis*—may be sufficient.

Thus, ICC requires cost, but not cost-effectiveness information, although such analysis often helps to advance a proposal that increases the cost of construction. ASHRAE SSPC 90.1 sees benefit in cost-effectiveness analysis, although it is not always seen as necessary in the consensus process. In both cases, cost-effectiveness, where used during the code development process, is applied to individual code change proposals and not codes as a whole. Many states require or encourage cost-effectiveness analysis of the energy code in adoption proceedings to demonstrate that, overall, the code has financial benefit to the group of building users as a whole.

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[7] Work plan presented and approved at ASHRAE SSPC 90.1 meeting in June 2014, Seattle, Energy Conservation Construction Code of New York State.

1.2 Evaluating Cost-effectiveness

Evaluating cost-effectiveness requires three primary steps: 1) evaluating the energy and energy cost savings of code changes; 2) evaluating the incremental and replacement costs related to the changes; and 3) determining the cost-effectiveness of energy code changes based on those costs and savings over time. The DOE methodology estimates the energy impact by simulating the effects of the code change(s) on typical new commercial buildings, assuming both old and new code provisions are implemented fully and correctly. The methodology does not estimate rates of code adoption or compliance. Cost-effectiveness is defined primarily in terms of LCC evaluation, although the DOE methodology includes several metrics intended to assist states considering adoption of new codes.

DOE intends to use the methodology described in this document to address DOE's legislative direction related to building energy codes. DOE also intends to use this methodology to inform its participation in the update processes of ASHRAE Standard 90.1 and the IECC, both in developing code change proposals and in assessing the proposals of others when necessary. DOE further intends to use this methodology in comparing the cost-effectiveness of new code editions to prior editions or existing state energy efficiency codes.

The focus of this document is commercial buildings, which DOE defines in a manner consistent with both Standard 90.1 and the IECC—buildings except one- and two-family dwellings, townhouses, and low-rise (three stories or less above grade) multifamily residential buildings.

This document is arranged into four primary parts covering the following:

1. **Estimating the Energy and Energy Cost Savings of Code Changes**—by simulating changes to representative building types. DOE defines commercial prototype buildings, establishes typical construction and operating assumptions, and identifies climate locations to be used in estimating impacts in all climate zones and all states. The building prototypes cover a range of the most typical commercial buildings and include a variety of building system types (e.g., heating and cooling equipment) to facilitate appropriate accounting for the energy use of different commercial occupancies.

2. **Estimating the Incremental Cost of Code Changes**—by comparing the first cost of baseline buildings to the first cost of buildings with the code implemented. Incremental replacement and maintenance costs are also accounted for. A combination of methods is used to arrive at a national incremental cost, and then adjustment factors are applied to arrive at incremental costs appropriate for states.

3. **Estimating the Cost-effectiveness of Code Changes**—by comparing energy cost savings to increases in the first cost of the buildings. The methodology defines four metrics—net present value (NPV) of savings, savings-to-investment ratio (SIR), scalar ratio, and simple payback period—that may be calculated. It also establishes sources for the economic parameters to be used in estimating those metrics and identifies sources of energy-efficiency measure costs.

4. **Aggregating Energy and Economic Results**—across building types and climate locations. The methodology establishes sources for weighting factors to be used in aggregating location- and building-type-specific results to state, national, climate zone, or other domain results.

This document also includes four appendices. Appendix A describes the process DOE uses to populate its state code adoption map on the energycodes.gov website. Appendix B describes how DOE will analyze the advanced benefits of a new energy code where appropriate or as requested by states, local jurisdictions, or model code development bodies. Appendix C describes the current Standard 90.1 cost-effectiveness parameters. Appendix D presents an example sensitivity analysis evaluating the potential variability of certain economic parameters.

1.3 Use of Methodology for National, State, and Local Analysis

This methodology is applicable for cost-effectiveness analysis at national, state, and local levels. DOE will obtain and use economic parameters and other inputs that are appropriate for the given location. For example, this includes inputs such as energy prices, material and labor costs, building types, and climate zones. Individual results for building types in a climate zone can be aggregated to a national, state, or local domain using weighting factors based on construction floor area for that domain.

2.0 Estimating Energy and Energy Cost Savings of Code Changes

The first step in assessing the impact of a code change or a new code is estimating the energy and energy cost savings of the associated changes. DOE will usually employ computer simulation analysis to estimate the energy impact of a code change. (Situations in which other analytical approaches might be preferred are discussed later.) Where credible energy savings estimates are not available, DOE intends to conduct analysis using an appropriate building energy estimation tool. In most cases, DOE will use the EnergyPlus[8] software as the primary tool for its analyses. If necessary, to accurately capture the relevant impacts of a particular code change, DOE may supplement EnergyPlus with other software tools, research studies, or performance databases. Such code changes will be addressed on a case-by-case basis.

Code changes affecting a particular climate zone will be simulated in a weather location representative of that zone. Where a code change affects multiple climate zones, DOE intends to produce an aggregate (national or state) energy impact estimate based on simulation results from weather locations representative of each zone, weighted to account for estimated new commercial construction by zone and the fraction of specific building types that will be affected by the code change. Code changes affecting a particular climate zone will be simulated in representative weather locations. DOE's methodology includes weighting factors based on recent new building construction data to allow the individual location results to be aggregated to climate zone and national averages as needed. These methodologies, weighting factors, and aggregation approaches are described in Section 5.0.

Recent energy codes have included provisions for additional efficiency measures above and beyond the prescriptive code requirements that must be included in the building design and construction. The additional efficiency comes in the form of energy credits where energy efficiency measures are assigned energy credits based on the percentage of annual total energy savings achieved over the baseline prescriptive energy code. Energy savings may be expressed in in terms of site energy, energy cost, or emissions. The higher the savings, the more energy credits assigned. In the model codes (Standard 90.1 and the IECC), energy credits are typically divided into traditional efficiency (envelope, HVAC, service water heating, air leakage, and appliances), and load management (renewable energy, demand flexibility, and energy storage) measures. The amount of energy credits for each measure is determined based on simulation analysis of the energy measure over the prescriptive code for each climate zone and building type. The energy code stipulates the amount of energy credits a building must achieve by climate zone and building type. Since the energy credits provide flexibility to meet the required credit amount, there can be various combinations of measures to meet the requirement. For the state and national level analyses, energy credit measures will be selected to meet the required number of energy credits based on several factors including standard practice, cost effectiveness, and the ability to quantify savings using the methodology described in this report.

2.1 Building Energy Use Simulation

The energy performance of most energy-efficiency measures in the scope of building energy codes can be estimated by computer simulation. In estimating the energy performance of pre- and post-revision codes, two building cases will be analyzed: (1) a building that complies with

[8] Available at: https://energyplus.net/

the pre-revision code; and (2) an otherwise identical building that complies with the revised code under analysis. These two building cases will be simulated in a variety of locations to estimate the overall (national average) energy impact of the new code or code proposal. The inputs used in those simulations are discussed in the following sections.

2.1.1 Energy Simulation Tool

DOE intends to use a whole-building simulation tool to calculate annual energy consumption for relevant end uses. For most situations, the EnergyPlus software, developed by DOE, will be the tool of choice. EnergyPlus provides for detailed time-step (hourly or shorter time steps are typical) simulation of a building's energy consumption throughout a full year, based on typical weather data for a given location. It covers most aspects of systems impacting energy use in commercial buildings: envelopes; heating, ventilating, and air-conditioning (HVAC) equipment and systems; water heating equipment and systems; lighting systems; and plug and process loads. Depending on how building energy codes evolve, it may be necessary to identify additional tools to estimate the impacts of some changes. For example, inputs to EnergyPlus are often established with survey data, separate engineering calculations, or ancillary analysis programs, as some systems are not directly covered within EnergyPlus (e.g., elevator operation, swimming pools, and two-dimensional heat transfer through assemblies of building materials).

DOE recognizes there are other tools that can produce credible energy estimates. DOE intends to use EnergyPlus as its primary tool because it includes advanced simulation capabilities, is under active development, is recognized as one of the leading simulation tools, and has the potential to include capabilities either unavailable or less sophisticated than in other accepted simulation tools. EnergyPlus has capabilities for detailed simulation of complex HVAC systems, advanced capabilities for simulating interaction between primary and secondary HVAC systems, and the potential for analyzing detailed control strategies.

2.1.2 Building Prototypes

Separate simulations are typically conducted for multiple commercial building prototypes. The prototypes used in the simulations are intended to represent a cross-section of common commercial building types covering 80% of new commercial construction. DOE developed 16 prototype building models, which were reviewed extensively by building industry experts on ASHRAE SSPC 90.1 during development and assessment of multiple editions of ASHRAE Standard 90.1. These prototype models, their detailed characteristics, and their development are published on DOE's Building Energy Codes Program (BECP) web site.[9] A detailed description of the prototypes can also be found in a technical report published by Pacific Northwest National Laboratory (PNNL), *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* (Thornton et al. 2011). The prototype models are further described in detail in the quantitative determination of the energy savings of Standard 90.1-2022 (Maddox et al. 2024). Table 1 shows the general characteristics DOE intends to use in analyzing the prototypes. Note that any of the prototype characteristics may be modified if a code change impacts it or such modification adds accuracy to the energy savings estimate for particular code changes.

[9] See https://www.energycodes.gov/prototype-building-models

Table 1. Commercial Prototype Building Basic Characteristics

Building Prototype	Floor Area (ft²)	Number of Floors	Aspect Ratio	Window-to-Wall Ratio	Floor-to-Floor Height (ft)
Small office	5,502	1	1.5	21%	10
Medium office	53,628	3	1.5	33%	13
Large office	498,588	12*	1.5	40%	13
Standalone retail	24,692	1	1.28	7%	20
Strip mall	22,500	1	4	11%	17
Primary school	73,959	1	1.3	35%	13
Secondary school	210,887	2	1.4	33%	13
Outpatient healthcare	40,946	3	N/A	20%	10
Hospital	241,501	5*	1.31	16%	14
Small hotel	43,202	4	3	11%	9, 11‡
Large hotel	122,120	6*	5.1, 3.8**	30%	10, 13‡
Warehouse	52,045	1	2.2	0.71%†	28
Quick-service restaurant	2,501	1	1	14%	10
Full-service restaurant	5,502	1	1	17%	10
Mid-rise apartment	33,741	4	2.74	20%	10
High-rise apartment	84,360	10	2.75	30%	10

* These buildings also include a basement, which is not included in the number of floors.
** The large hotel basement aspect ratio is 3.8:1; all other floors have an aspect ratio of 5.1:1.
† For the warehouse, 0.71% is the overall WWR ratio. The warehouse area has no windows; the WWR ratio for the small office in the warehouse is 12%.
‡ The second number is the height of the first floor only.

DOE may select a subset of these prototype buildings and simulate them in representative climate locations for the cost-effectiveness analysis to represent most of the energy and cost impacts of the code changes in a particular code or proposal analysis. This approach is based on the fact that not all code requirements will apply to a set of standardized prototypes. The overall savings of a code edition will be well characterized if the preponderance of code measures and climate zones are directly modeled. The selection approach is discussed further in Section 5.1.

2.1.3 Default Inputs

Input values for building components that do not differ between the two subject codes will be set to (1) match a shared code requirement if one exists, (2) match standard reference design specifications from the code's performance path if the component has such specifications, or (3) match best estimates of typical practice otherwise. Examples of these items are wall insulation R-values that are the same in both code editions, the heating system type required for performance analysis, and typical internal equipment (plug) loads based on surveys or load calculation handbooks, respectively. Because such component inputs are used in both pre- and post-revision simulations, their specific values are considered neutral and are of secondary importance, so it is important only that they be reasonably typical of the construction types being evaluated.

2.1.4 Provisions Requiring Special Consideration

Some building components or energy conservation measures do not lend themselves to straightforward pre- and post-change simulation of energy consumption. For example, the use of hourly simulation is of dubious value in assessing the energy impact of service water heat piping insulation. Rather than including an exact piping heat loss model in the building simulation, typical expected losses may be separately calculated and entered as loads into the simulation model.

Another situation requiring special consideration involves analysis of new or innovative equipment that cannot be implemented directly in the energy simulation software. One example is a heat-recovery device for service water heating that uses heat rejected from the chiller. Analysis of such a proposal can be effectively performed by analyzing the load outputs from EnergyPlus in a separate tabular analysis using standard engineering formulas for the impact of heat recovery on the energy use of the building. Another example of post-processing is analysis of water-side economizers for Addendum *du* to ASHRAE Standard 90.1-2013 using hourly data extracted from EnergyPlus models (Hart et al. 2014).

2.2 Weather Locations

Simulations (and other analyses as appropriate) will usually be conducted in one representative weather location per selected climate zone in the code, including a separate location for each moisture regime.[10] ASHRAE SSPC 90.1 updated the representative cities to adopt changes made in ASHRAE Standard 169-2013, *Climatic Data for Building Design Standards*, and to provide a better match for actual climate in each climate zone. DOE began using these updated representative locations for analysis starting with Standard 90.1-2016 and the 2018 IECC. Table 2 shows the climate locations typically used for a national savings analysis, each of which is represented by the Typical Meteorological Year version 3 (TMY3) weather data file.

Table 2. Climate Locations Used in Energy Simulations

Climate Zone*	Moisture Regime	City, State	Climate Zone*	Moisture Regime	City, State
1A	Moist	Miami, FL	4C	Marine	Seattle, WA
2A	Moist	Tampa, FL	5A	Moist	Buffalo, NY
2B	Dry	Tucson, AZ	5B	Dry	Denver, CO
3A	Moist	Atlanta, GA	5C	Marine	Port Angeles, WA
3B	Dry	El Paso, TX	6A	Moist	Rochester, MN
3C	Marine	San Diego, CA	6B	Dry	Great Falls, MT
4A	Moist	New York, NY	7	N/A	International Falls, MN
4B	Dry	Albuquerque, NM	8	N/A	Fairbanks, AK

There are several approaches for climate zone selection:

- For a national-level energy saving analysis, up to 16 climate locations are used, selected from those shown in Table 2.

[10] Moisture regimes reflect the average humidity in a climate zone. As seen in Table 2, moisture regime A represents higher humidity (moist) than B (dry), while marine zones (C) have some moisture, but also have more moderate temperature ranges.

- For a national-level cost-effectiveness analysis, DOE may select a subset of the climate zones to represent most of the energy and cost impacts of the code changes in a particular code or proposal analysis. The selection approach is discussed further in Section 5.1.

- For a state-level code cost-effectiveness analysis, alternate cities located in each climate zone for the state are selected. A TMY3 weather station with robust data is selected within the state where possible, or adjacent to the state being analyzed if better data are in the adjacent city.

- For measures or code changes that impact primarily building envelope or are not impacted by humidity conditions, the cities representing thermal climate zones may be used, with the results applying to the climate zones that share the same thermal climate zone numbers, regardless of moisture regime.

- Some analyses are conducted only for the adjoining climate zones where requirements are proposed to change. For example, increased exterior duct insulation in climate zone 5 and colder only requires an analysis in thermal climate zones 4 and 5 where analysis shows the extra insulation is not cost-effective in climate zone 4, but is cost-effective in climate zone 5. Because a logical argument can be made that colder climate zones will result in more heat loss, the extra insulation can be presumed to be cost-effective in climate zones 6 through 8.

2.3 Energy Cost Savings

Annual energy costs are a necessary part of the cost-effectiveness analysis. They are based on energy consumption multiplied by average energy prices. For the national Standard 90.1 analysis, DOE will use the same energy prices as approved by ASHRAE SSPC 90.1 for standard development – energy prices that were based on EIA data. Using the same prices from development of a particular edition of Standard 90.1 provides a consistent approach and applies a similar cost-effectiveness threshold to the entire standard that was used for individual proposals as the standard was developed. The ASHRAE 90.1 Scalar Method identifies a fossil fuel rate[11] that is primarily applied to heating energy use, with some application to service water heating. DOE may apply this mixed fuel approach to state cost-effectiveness analysis.

In any event, prices used for cost-effectiveness energy analyses are derived from the EIA data (EIA 2022). DOE intends to use the most recently available national or state annual average commercial energy prices from the EIA. Annual average prices are used to avoid selecting a short-term price that is subject to seasonal fluctuations. If energy prices from the most recent year(s) are unusually high or low, DOE may use a longer-term average of energy prices, such as the average from the past 3 years and projections for the next 2 years.[12] For individual state analysis, DOE intends to use state annual average commercial energy prices from EIA. The

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[11] The ASHRAE 90.1 Scalar Method fossil fuel rate is a blended heating rate and includes proportional costs for natural gas, propane, heating oil, and electric heat relative to national heating fuel use share. Heating energy use in the prototypes for fossil fuel equipment is calculated in therms based on natural gas gas equipment, but in practice, similar equipment may be operated on propane, or boilers that are modeled as natural gas may use oil in some regions.

[12] EIA energy projections are available from either the *Short-Term Energy Outlook or Annual Energy Outlook*.

energy prices used in a specific analysis along with their source will be declared and documented in that analysis.

2.3.1 Time of Use Energy Costs

Calculating the energy cost impact of some model code requirements may not be appropriate using an annual average energy price and may require a time-of-use energy rate. For example, ASHRAE 90.1 committee has approved a representative time-of-use electricity rate for evaluating code change proposals that impact both consumption and peak demand. Where applicable, the approved ASHRAE 90.1 time-of-use electric rate (ASHRAE TOU) will be applied when evaluating code requirements designed to shift or reduce peak building electricity loads.

The ASHRAE TOU rate is representative of a typical U.S. TOU electricity rate and was developed to serve as a proxy for assessing the time-dependent-value (TDV) of efficiency. It was developed from nearly 1,700 published commercial building electricity rates that include demand charges offered by utilities located across the country. The rates include electricity kilowatt-hour (kWh) and kilowatt (kW) charges that vary by hour of day, day of the week, and season. The daily and seasonal variations established for the representative rate are as follows:

Winter kWh Peak Period: October – May, Monday–Friday, 6 AM to 10 AM and 5 PM to 9 PM

Summer kW and kWh Peak Period: June – September, Monday–Friday, 1 PM to 9 PM.

The use of a representative rate defined at the national level is appropriate for model energy code development. However, state and local governments may choose to use local utility published rate data to more accurately ascertain the regional grid benefits associated with code change amendments.

3.0 Estimating the Incremental Costs of Code Changes

The second step in assessing the cost-effectiveness of a proposed code change or a newly revised code is estimating the first cost of the changed provision(s). The first cost of a code change refers to the marginal cost of implementing one or more changed code provisions. For DOE's analyses, first cost refers to the retail cost (the total cost to a building developer) prior to amortizing the cost over multiple years through financing, and includes the full price paid by the building developer, including materials, sales taxes, labor, overhead, and profit. First cost excludes maintenance and other ongoing costs associated with the new code provision(s). Where regular maintenance costs are expected to be significantly different as a result of code requirements, they are estimated and converted to an annual maintenance cost, then accounted for separately on an annualized basis in the LCC calculation. There are also replacement costs estimated when individual component life is shorter than the economic study period.

DOE recognizes that estimating the first cost of a code change can be challenging and will attempt to identify credible cost estimates from multiple sources when possible. Judgment is often required to determine an appropriate cost for energy code analysis when multiple credible sources of construction cost data yield a range of first costs. Cost data will be obtained from existing sources, including cost-estimating publications such as RS Means handbooks;[13] industry sources (often through websites); and other resources including journal articles, research, and case studies. DOE may also subcontract with engineering or architectural professionals to provide specialized expertise and complete cost estimates for energy efficiency measures or representative building systems. DOE will use all of these resources to determine the most appropriate construction cost parameters based on factors including the applicability and thoroughness of the data source.

3.1 Cost-Estimating Approach

The first step in developing the incremental cost estimates is to define the items to be estimated, such as specific pieces of equipment and their installation. The second step begins by defining the types of costs to be collected. Cost estimates cover incremental costs for material, labor, construction equipment, commissioning, maintenance, and overhead and profit. These costs are estimated both for initial construction and for replacing equipment or components at the end of their useful life during the study period. The third step is to compile the unit and assembly costs needed for the cost estimates. These costs are derived from multiple sources:

- Cost-estimating consulting firms; mechanical, electrical, and plumbing (MEP) consulting engineering firms; or specialized consultants (such as daylighting) may be retained to develop general cost estimates applicable to code changes in the prototypes.
- Cost estimates for new work and later replacements are developed to approximate what a general contractor typically submits to the developer or owner and include subcontractor and contractor costs and markups.
- Maintenance costs are intended to reflect what a maintenance firm would charge. Once initial costs are developed, a technical review is often conducted by members of the ASHRAE SSPC 90.1 and PNNL internal sources.

[13] RS Means cost estimating handbooks are available at www.rsmeans.com/

3.2 Sources of Cost Estimates

Table 3 describes typical sources of cost estimates by category. This table is an example based on the national cost-effectiveness analysis of Standard 90.1-2022 (Tyler et al. 2024) and is typical of sources that will be used in completing cost-effectiveness analyses of codes and efficiency standards for commercial buildings. In this example, RS Means refers to any of the appropriate RS Means cost-estimating handbooks.

Table 3. Example Sources of Cost Estimates by Category

Cost Category	Source
HVAC Motors included in this category	Cost estimator and PNNL staff used quotes from suppliers and manufacturers, online sources, and their own experience. *
HVAC: Ductwork, piping, selected controls items	MEP consulting engineers provided ductwork and plumbing costs based on one-line diagrams they created as well as the model outputs, including system airflows, capacity, and other factors, and provided detailed costs by duct and piping components using RS Means 2012. The MEP consulting engineers also provided costs for several control items. Additional items were priced using RS Means 2023. *
HVAC Selected items	PNNL used internal expertise and experience supplemented with online sources. *
Lighting Interior lighting power allowance and daylighting controls	PNNL staff with input from ASHRAE 90.1 Lighting Subcommittee. Product catalogs were used for consistency with some other online sources where needed.
Envelope Fenestration	Costs dataset developed by specialist cost estimator with additional input from the Standard 90.1 Envelope Subcommittee. *
Commissioning	Cost estimator, RS Means, MEP consulting engineers, and PNNL staff expertise.
Labor	RS Means 2023 and the MEP consulting engineers for commissioning rate.
Replacement life	Lighting equipment including lamps and ballasts from product catalogs. Mechanical from ASHRAE 90.1 Mechanical Subcommittee protocol for cost analysis.
Maintenance	Originator of the other costs for the affected items or PNNL staff expertise.

* Detailed costs developed in 2012 or 2014 were updated to 2023 using equipment-specific inflation factors developed from RS Means handbooks, as discussed in Section 3.4.

3.2.1 Approach to Cost Data Collection

For code changes that impact many systems or construction assembly elements of a building, DOE consults multiple national construction cost estimation publications published by RS Means, which provide a wide variety of construction cost data. This is appropriate for many code changes that impact the construction of commercial buildings (e.g., increasing insulation thickness on piping) where the efficiency change can be tied to incremental changes in material thickness or items clearly identified in the estimating guides. RS Means handbooks do not always identify the efficiency levels of products and may not have both standard and high-efficiency options. They do not, for example, have detailed costs on improved duct sealing or building envelope sealing, and the costs for fenestration products (windows, doors, and skylights) are focused on aesthetic features rather than energy efficiency characteristics such as solar heat gain coefficient or low-e coatings.

When a code change impacts only the materials used in a building, without impacting labor, cost data can often be obtained from national suppliers. These sources can have the advantage of providing recent costs, and the costs can be localized if a state or local analysis is needed. However, these sources often do not provide all the specific energy efficiency measure improvements that are typically needed for code improvement analyses.

As needed, DOE conducts literature searches of specialized building science research publications that assess the costs of new or esoteric efficiency measures that are not covered in other data sources. Examples include energy efficiency case studies, surveys of demonstration projects, utility or regional energy economic potential savings studies, and journal articles.

3.2.2 Economies of Scale and Market Transformation Effects

Construction costs often show substantial differences between regions, sometimes based primarily on local preferences and the associated economies of scale. Because new code changes may require building construction with new and potentially unfamiliar techniques in some locations, initial local cost estimates may overstate the long-term costs of implementing the change. For example, economizer fault diagnostics or light-emitting diode (LED) parking lot lighting may be reasonably priced in California, where the technology has already been required by code for some time. In states with older codes, the price for the same technology may be high, due to contractor unfamiliarity. Similar issues may arise where manufacturers produce large quantities of a product that just meet a current energy code requirement, giving that product a relatively low price in the market. Should the code requirement increase, it is likely that manufacturers will increase production of a new conforming product, lowering its price relative to the current premium for what is now a high-efficiency product.

DOE intends to evaluate new code changes case by case to determine whether it is appropriate to adjust current costs for anticipated market transformation after a new code takes effect. DOE intends to evaluate specific new or proposed code provisions to determine whether and how prices might be expected to follow an experience curve with the passage of time. It is noted that site-built construction may involve several types of efficiency improvements. The real cost of code changes requiring new technologies may drop in the future as manufacturers learn to produce them more efficiently. The long-term cost of code changes that involve new techniques may likewise drop as contractors learn to implement them in the field more efficiently and with less labor. Finally, code changes that simply require more of a currently used technology or technique may have relatively stable real costs, with prices generally following inflation over time.

3.2.3 Addressing Code Changes with Multiple Approaches to Compliance

One challenge of estimating the costs of energy code changes is selecting an appropriate characterization of new code requirements. A requirement for lower fan horsepower, for example, might be met with a more efficient fan, high surface area filters, better belts, a premium efficiency motor, more but smaller fan units, larger ductwork, or some combination of these options. Each approach will have different costs and may be subject to differing constraints depending on the situation. Some approaches, for example, may be inappropriate in certain building types. Other approaches may open the possibility for new and less expensive construction approaches. Overall, DOE intends to apply two principles in reviewing options in the code:

- A single option will be selected for analysis that is expected to be the least-cost method of compliance that is considered to represent typical construction.
- If a requirement includes multiple options, and one analyzed option that is widely applicable is found to be cost-effective, the requirement will be deemed cost-effective. It is not necessary to demonstrate the cost-effectiveness of all options. This is because there is a cost-effective path through the code, and if a higher cost option is chosen, that is the developer's or designer's choice.

It is difficult for DOE to anticipate either the types of code changes that will emerge in future building energy codes or the way developers will choose to meet the new requirements; however, DOE intends to evaluate changes case by case and seek the least-cost way to achieve compliance unless that approach is deemed inappropriate in a large percentage of situations. For code changes that touch on techniques with recent research experience (e.g., through DOE's FEMP[14] and Building Technologies Office[15]), DOE will consult the relevant publications or researchers for advice on appropriate construction assumptions.

DOE anticipates that some new code provisions may have significantly different first costs depending on unrelated aesthetic choices or exceptions and flexibility options in the code. For example, a requirement for window shading could be met with interior blinds, electrochromic windows, static exterior shading devices, or an active tracking exterior shading system. In addition, optional tradeoffs may be included in the code that guarantee minimum energy performance but are not necessarily evaluated for cost-effectiveness. For example, a maximum window-to-wall ratio may be established as a baseline, but a predetermined tradeoff may allow the building design to exceed that ratio if an energy recovery device or other energy-saving options are included. Because the additional windows and energy-saving options are optional, it is not necessary to establish the cost-effectiveness of the alternative design combination.

Finally, some new code provisions may come with no specific construction changes at all, but rather be expressed purely as a performance requirement. It is also conceivable that a code could be expressed simply as energy-use intensity, where the requirement is a limit on energy use per square foot of conditioned floor area. DOE intends to evaluate any such code changes case by case and will conduct literature research or new analyses to determine the reasonable set of construction changes that could be expected to emerge in response to such new requirements. Again, DOE intends to focus on the least-cost approach deemed to be reasonable, cost-effective, and meet the code requirement.

3.3 Cost Parameters

Several general parameters are typically applied to all cost estimates. These items include new construction material and labor cost adjustments, a replacement labor-hour adjustment, replacement material and labor cost adjustments, and a project cost adjustment. The cost adjustments were first developed by PNNL during the cost-effectiveness analysis of Standard 90.1-2010 and were based on cost-estimating guides and practices of cost-estimating consultants for that study (Thornton et al. 2013). DOE intends to use these parameters for future estimates unless there are changes noted in the industry. They are described in Table 4.

[14] See https://www.energy.gov/femp/federal-energy-management-program
[15] See https://www.energy.gov/eere/buildings/building-technologies-office

Table 4. Cost Estimate Adjustment Parameters

Cost Items	Value*	Description**
New construction labor cost adjustment	52.6%	Labor costs used are base wages with fringe benefits. Added to this is 19%: 16% for payroll, taxes, and insurance including worker's compensation, Federal Insurance Contributions Act, unemployment compensation, and contractor's liability, and 3% for small tools. The labor cost plus 19% is multiplied by 25%: 15% for home office overhead, and 10% for profit. A contingency of 2.56% is added as an allowance to cover wage increases resulting from new labor agreements.
New construction material cost adjustment	15.0% to 26.5%	Material costs are adjusted for a waste allowance set at 10% in most cases for building envelope materials. For other materials such as HVAC equipment, 0% waste is the basis. The material costs plus any waste allowance are multiplied by the sum of 10% profit on materials, and sales taxes. An average value for sales taxes of 5% is applied.
Replacement - additional labor allowance	65.0%	Added labor hours for replacement to cover demolition, protection, logistics, cleanup, and lost productivity relative to new construction. Added prior to calculating replacement labor cost adjustment.
Replacement labor cost adjustment	62.3%	The replacement labor cost adjustment is used instead of the new construction labor cost adjustment for replacement costs. The adjustment is the same except for subcontractor (home office) overhead, which is 23% instead of 15% to support small repair and replacement jobs.
Replacement material cost adjustment	26.5% to 38.0%	The replacement material cost adjustment is used instead of the new construction material cost adjustment for replacement costs. The adjustment is for purchase of smaller lots and replacement parts. 10% is added and then adjusted for profit and sales taxes.
Project cost adjustment	28.8%	The combined labor, material, and any incremental commissioning or construction costs are added together and adjusted for subcontractor general conditions and for general contractor overhead and profit. Subcontractor general conditions add 12% and include project management, job-site expenses, equipment rental, and other items. A general contractor markup of 10% and a 5% contingency are added to the subcontractor subtotal as an alternative to calculating detailed general contractor costs (RS Means 2023).

* Values shown and used are rounded to first decimal place.
** Values provided by the cost estimator except where noted.

For national cost-effectiveness studies, costs are not adjusted for climate locations. The climate location results are intended to represent an entire climate subzone even though climate data for a particular city is used for simulation purposes. Costs will vary significantly between a range of urban, suburban, and rural areas within the selected climate locations, which typically cross multiple states. For state-level cost-effectiveness analysis, costs are adjusted for specific cities based on city cost index adjustments from RS Means or other sources.

3.4 Cost Updating for Inflation

Cost estimates are typically developed for current national average prices. Labor costs are based on estimated hours and current crew labor rates from RS Means. In some cases, cost estimates completed for a prior code cycle are still applicable and are adjusted for inflation rather than creating a new cost estimate or obtaining current unit prices throughout the cost estimate. Where cost estimates are updated, inflation factors specific to the equipment are used. These inflation factors are developed for each specific equipment or insulation type by comparing RS Means from the time of the estimate with the current RS Means.

3.5 Cost Estimate Spreadsheet Workbook

To provide a transparent view of the costs used in the analysis, a spreadsheet will typically be prepared in conjunction with the cost-effectiveness report. The intent is to show the basis for costs used in the analysis, although in some cases detailed information obtained from individual manufacturers will be averaged and only the average value included in the documentation. For some individual proposals, a spreadsheet may not be necessary, as the costs may be cited from other documents or sources. As one example, the cost estimate spreadsheet for the analysis of Standard 90.1-2019 (Tyler et al. 2021a) was organized in the following sections:

1. Introduction
2. HVAC methodology
3. HVAC cost estimates
4. Lighting methodology
5. Lighting cost estimates
6. Envelope, power, and other cost estimates
7. General cost parameters
8. Construction weights
9. Economic analysis parameters
10. Cost estimate summaries by building type and climate zone
11. Cost-effectiveness analysis results

DOE may also provide a calculating tool that allows cost adjustments to be entered, especially for state analysis. This allows local evaluation of particular cost or other economic impacts to be adjusted in evaluating codes for use by states in the adoption process. The cost adjustment is entered as a cost multiplier, where a value greater than 1.0 indicates higher than national average costs, while a value lower than 1.0 results in lower costs. For DOE's assessment of cost-effectiveness, the researched input values for economic and cost parameters will continue to be used.

4.0 Estimating the Cost-effectiveness of Code Changes

The last step in assessing the cost-effectiveness of a proposed code change or a newly revised code is calculating the corresponding economic impacts of the changed provision(s). These impacts are measured under different economic scenarios with several economic metrics.

4.1 Cost-effectiveness Analysis

The intent of the DOE cost-effectiveness methodology is to determine whether code changes are economically justified from the perspective of a public policy that balances increased building costs against energy savings over time. The DOE methodology accounts for the benefits of energy-efficient building construction to building owners and tenants that accrue over 30 years. To accommodate multiple economic views, the LCC analysis is applied to multiple scenario methods: Publicly Owned Method; Privately Owned Method; and ASHRAE 90.1 Scalar Method. The scenarios, methodologies, and input parameters are described in this section.

Cost-effectiveness is analyzed using the incremental cost information presented in Section 3.0 and the energy cost information presented in Section 2.0. Multiple economic metrics are available, as discussed further in Section 4.2. Several of these may be presented in a particular analysis and are selected from the following:

- Lifecycle Cost (LCC) net savings (NPV of savings)
- Savings-to-investment ratio (SIR)
- ASHRAE 90.1 Scalar Ratio
- Simple payback period.

4.1.1 Economic Scenarios

Commercial building developers and owners have different perspectives, depending primarily on whether the ownership is public or private. The building owner has a different view of the economic impact of energy purchases as a landlord than as an owner who occupies the building. In tenant situations, the energy operating costs may be paid by the tenant directly to utilities or indirectly via the building owner through a net lease. In the latter situation, the costs for energy efficiency may be paid by an owner who does not receive energy benefits through reduced bills; however, these incremental costs can be considered as passed through to the tenant in the lease rates. In every case, someone will pay the energy bill for the building—having savings if it is a more efficient building—and someone will pay the added cost of a more efficient building. While local rental market conditions may result in higher or lower lease rates relative to the incremental cost of efficiency improvements, a complete economic model of such variability would be quite difficult to implement. To provide a straightforward and economic equivalent analysis, the cost-effectiveness analysis will be from the point of view of a building owner who receives the benefits of energy savings. This approach puts the analysis of the costs and savings of all energy-saving measures on a common footing for analysis.

DOE evaluates energy codes and code proposals based on LCC analysis over a multiyear study period, accounting for energy savings, incremental investment for energy efficiency measures, and other economic impacts. The value of future savings and costs are discounted to a present value, with improvements deemed cost-effective when the NPV of savings (present value of savings minus present value of costs) is positive. Because the economic criteria of different commercial building owners vary, up to three scenarios may be used for cost-effective analysis:

- **Scenario 1** (also referred to as the ***Publicly Owned Method***): LCC analysis method representing government or public ownership without borrowing or taxes. This scenario uses a real dollar methodology and economic inputs that have been established for federal projects under FEMP as amended by the Energy Independence and Security Act of 2007 (EISA).
- **Scenario 2** (also referred to as the ***Privately Owned Method***): LCC analysis method representing private or business ownership. This scenario uses typical commercial economic inputs with initial costs being financed with loans. The general methodology is identical to that used in Scenario 1, except that it is a nominal dollar analysis with additional consideration for financing and a private sector discount rate.
- **Scenario 3** (also referred to as the ASHRAE 90.1 ***Scalar Method*** (McBride 1995)): Represents a pre-tax private investment point of view, and uses economic inputs established by the ASHRAE SSPC 90.1. The ASHRAE 90.1 Scalar Method uses standard lifecycle costing techniques in a similar manner to Scenarios 1 and 2, although the parameters and methodology used in the analysis are established by ASHRAE SSPC 90.1.

It is important to understand that, except for the minor adjustments noted here, DOE uses methods and parameters established by others for Scenarios 1 and 3. Scenario 1 parameters are established by federal statute (42 U.S.C. 8254). Scenario 3 parameters are established by ASHRAE SSPC 90.1 for each edition of Standard 90.1. The method and parameters used for Scenario 2 are established by DOE, although they are developed and selected to be consistent with Scenario 1, except where typical private investment criteria support different parameters.

When selecting scenarios for a particular cost-effectiveness analysis, DOE notes that Scenarios 2 and 3 both reflect a private-ownership view. As a result, each analysis typically includes Scenario 1 to reflect a public-ownership view and the private-ownership view is reflected by either Scenario 2 or 3. For a national analysis, the ASHRAE Scalar Method (McBride 1995) is used for the private-ownership view, as this was the method applied to individual proposals in development of the standard. The ASHRAE energy prices are typically used for the national analysis, again for consistency with the individual proposal analyses. For individual state analysis, DOE typically uses local state energy prices, and cost-effectiveness is determined based on LCC using Scenarios 1 and 2 economic parameters. Scenario 2 is used as the Private-Ownership Method for state analysis since the method and parameter selection can be maintained on a consistent basis by DOE. Scenario 2 also more closely matches Scenario 1 and the cost-effectiveness method used for residential codes than does Scenario 3.

4.1.2 Cost-effectiveness Methodology

The primary basis of a cost-effectiveness assessment is an LCC analysis. The LCC analysis perspective compares the present value of incremental costs, replacement costs, and maintenance and energy cost savings for each prototype building and climate location. The degree and impact of borrowing varies considerably for different building projects, creating many possible cost scenarios. These varying costs are not included in the Scenario 1 Publicly Owned Method LCC analysis but are included with the Scenario 2 Privately Owned Method analysis and the Scenario 3 SSPC 90.1 Scalar Method.

The LCC analysis approach is based on the method used by FEMP,[16] a method required for federal projects and used by other organizations in both the public and private sectors (NIST 1995). The LCC analysis method consists of identifying costs (and revenues, if any) and the year in which they occur and determining their value in present dollars (or NPV). This method uses fundamental engineering economics relationships about the time value of money. For example, money in hand today is normally worth more than money received tomorrow, which is why people pay interest on a loan and earn interest on savings. Future costs are discounted to the present based on a discount rate. The discount rate may reflect what interest rate can be earned on other conventional investments with similar risk, or in some cases, the interest rate at which money can be borrowed for projects with the same level of risk.

4.1.2.1 Discounted Value

The following calculation method can be used to account for the present value of costs or revenues:

$$\text{Present Value} = \text{Future Value} / (1+ i)^n$$

i is the discount rate (or interest rate in some analyses)

n is the number of years in the future the cost occurs

The present value of any cost that occurs at the beginning of year 1 of an analysis period is equal to that initial cost. For this analysis, initial construction costs occur at the beginning of year 1, and all subsequent costs occur at the end of the future year identified.

4.1.2.2 Study Period

The LCC analysis depends on the number of years into the future that costs and revenues are considered, known as the study period. While the FEMP method allows a 40-year[17] study period (42 U.S.C. 8254(a)(1)), the DOE code analysis method uses 30 years for Scenarios 1 and 2 and 40 years for Scenario 3. Thirty years is the same study period used for the cost-effectiveness analysis of the residential energy code, conducted by PNNL (Salcido et al. 2021), and is the same period used in previous cost-effectiveness evaluations of Standard 90.1 (Thornton et al. 2013; Hart et al. 2020, Tyler et al. 2021b, Tyler et al. 2024). The National Institute of Standards and Technology (NIST)-provided energy escalation and discount rates are also limited to 30 years. The 30-year study period is also widely used for LCC analysis in government and industry, and the Office of Management and Budget long-term study period is set at 30 years. The study period is also a balance between capturing the impact of future replacement costs, inflation, and energy escalation; the higher the uncertainty of these costs, the further into the future they are considered.

4.1.2.3 Residual Value

When the length of the study period does not exactly match the measure life, the analysis accounts for the residual value of equipment at the end of the analysis period. The FEMP LCC analysis method includes a simplified approach for determining the residual value. The residual value is the proportion of the initial cost times the remaining years of service divided by the service life. For example, the residual value of a wall assembly in year 30 (40-year service life)

[16] See 10 CFR part 436, subpart A, “Methodology and Procedures for Life Cycle Cost Analyses,” Jan. 1, 2024.
[17] Section 441 of EISA amended the FEMP cost-effective methodology to increase the maximum study period from 25 to 40 years (42 U.S.C. 8254(a)(1)).

is (40-30)/40 or 25% of the initial cost. The residual values in year 30 are discounted from year 30 to a present value and included as a reduction in the total present value of cost. Three cases need to be considered for residual value:

- Where the measure life matches the study period, or an even multiple of the life matches the study period, there is no residual value. For example, electronic controls with a 15-year life in a 30-year study period include a replacement cost at year 15, and that replacement has no further value at year 30, so the residual value is zero.
- Where the useful life of equipment or materials extends beyond the study period, there is a residual value. For code measures analyzed, the longest useful life defined is 40 years for all envelope cost items, such as wall assemblies, as recommended by the SSPC 90.1 Envelope Subcommittee. Forty years is longer than the 30-year study period used in Scenario 1 and 2 LCC analyses. A residual value of the unused life of a cost item is calculated at the last year of the study period for components with longer lives than the study period. So, for example, a measure with a 40-year life in a 30-year study period would have a residual value of 25% of its first cost.
- Where the replacement life does not fit neatly into the study period (e.g., a chiller with a 23-year useful life), the residual value is not a salvage value, but rather a measure of the available additional years of service not yet used for the replacement. To use the chiller example with a 30-year study period, at 30 years there is a 16-year (23+23-30) residual life remaining. Thus, the residual value would be (46-30)/23, or 69.5% of the replacement cost, discounted from year 30 to present value.

4.2 Economic Metrics

In evaluating code change proposals and assessing new editions of commercial building energy codes, DOE intends to calculate multiple metrics selected from the following:

- LCC net savings (NPV of savings)
- Savings-to-investment ratio (SIR)
- SSPC 90.1 Scalar Ratio
- Simple payback period.

LCC net savings is the primary metric DOE intends to use to evaluate whether a particular code change is cost-effective. Any code change that results in an LCC net savings greater than or equal to zero (i.e., monetary benefits exceed costs) will be considered cost-effective. The payback period and SIR analyses provide additional information DOE believes is helpful to other participants in code change processes and to states and jurisdictions considering adoption of new codes. These metrics are discussed further below.

4.2.1 Lifecycle Cost Net Savings

LCC net savings is a robust cost-benefit metric that sums the costs and benefits of a code change over a specified period. Sometimes referred to as *NPV* analysis or *engineering economics*, LCC analysis is a well-known approach to assessing cost-effectiveness. Because the key feature of LCC analysis is the summing of costs and benefits over multiple years, it requires that cash flows in different years be adjusted to a common year for comparison. This is done with a *discount rate* that accounts for the time value of money. Like most LCC implementations, DOE's method sums cash flows in year-zero dollars, which allows the use of standard discounting formulas. Cash flows adjusted to year zero are termed *present values*. The procedure used for discounting is taken directly from the FEMP cost-effectiveness methodology for federal buildings as described in *NIST Handbook 135* (Kneifel and Webb 2022). Formulas shown in Section 4.3.2 are taken from or adapted directly from formulas in NIST Handbook 135. Where situations are not covered by the FEMP cost-effectiveness methodology, DOE will apply concepts from two ASTM International standard practices, E917 (ASTM 2023) and E1074 (ASTM 2020), or as outlined in the *ASHRAE HVAC Applications Handbook* (ASHRAE 2023). The resultant procedure is both straightforward and comprehensive and is in accord with the methodology recommended and used by NIST.[18]

Present values can be calculated in either nominal or real terms. In a nominal analysis, all compounding rates (discount rate, mortgage rate, energy escalation rate, etc.) include the effect of inflation, while in a real analysis inflation is removed from those rates. The two approaches are algebraically and economically equivalent, and for commercial analysis DOE intends to use a real analysis for Scenario 1. In Scenario 2, nominal discounting is applied for constant future cash flows such as loan payments, while a private sector real discount rate is applied to account for inflation on items such as maintenance and replacement costs and energy savings.[19] This approach is equivalent to a nominal analysis. Scenario 3 is a nominal analysis from a private-ownership viewpoint.

LCC is defined formally as the present value of all costs and benefits summed over the period of analysis. For Scenarios 1 and 2, DOE will typically use NPV of savings as the commercial test metric, which is one of three equivalent ways to quantify LCC:

- Calculate the LCC of both options, including all costs (first, maintenance, replacement, and energy) independently and compare them. In this case, the lower LCC would be the preferable alternative, and the case representing the new code would need a lower LCC than the old code case to be considered cost-effective.
- Calculate the present value of the incremental costs and subtract the present value of the incremental benefits. The result is the LCC of the change, expressed as a cost. In this case, the net cost should be negative to justify the change.
- Calculate the present value of the incremental benefits and subtract the present value of the incremental costs. The result is the LCC net savings or the NPV of savings. In this case, the NPV of savings should be positive or zero to justify the change. Since a positive result represents a cost-effective outcome, this metric is preferred, and its calculation is shown in Eq. (1).

$$\text{NPV of savings} = \text{PV(Incremental Benefits)} - \text{PV (Incremental Costs)} \quad (1)$$

In LCC analysis, a future cash flow (positive or negative) is brought into the present by assuming a discount rate (D). The discount rate is an annually compounding rate[20] by which future cash flows are discounted in value. It represents the minimum rate of return demanded of the investment in energy-saving measures. It is sometimes referred to as an alternative investment rate.

[18] For a detailed discussion of LCC and related economic evaluation procedures specifically aimed at private sector analyses, see Ruegg and Petersen 1987.
[19] Using a real discount rate to discount uninflated future values is equivalent to using a nominal discount rate to discount inflated future values.
[20] The analysis can be done for other periods of time (e.g., monthly), but for simplicity DOE uses annual periods for the subject analyses.

4.2.2 Savings-to-Investment Ratio

An additional metric that may be used in Scenarios 1 and 2 is savings-to-investment ratio (SIR), a ratio of benefits to costs, as shown in Eq. (2). The SIR of a code change must be greater than or equal to 1.0 for the change to be considered cost-effective, unless costs are negative and the code change is obviously cost-effective.

$$SIR = \frac{PV(Benefits)}{PV\ (Costs)} \tag{2}$$

The calculation of SIR is further defined in the regulations for the FEMP cost-effective methodology for federal buildings. The SIR has the advantage of allowing comparison between multiple alternative items reviewed for cost-effectiveness. When a threshold of “SIR greater than 1.0” is used, the assessment of cost-effectiveness is the same as it is for the NPV of savings metric.

4.2.3 Scalar Ratio

The scalar ratio is used specifically for Scenario 3, the ASHRAE SSPC 90.1 Scalar Method. Using this approach, the payback is calculated as the sum of the first costs and present value of the replacement costs, divided by the difference of the energy cost savings and incremental maintenance cost. The result is compared to the scalar ratio limit that is dependent on the life of a measure. A code change is considered cost-effective if the payback is less than or equal to the limit. For the analysis of 90.1-2022 with a 40-year study period, the scalar ratio limit is 25.1 for heating or fossil fuel savings, 22.0 for cooling or electric savings, or a weighted limit for mixed savings. Unlike the simple payback period, this is a true cost-effectiveness method, because the scalar ratio threshold has been developed similar to a discounted payback using cost-effectiveness methods.

4.2.4 Simple Payback Period

The simple payback period is a straightforward metric that includes only the costs and benefits directly related to the implementation of the energy-saving measures associated with a code change. It represents the number of years required for the energy savings to offset the cost of the measures, without regard for changes in energy prices, tax effects, measure replacements, resale values, etc. The payback period *P*, which has units of *years*, is defined as the marginal cost of compliance with a new code (*C*, the “first costs” above and beyond the baseline code), divided by the annual marginal benefit from compliance (ES_0, the energy cost savings in year 0, less M_a, annual maintenance cost increases), as shown in Eq. (3).

$$P = \frac{C}{ES_0 - M_a} \tag{3}$$

The simple payback period is a metric useful for its simplicity and ubiquity. Because it focuses on the two primary characterizations of a code change—cost and energy performance—it allows an assessment of cost-effectiveness that is easy to compare with other investment options and requires a minimum of input data. The simple payback period is used in many contexts and may be desired by state agencies considering the adoption of new energy codes; hence, DOE will calculate the payback period when it assesses the cost-effectiveness of code changes. However, because payback period ignores many of the longer-term factors in the economic performance of an energy efficiency investment, DOE does not intend to use the payback period as a primary indicator of cost-effectiveness for its own decision-making purposes.

This method does not consider any costs or savings after the year in which payback is reached, does not consider the time value of money, and does not consider any replacement costs, even those that occur prior to the year in which simple payback is reached. The method also does not have a defined threshold for determining whether an alternative's payback is cost-effective. Decision-makers generally set their own threshold for a maximum allowed payback. The simple payback perspective is reported for information purposes only, not as a basis for concluding that a particular code, standard, or proposal is cost-effective.

4.2.5 Economic Metric Summary

To provide a better understanding of the relationship of the various economic metrics, Table 5 summarizes the applicable scenarios and cost-effective thresholds for each metric.

Table 5. Economic Metrics

Metric	Used in Scenarios	Cost-effectiveness Threshold
LCC Net Savings (NPV of Savings)	1,2	≥ 0
Savings-to-Investment Ratio (SIR)	1,2	≥ 1.0
Simple Payback	1,2,3	Does not measure cost-effectiveness
Scalar Ratio*	3	≤ 25.1 for 40-year life heating ≤ 22.0 for 40-year life cooling

*The scalar ratio is tested against a limit set by the measure life, fuel type, and economic parameters used for each edition of Standard 90.1. The values shown are for 90.1-2022. Heating is a blended fossil fuel rate, and cooling is for electric measures.

4.3 Economic Parameters and Other Inputs

Calculating the metrics described above requires defining various economic parameters. Table 6 shows the primary parameters of interest and how they apply to the four metrics. There is also some variation of requirements depending on the economic scenario.

Table 6. Economic Parameters Required for Cost-effectiveness Metrics

Parameter	Parameter Needed for Metric			
	Scenario 1 LCC & SIR	Scenario 2 LCC & SIR	Scenario 3 Scalar Ratio	Simple Payback Period
First costs, including sales tax on materials	Yes	Yes	Yes	Yes
Energy savings	Yes	Yes	Yes	Yes
Energy prices	Yes	Yes	Yes	Yes
Energy price escalation rates	Yes	Yes	Yes	No
Period of analysis	Yes	Yes	Yes	No
Replacement costs and residual value	Yes	Yes	Yes	No
Discount rate (real and nominal)	Real	Nominal	Nominal	No
Loan parameters (rate and term)	No	Yes	Yes	No
Inflation rate	No	Yes	Yes	No

These parameters are chosen to represent the economic impact of a typical commercial building ownership or tenant situation. DOE intends to consult appropriate sources of information to obtain financial, economic, and energy price information. Whenever possible, economic data will be obtained from the published sources discussed below. DOE notes that most values vary across time, location, markets, institutions, circumstances, and individuals. Where multiple sources for any parameter are identified, DOE will prefer recent values from sources DOE deems best documented and most reliable.

DOE intends to update parameters for future analyses to account for changing economic conditions. The parameters used in analyzing proposals for Standard 90.1-2022 are included in Appendix C. In some cases, state-level analysis of the completed edition of a code may use different economic parameters than were used for individual proposals, as individual proposals are typically analyzed at a national level, and several years earlier than the final evaluation of a code edition. The parameters used and their sources will be documented in each analysis. Parameters for this methodology have been published at the BECP web site[21] starting with analysis for 2015 IECC in mid-2012.

Table 7. Economic Parameters and Their Symbols

Parameter	Symbol
Period of Analysis	L
Energy Prices	*N/A*
Energy Escalation Rates	*N/A*
Loan Term	M_L
Loan Interest Rate	I
Nominal Discount Rate	D_n
Real Discount Rate	D_r
Inflation Rate	R_{INF}

4.3.1 Scenario 1: Publicly Owned Method Parameters

The LCC analysis requires assumptions about the value of money today relative to the future, and about how costs will change over time, such as the cost of energy and HVAC equipment. These values will change depending on the purpose of the analysis. In the case of the FEMP LCC analysis method, NIST periodically publishes an update of economic factors (Lavappa et al. 2022).

The DOE nominal discount rate is based on long-term Treasury bond rates averaged over the 12 months prior to publication of the NIST report. The nominal rate is converted to a real rate to correspond with the constant dollar analysis approach for this analysis. The method for calculating the real discount rate from the nominal discount rate uses the projected rate of general inflation published in the most recent *Report of the President's Economic Advisors, Analytical Perspectives* (referenced in the 2022 annual supplement without citation). The mandated procedure would result in a discount rate for 2022 lower than the 3.0% floor prescribed in 10 CFR 436. Thus, the 3.0% floor is used as the real discount rate for FEMP analysis in 2022. The implied long-term average rate of inflation was calculated as -1.0% (Lavappa et al. 2022).

[21] See https://www.energycodes.gov/methodology

4.3.2 Scenario 2: Privately Owned Method Parameters

For Scenario 2, there are numerous primary cash flows that are relevant to LCC analysis of energy code changes. The total cost of the code changes is not directly included in the analysis; rather, the incremental cost (C) is accounted for as loan payments assumed to occur over the 30-year (or other) study period. Replacement costs (C_r) for items that have shorter lives than the study period are often calculated at a higher cost than the initial installation to account for more difficulty installing during replacement than during new construction. The replacement costs are also incremental costs, reflecting cost increases or reductions required due to the new code. The replacement is made, and the same efficiency and savings are estimated to continue. Where a measure or replacement does not have a life equal to or evenly divisible by the study period, there is a residual value, incurred at the end of the analysis period. The residual value is the cost of the code changes, multiplied by the fraction of the lifetime (i.e., value) of the code changes or replacements remaining at the end of the study period.

This is a simplified treatment of residual value, similar to straight-line depreciation, but is meant to encapsulate an average of the remaining lifetime of all components. The replacement and residual costs are discounted using a real discount rate to account for inflation, which is equivalent to inflating the costs, then discounting them with a nominal rate. Annual maintenance costs (M_a) are also considered.

Energy savings occur every year, starting at year 1, and are equal to the calculated energy cost savings at year 0 (ES_0), adjusted by the real escalation rates required to be used in the FEMP cost-effective methodology. These escalation rates exclude inflation, so the escalated energy savings are discounted to present value using a real discount rate (D_r), which again is equivalent to applying a combination of inflation and escalation to energy costs, to estimate their nominal future value, and then discounting with a nominal discount rate (D_n). Discount and escalation rates for the FEMP cost-effective methodology are established annually by NIST and published in the *NIST Handbook 135 Supplement* (Lavappa et al. 2022). Loan payments occur every year of the study period, are constant payments, and are calculated as an annual payment, as calculated using the standard equation shown in Table 8.

Table 8. Present Value Cost and Benefit Components for Scenario 2

Cost Item	Equation for Present Value	Discount Rate	Cost or Benefit
First Cost*	C	N/A	N/A
Loan Payments	$C\left(\frac{i(1+i)^{M_L}}{(1+i)^{M_L}-1}\right)\left(\frac{(1+D_n)^{M_L}-1}{D_n(1+D_n)^{M_L}}\right)$	Nominal	Cost
Replacement Costs and Residual Value	$\sum_{Y=1}^{L}\frac{C_r}{(1+D_r)^Y}$	Real	Cost
Maintenance Costs	$M_a\left(\frac{(1+D_r)^L-1}{D_r(1+D_r)^L}\right)$	Real	Cost
Energy Savings	Annual Energy Savings escalated with NIST rates that change over time, and then discounted with real discount rate D_r to be equivalent to applying inflation and then using a nominal discount rate D_n	Real, escalated	Benefit

Cost Item	Equation for Present Value	Discount Rate	Cost or Benefit
Loan Interest	$\sum_{Y=1}^{M_L} \frac{LI_Y}{(1+D_r)^Y}$	Nominal	Benefit

Note: Symbols for variables are listed in Table 7 and discussed in Section 4.3.4.
* First cost (C) is not directly used in the Scenario 2 LCC or SIR. As previously discussed, Scenario 2 uses a financed approach, and the present value of the loan payments is treated as a cost in the LCC or SIR.
** Loan interest paid in a given year (LIY) is simply the mortgage interest rate multiplied by the loan balance. The loan balance is calculated as the present value in year Y of the remaining stream of loan payments, discounted at the mortgage interest rate.

For Scenario 2, loan interest payments begin in year 1 and continue through the end of the 30-year analysis period.

4.3.3 Scenario 3: ASHRAE 90.1 Scalar Method Parameters

The SSPC 90.1 does not consider cost-effectiveness of the entire set of changes for an update to the whole Standard 90.1. However, cost-effectiveness is often considered when evaluating a specific addendum to Standard 90.1. The Scalar Method was developed by SSPC 90.1 to evaluate the cost-effectiveness of proposed changes (McBride 1995). The Scalar Method is an alternative LCC approach for individual energy efficiency changes with a defined useful life, taking into account first costs, annual energy cost savings, annual maintenance, inflation, energy escalation, and financing impacts. The Scalar Method allows a discounted payback threshold (scalar ratio limit) to be calculated based on the measure life. Because this method is designed to be used with a single measure with one value for useful life, it does not account for replacement costs. A measure is considered cost-effective if the simple payback (scalar ratio) is less than the scalar ratio limit.

As an example, Table 9 shows the economic parameters used in the 90.1 Scalar Method for the Standard 90.1-2022 analysis. These parameters were adopted by the SSPC 90.1.

Table 9. Scalar Method Economic Parameters and Scalar Ratio Limits for Standard 90.1-2022

Input Economic Variables	
Economic Life – Years	40
Down Payment – $	$0.00
Energy Escalation Rate – %*	NIST rates + 2.90% heating, NIST rates + 2.25% cooling
Nominal Discount Rate – %	8.1%
Loan Interest Rate – %	5.0%
Heating – Fossil Fuel† Price, $/therm	$0.983
Heating - Scalar Ratio Limit	25.1
Cooling – Electricity Price, $/kWh	$0.1099
Cooling - Scalar Ratio Limit	22.0

* The NIST escalation rates are from the NIST 2022 supplement (Lavappa et al. 2022). The real escalation rates are combined with an inflation rate for this nominal analysis.
** Tax rates are zero for Standard 90.1 because a nominal discount rate based on before-tax investments was selected.
† The ASHRAE Scalar Method identifies a fossil fuel rate that is primarily applied to heating energy use. For this reason, the fossil fuel rate is a blended heating rate and includes proportional (relative to national heating fuel use) costs for natural gas, propane, heating oil, and electric heat. Heating energy use in the prototypes for fossil fuel equipment is calculated in therms based on natural gas equipment, but in practice, natural gas equipment may be operated on propane, or boilers that are modeled as natural gas may use oil in some regions.

DOE extends the Scalar Method to allow for the evaluation of multiple measures with different useful lives. This extended method takes into account the replacement of different components in the total package of Standard 90.1 changes, allowing the NPV of the replacement costs to be calculated over 40 years. The SSPC 90.1 Envelope Subcommittee uses a 40-year replacement life for envelope components, and the useful lives of all other cost components are less than that. For example, an item with a 20-year life would be replaced once during the study period. The residual value of any items with useful lives that do not fit evenly within the 40-year period is calculated using the method described in Section 4.1.2.3. Using this approach, the simple payback is calculated as the sum of the first costs and present value of the replacement costs, divided by the difference of the energy cost savings and incremental maintenance cost.

To determine cost-effectiveness, the result is compared to the scalar ratio limit for the 40-year period, 25.1 for heating or fossil fuels or 22.0 for electric or cooling, as shown in Table 9. For measures or evaluations that have a mixture of electric and fossil fuel savings, the separate scalar ratio limits are weighted by the proportion of each type of cost savings. The scalar ratio limit represents the simple payback for a 40-year life measure that would have a positive LCC using the other economic parameters shown. The packages of changes for each combination of prototype and climate location are considered cost-effective if the corresponding scalar ratio is less than the scalar ratio limit. The parameters shown in Table 9 are based on consensus of the SSPC 90.1.

4.3.4 Detailed Discussion of Economic Parameters

The meaning and source of each economic input parameter is discussed below. Where there are variations in the meaning or source for the different scenarios, these are discussed as well.

4.3.4.1 Economic Study Period (L)

DOE's economic analysis is intended to examine the costs and benefits impacting all the owners or tenants who use a commercial building and pay for energy use either directly or through a net lease. Because energy efficiency features may last longer than the average length of ownership or tenancy, a longer analysis period than the initial ownership or tenancy is used. Assuming a single owner keeps the property throughout the analysis period accounts for long-term energy benefits without requiring complex accounting for resale values at property turnover. Commercial buildings will typically last 50 years or more. However, some energy efficiency measures may not last as long as the building does. Although 30 years is less than the life of the building, some efficiency measures, equipment in particular, may require replacement during that timeframe. As discussed earlier, when energy-saving equipment costs are analyzed, replacement costs will be included at the life of the equipment. The replacement costs are then discounted to present value as part of the cost. The impact of the selection of a study period is significantly moderated by the effect of the discount rate in reducing the value of costs and benefits far into the future.

DOE's methodology for Scenarios 1 and 2 is intended to assess cost-effectiveness based on a 30-year period of analysis or study period. The FEMP cost-effective methodology for federal buildings was amended by EISA to allow a study period of up to 40 years (42 U.S.C. 8254(a)(1)), while the DOE cost-effectiveness method for commercial building codes uses 30 years. The 30-year study period is used in the methodology for consistency with DOE's residential code cost-effectiveness analysis and is also widely used for LCC analysis in government and industry. The study period is also a balance between capturing the impact of future replacement costs, inflation, and energy escalation, and limiting uncertainty; the further into the future these costs are projected, the greater their uncertainty. The perspective of a single 30-year owner allows consideration of economic impacts on building owners or tenants, either single or multiple in succession, as well as consideration of long-term energy savings. While the full study period of 30 years is appropriate when analyzing the impact of an entire code, when individual measures are analyzed, a shorter study period equal to the measure life may be used. In this situation, the measure life will be determined based on measure life references. The primary reference is the *ASHRAE HVAC Applications Handbook* (ASHRAE 2023), and secondary resources include the Database for Energy Efficient Resources (DEER),[22] utility program guidelines (GDS 2007; KEMA 2009; Skumatz 2012), or Appendix J to the *Oregon State Energy Efficient Design Guidelines* (ODOE 2011).

Note that the parameters and methodology for Scenario 3, the ASHRAE 90.1 Scalar Method, are developed by the ASHRAE SSPC 90.1. A 40-year maximum study period is established by the SSPC for that method, with the cost of interim replacements of shorter-lived equipment or measures added during the study period. This is a departure from the way the ASHRAE 90.1 Scalar Method is applied in the SSPC 90.1 and is necessary because DOE typically analyzes the entire code that contains multiple measures with different lives, while in the typical analysis for the ASHRAE SSPC 90.1, a single measure with a fixed life is analyzed. The 40-year life is the maximum used in SSPC analysis, usually for envelope measures.

4.3.4.2 First Cost (C)

As discussed earlier, the first cost represents the incremental cost of code-related energy features to a building owner. It represents the full (retail) cost of such features, including materials, sales tax[23] on materials, labor, and contractor overhead and profit, but excludes any future costs such as for maintenance.

4.3.4.3 Loan Interest Rate (i)

Commercial real estate is highly leveraged with an effective loan-to-value (LTV) of 59% since 2022.[24] Conventional mortgages for commercial property typically allow up to 75% LTV (investment) and 85% LTV (owner-occupied). Accordingly, for the analysis of the economic benefits to the commercial building owners and tenants for improved energy efficiency, DOE intends to assume that buildings are purchased or refinanced using a loan. Note that Scenario 1 does not evaluate loan impact as publicly-owned buildings do not use traditional financing. For simplification, no down payment is assumed in Scenarios 2 and 3. For Scenario 3, the loan rate is established by the ASHRAE 90.1 committee. The committee uses the average of 3-year history and 4-year projection to get a levelized projected mortgage rate. DOE intends to use this same process for the Scenario 2 interest rate.

4.3.4.4 Loan Term (ML)

For the analysis of cost-effectiveness, the loan term will be set equal to the study period. While a typical commercial loan may be shorter, it is quite common for commercial buildings to be resold to a buyer who will take out a new loan or refinance during their ownership period. While these are separate serial loans, the economic effect is similar to a single, longer-term loan.

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[22] The Database for Energy Efficient Resources is California Energy Commission and California Public Utilities Commission sponsored and designed to provide well-documented estimates of energy and peak demand savings values, measure costs, and effective useful life all in one source. See https://cedars.sound-data.com/deer-resources/.

[23] Sales tax from online sources: https://taxfoundation.org/data/all/state/2024-sales-taxes/.

[24] https://www.cohenandsteers.com/insights/the-commercial-real-estate-debt-market-separating-fact-from-fiction/

4.3.4.5 Discount Rate (D)

The purpose of the discount rate is to reflect the time value of money. Because DOE's economic perspective is that of a building owner, that time value is determined primarily by the investor's best alternative investment at similar risk to the energy features being considered. The discount rate is chosen to represent the desired perspective of the economic analysis, for Scenario 1, a public building owner, for Scenario 2, a private building owner or developer in a post-tax context, and for Scenario 3, a private building owner or developer in a pre-tax context.

For Scenario 1, DOE intends to use the real discount rate (D_r) established annually in the *NIST Handbook 135 Supplement* for the FEMP analysis. For Scenario 2, DOE intends to set the nominal discount rate (D_n) to be equivalent to the commercial loan interest rate (i). Because commercial lending is a viable source of funds for real estate investors, the associated loan rate is a reasonable estimate of an investor's alternative post-tax investment rate of return or discount rate. That real estate investors borrow money at that rate demonstrates that their implicit discount rate must be at least that high. As previously discussed, a real discount rate (D_r) is also used in Scenario 2 for discounting items that experience inflation. The selection of that rate is discussed below under Inflation Rate and the type of discount rate used for different cash flows is shown in Table 8.

For Scenario 3, the nominal discount rate (D_n) is established by the ASHRAE SSPC 90.1. As a point of comparison for the current parameters in Appendix C, the 8.1% nominal discount rate in Scenario 3 is based on industry surveys of commercial real estate investors' expected rate of return before taxes. While the 8.0% nominal discount rate for Scenario 2 appears slightly lower, this is an after-tax discount rate.

4.3.4.6 Income Tax Rate

The federal corporate tax rate is currently a flat rate of 21% (IRS 2024) and the average state corporate income tax rate is 6.0%. Note that DOE uses the latest available federal corporate tax rate and average state corporate income tax rate from IRS or other relevant sources. Where state corporate income taxes apply, rates will be taken from state sources or collections of state data such as those provided by the Federation of Tax Administrators.[25]

4.3.4.7 Inflation Rate (R_{INF})

An inflation rate is not needed in the real or constant dollar analysis in Scenario 1, and the inflation rate for Scenario 3 is determined by the ASHRAE SSPC 90.1. The inflation rate R_{INF} is used to determine a real discount rate (D_r) for Scenario 2. This real discount rate is applied to items that are subject to inflation as shown in Table 8. A long-term inflation rate appropriate for the study life is necessary. To capture a relatively constant long-term inflation rate over time that is appropriate for the study period, the inflation rate for the past 30 years will be applied to the next 30 years. Estimates of an annual inflation rate will be based on current (CI_C) and past (CI_P) indices from Producer Price Index (PPI) data published by the Bureau of Labor Statistics.[26] The past (CI_P) index is selected 30 years prior to the current (CI_C) index. For the period since June 2009,[27] "final demand construction" index data are used, normalized to "finished goods less food and energy" data that are used for earlier periods. The equivalent compound inflation rate

[25] Federation of Tax Administrators: www.taxadmin.org.
[26] Bureau of Labor Statistics. See www.bls.gov/.
[27] "Final demand construction" Producer Price Index data were initiated in June 2009 and are not available for earlier periods.

(R_{INF}) is calculated from the current (CI_C) and past (CI_P) construction indices as shown in Eq. (4).

$$R_{INF} = \left(\frac{CI_C}{CI_P}\right)^{1/30} - 1 \quad (4)$$

The real discount rate (D_r) for Scenario 2 is found based on the nominal discount rate (D_n) as shown in Eq. (5).

$$D_r = \left(\frac{1 + D_n}{1 + R_{INF}}\right) - 1 \quad (5)$$

4.3.4.8 Energy Prices

Energy prices over the period of analysis are needed to determine the energy cost savings from improved energy efficiency. Both current energy prices and energy price escalation rates are needed to establish estimated energy prices in future years. DOE will use the most recently available national annual average commercial energy prices from the EIA. Annual average prices are used to avoid selecting a short-term price that is subject to seasonal fluctuations. If energy prices from the most recent year(s) are unusually high or low, DOE may consider using a longer-term average of energy prices, such as the average from the past 3 years and projections for the next 2 years. For individual state analysis, DOE will use the most recently available state annual average commercial energy prices from EIA.

4.3.4.9 Energy Price Escalation

Energy price escalation accounts for the fact that energy prices generally have increased faster than general inflation. Energy price escalation rates for Scenarios 1 and 2 will be obtained from the most recent projections in the *NIST Handbook 135 Supplement* to account for projected changes in energy prices. Currently, ASHRAE SSPC 90.1 uses the same escalation rates, and they will also be used for Scenario 3. Note that these escalation rates do not include inflation. Inflation is not necessary in Scenario 1, as it is a current dollar or real discount analysis. In Scenario 2, the real discount rate is used rather than the nominal discount rate for energy savings, as the escalation does not include inflation. In the ASHRAE 90.1 Scalar Method, inflation is added to the future energy savings along with the escalation rate above inflation, and then a nominal discount rate is used to arrive at a present value. While each of these procedures appears different, they each arrive at the correct present value of energy savings based on the parameters and methods used in the scenario.

5.0 Aggregating Energy and Economic Results

5.1 Weighting Factors: Building Types and Climate Zones

Simulation results for the building types and climate zones will be weighted based on weighting factors shown in Table 10 and Table 11, respectively. Weighting factors are from disaggregated construction volume data found in McGraw-Hill Construction Project Starts Database (Dodge Reports). The database contains the floor area of new construction in the United States for the years 2003 to 2018. PNNL analyzed this database to develop detailed construction weights by building type, climate zones, and states (Lei et al. 2020), used in developing weighted national energy savings estimates. For each analysis, the weights are normalized for the prototypes used in the analysis, so weightings total 100%. These weighting factors are based on climate zones used through at least Standard 90.1-2022. Revisions that change the climate zones will require an update of the weighting factors. The energy savings analysis of Standard 90.1-2022 used the values shown below in Table 10 and Table 11 (Maddox et al. 2024).

Table 10. National Weighting Factors by Prototype

Prototype	Construction Weights, %
Small office	3.8
Medium office	5.0
Large office	3.9
Standalone retail	10.9
Strip mall	3.7
Primary school	4.8
Secondary school	10.9
Outpatient healthcare	3.4
Hospital	4.5
Small hotel	1.6
Large hotel	4.2
Warehouse	18.6
Quick-service restaurant	0.3
Full-service restaurant	1.0
Mid-rise apartment	13.7
High-rise apartment	9.6
Total	100

Table 11. Commercial Weighting Factors by Climate Zone

Climate Zone	Thermal Climate Zone	Moisture Regime	Overall Location Weight, %
1A	1	Moist	3.94
2A	2	Moist	16.85
2B		Dry	2.52
3A	3	Moist	14.89
3B		Dry	8.67
3C		Marine	2.06
4A	4	Moist	20.94
4B		Dry	0.43
4C		Marine	3.39
5A	5	Moist	17.60
5B		Dry	4.59
5C		Marine	0.05
6A	6	Moist	3.17
6B		Dry	0.49
7	7	N/A	0.38
8	8	N/A	0.03

5.2 Building Prototype Selection

DOE may select a subset of the prototype buildings and simulate them in selected representative climate locations for the cost-effectiveness analysis to represent most of the energy and cost impacts of code changes in a particular code or proposal analysis.

For example, for the Standard 90.1-2010 through 90.1-2022 national analyses, six of the prototype buildings were selected for cost estimate development in five climate locations, as shown in bold font in Table 12. The selected prototypes provide a good representation of the overall code cost-effectiveness, without requiring simulation and analysis of all 16 prototypes.[28] DOE intends to continue to use these prototypes unless a code change is identified that is not represented and has a large impact in one of the other prototypes. The resulting cost-effectiveness analysis represents most of the energy and cost impacts of the changes in Standard 90.1. The prototypes were chosen to represent the energy impact of five of the eight commercial principal building activities. The five represented principal building activities account for 74% of the new construction by floor area covered by the full suite of 16 prototypes.

[28] An analysis of the six prototypes presented at the interim SSPC 90.1 meeting on October 19, 2011, showed savings for 90.1-2010 v. 2004 to be within 2.5% of the full set of 16 prototype analysis.

Table 12. Prototype Buildings

Principal Building Activity	Building Prototype	Included in Cost-Effectiveness Analysis
Office	Small Office	Yes
	Medium Office	No
	Large Office	Yes
Mercantile	Standalone Retail	Yes
	Strip Mall	No
Education	Primary School	Yes
	Secondary School	No
Healthcare	Outpatient Healthcare	No
	Hospital	No
Lodging	Small Hotel	Yes
	Large Hotel	No
Warehouse	Warehouse (non-refrigerated)	No
Food Service	Quick-service Restaurant	No
	Full-service Restaurant	No
Apartment	Mid-rise Apartment	Yes
	High-rise Apartment	No

5.3 Represented HVAC Equipment Types

Various types of space heating, cooling, and water heating equipment are selected for the prototypes to determine the impact of code changes on various equipment and types of energy (electricity and fossil fuel). The goal is to represent a wide variety of the many HVAC and other systems used in commercial buildings. The selections were vetted by building experts including representatives of ASHRAE SSPC 90.1. The heating and cooling source and predominant and additional HVAC system types are shown in Table 13.

Table 13. HVAC Primary and Secondary Equipment

Building Prototype	Heating	Cooling*	Predominant System*	Additional System*
Small office	Heat pump	Unitary DX	Packaged CAV	No
Medium office	Gas furnace	Unitary DX	Packaged VAV w/reheat	No
Large office	Boiler	Chiller, cooling tower	VAV w/reheat	No
Standalone retail	Gas furnace	Unitary DX	Packaged CAV	No
Strip mall	Gas furnace	Unitary DX	Packaged CAV	No
Primary school	Boiler	Unitary DX	VAV w/reheat	Packaged CAV
Secondary school	Boiler	Air-cooled chiller	VAV w/reheat	Packaged CAV
Outpatient healthcare	Boiler	Unitary DX	Packaged VAV w/reheat	No
Hospital	Boiler	Chiller, cooling tower	VAV w/reheat	Central CAV
Small hotel	Electricity	DX	PTAC	Unit heater and packaged CAV
Large hotel	Boiler	Air-cooled chiller	Fan-coil units	VAV w/reheat
Warehouse	Gas furnace	Unitary DX	Unit heater	Packaged CAV
Quick-service restaurant	Gas furnace	Unitary DX	Packaged CAV	No
Full-service restaurant	Gas furnace	Unitary DX	Packaged CAV	No
Mid-rise apartment	Gas	DX	Split DX system	No
High-rise apartment	Boiler	Fluid cooler	WSHP	No

* System abbreviations: DX = direct expansion; CAV = constant air volume; VAV = variable air volume; PTAC = packaged terminal air conditioners; WSHP = water source heat pump.

5.4 Aggregation Across Building Type and Climate Zone

DOE may use one of two approaches to demonstrate overall cost-effectiveness for a code or standard edition.

- If all the individual building types and climate zones included in the analysis are found to be cost-effective independently, using the metrics and scenarios applied, the overall cost-effectiveness is demonstrated.
- For situations where some building type and climate zone combinations do not meet cost-effective criteria, if the preponderance of individual building type and climate zones included in the analysis are found to be cost-effective independently, using the metrics and scenarios applied, the overall cost-effectiveness is demonstrated even though a minority of the building type and climate zone combinations may not meet some economic criteria. To verify the impact in this case, DOE will aggregate the costs and savings on a national or state level.

5.4.1 National and State-Level Aggregations

When energy code proposals are developed, they are typically shown to be cost-effective for situations and building types where they are likely to be applied. The proposal cost-effectiveness analysis does not usually cover all building types or climate zones. In combination with a sample-based cost-effectiveness analysis, professional judgment of the consensus body is used to determine if a particular proposal is appropriate for addition to the standard or code. Proposals are evaluated using national average energy prices and the prices in some states can be lower. This means that for some building types in some climate zones, individual proposals may not be cost-effective. For individual code cycles, it is possible that some building type and climate zone combinations may not meet cost-effectiveness metric criteria, especially when analyzed at the state level with lower energy prices.

Individual results for building types in a climate zone can be aggregated to a national or state domain using weighting factors based on construction floor area for that domain as described earlier in Section 5.1. DOE relies on construction volume data from Dodge Data & Analytics to develop weighting factors as described in Lei et al. When a subset of climate zones or building types is selected for analysis, the weighting factors will be normalized so that the weightings for selected climate zones and building types each total 100%. Individual results are then multiplied by the weighting factors to arrive at an aggregate result.

5.4.2 Demonstration of Aggregate Cost-effectiveness

It is possible that some building type and climate zone combinations do not meet cost-effective criteria. If the weighted aggregate result meets the cost-effectiveness criteria, then DOE will deem that cost-effectiveness has been demonstrated.

5.5 Supplemental Range of Results or Sensitivity Analysis

It may be desirable to understand the range of results that might occur given variation in some of the analysis parameters. This type of analysis shows the sensitivity of the cost-effectiveness to each parameter and shows the range of possible results. This analysis can be conducted using either a Monte Carlo or discrete probability method.[29] An example of such an analysis is shown in Appendix D. This type of analysis may help demonstrate the cost-effectiveness of a code or standard in aggregate when some individual building type and climate zone combinations do not meet cost-effectiveness criteria.

[29] A Monte Carlo analysis uses multiple random values of sensitive variables in an iterative analysis to find the range and distribution of possible outcomes, while a discrete probability method uses selected values that are assigned expected probabilities to determine an expected range of outcomes.

6.0 Conclusion

The Department of Energy (DOE) established this methodology to document the process for evaluating the energy and economic performance of residential energy codes. DOE's measure of cost-effectiveness balances longer-term energy savings against incremental construction costs through a lifecycle cost perspective. As DOE participates in code development processes, the outlined methodology establishes a consistent and replicable approach to assess both DOE and other proposals based on energy efficiency and cost-effectiveness. In addition, DOE will use this approach to evaluate recently published codes, which will help states and local jurisdictions better understand the impacts of updating residential energy codes.

7.0 References

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Appendix A - State Code Adoption Map Analysis

The Building Energy Codes Program (BECP) tracks and analyzes energy codes at the state level, which is presented in the Status of State Energy Code Adoption Map on energycodes.gov. [30] State level tracking includes a map and table of adopted energy codes by state, along with a quantitative assessment of each state's energy code. The energy impacts of state adopted codes are quantified through energy simulation and compared to the national model energy codes – the International Energy Conservation Code (IECC) for residential buildings and ASHRAE Standard 90.1 for commercial buildings (42 USC 6833). This assessment is typically updated quarterly to reflect new state energy codes going into effect and representing the performance of state energy codes across the U.S. The map and underlying analysis are available for residential and commercial building energy codes in the State Portal on energycodes.gov.[31]

The state code adoption map analysis serves as the baseline for additional state-specific resources and analysis, such as cost-effectiveness and impacts analyses, fact sheets, COMcheck software, and other implementation resources.

A.1 State Adoption Map Analysis Methodology

A quantitative analysis is performed quarterly to assess energy code energy impacts within a given state, which is presented using an energy index metric. The commercial energy index represents the ratio between the whole-building site energy intensity (kBtu/ft^2-yr) based on a weighted statewide average of the state code and that of Standard 90.1-2004 within that same state. As the basis for this analysis, DOE uses the same simulation tool, building prototypes, and default assumptions described in Section 2.0 of this report. To report energy indices at the state level, DOE models all state specific energy code requirements and aggregates results across building types and climate zones using state specific weighting factors based on published construction volume data, as described in Section 5.0 of this report.

A.1.1 Analysis Steps

1. Once a new state energy code is adopted, DOE conducts a qualitative review of the adopted code language inclusive of specific amendments and other modifications.
2. All state specific amendments and modifications are noted, and a consistent quantitative analysis and modeling approach is applied to account for overall energy impacts of the proposed code.
3. State energy code is modeled across DOE commercial prototypes while accounting for all minimum and maximum requirements, as specified in the code.
4. Weighted energy results are presented in the form of an energy use index (EUI) and converted into an energy index (as previously described).
5. The final state energy index represents the overall energy impact of the state adopted code, which is then compared to the modeled energy index based on the six most recent model energy codes, as applied in the state.

[30] https://www.energycodes.gov/state-portal
[31] https://www.energycodes.gov/state-portal

6. State energy code is then designated at an equivalent model energy code based on where it aligns with model code energy indices. This process is described in greater detail in Section A.1.2.

A.1.2 Code Equivalency Designation

The underlying EUIs are derived from per-building intensities (kBtu/building-yr), which are aggregated across building types and climate zones using weighting factors based on published construction volume data. The energy index represents the ratio between the site energy intensity of a state energy code and that of Standard 90.1-2004. As defined, the energy indices for Standard 90.1-2004 (referred to as the baseline model code) are 1.0 for all states. The energy index for any given state energy code is the EUI of that code divided by the EUI of the baseline model code. Energy indices less than 1.0 indicate EUIs lower (less energy use) than Standard 90.1-2004. The energy index of the state adopted code is compared to the baseline (Standard 90.1-2004) and all model energy codes published thereafter, to determine a relative code equivalency and the category reflected on the state map. When a state's energy index is equal to or within 1.5% of the energy index of the next model code edition, the state adopted code is deemed equivalent to the better edition. For example, if the EUI of the state adopted code is 36.9 and the EUI of Standard 90.1-2019 is 36.7, the state adopted code is deemed equivalent to Standard 90.1-2019.

For states adopting amended energy codes, amendments with quantifiable energy impacts are included in the analysis. These amendments are categorized as

- **Strengthening**: Decreasing energy use.
- **Weakening**: Increasing energy use.
- **Neutral**: Administrative, including procedural compliance aspects, complementary code requirement, and changes to performance/ERI compliance.

The amendments influence how a state adopted code will perform compared to the model energy code editions. For example, a state adopting Standard 90.1-2016 with only strengthening amendments could possibly be characterized as equivalent to Standard 90.1-2019. Assessments of code stringency compared to model codes are based only on the minimum requirements of the adopted code, including applicable amendments, and do not account for market-based performance better than the code requires or typical local construction practice. For example, if a state adopts a commercial model code with a lighting power allowance of 1.0 W/ft^2 for office buildings, and compliance field studies have documented that standard practice for new office buildings in that state is 0.75 W/ft^2, the analysis will use 1.0 W/ft^2 as the minimum requirement.

A.1.3 Applied Assumptions

Consistent with other state-based code analysis, the state map methodology only considers the minimum and maximum provisions specified in the state code and does not account for market baselines or other field data representing typical energy efficient measures installed in the field.

Where a state adopts code provisions that are not currently considered in the prototype buildings (e.g., controls, drain water heat recovery, renewable energy, etc.), DOE will determine the strategy to model these code provisions based on research and best practice.

A.2 State Code Adoption Map Updates

The State Portal[32] consists of the Status of State Energy Code Adoption maps for both residential and commercial buildings, a summary table of all state code adoption results, and links to the state-level results spreadsheets for both residential and commercial analyses. An infographics page[33] that can be accessed from the adoption map page features tables and charts highlighting the state code adoption analysis results and comparisons of the state adopted codes to the latest model energy codes. Figure A.1 shows an example of the commercial state code adoption map.

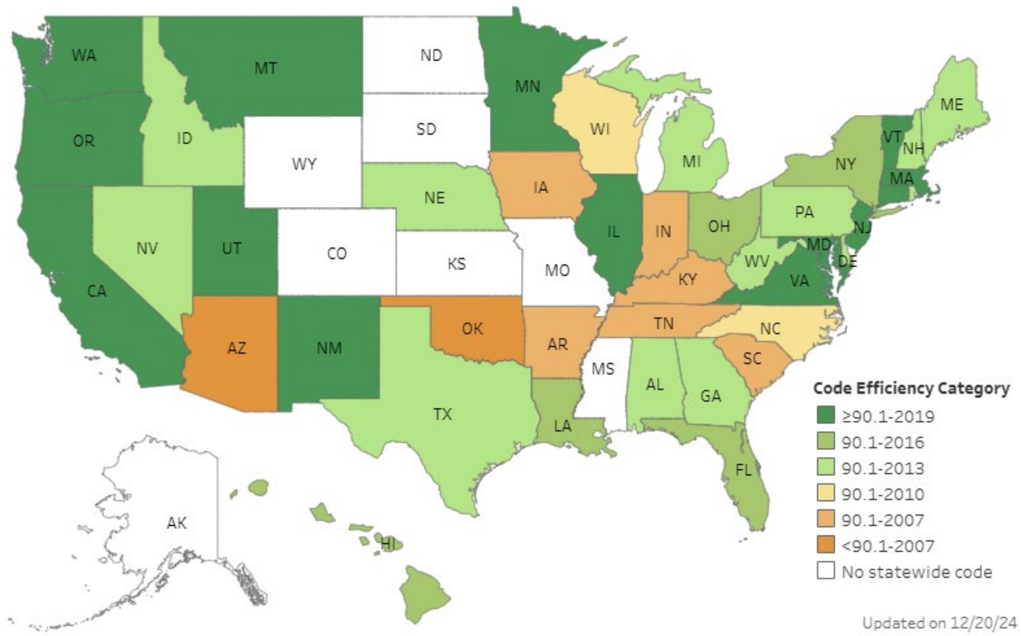


Figure A.1. Commercial State Code Adoption Map

The quarterly state adoption map analysis is performed for all states based on their current adopted energy codes and compares those results to various editions of the model energy codes to determine code equivalency. For states adopting new energy codes in the previous quarter, the code equivalency is updated in the state code adoption map while all other state's energy code performances remain at the same level. State-level results spreadsheets and data for the infographics webpage are updated quarterly for all states based on the quantitative analysis results for the state energy codes currently in effect. The latest model energy codes are typically added to the state adoption maps no more than two years after DOE issues an affirmative determination, when states are required to certify that they have reviewed the provisions of their commercial building code regarding energy efficiency, and as necessary, update their codes to meet or exceed the updated edition.

[32] https://www.energycodes.gov/state-portal
[33] https://www.energycodes.gov/infographics

Appendix B - Advanced Benefits Analysis

DOE's default methodology for evaluating cost-effectiveness of energy code and standard proposals and editions does not consider advanced benefits beyond traditional energy and energy cost savings. However, states, local jurisdictions, and model code development bodies may be interested in considering impacts like emissions monetization, job creation, health impacts, resilience, grid reliability, and avoided future costs. This section outlines the approach that DOE will use if requested to evaluate these advanced benefits.

B.1 Monetization of Emissions

While avoided emissions can be quantified in terms of mass (e.g., pounds or tons of CO_2e), monetization of those emissions is also often of interest, as it helps the model code bodies, as well as adopting states and local jurisdictions better understand the full range of expected benefits. The model energy code development technical committees – including IECC Residential, IECC Commercial, and ASHRAE Standard 90.1 – have all adopted economic criteria to evaluate the monetized benefits of emissions reductions resulting from code updates. The adopted methodologies may require reporting cost effectiveness with and without consideration of the monetized benefit of emissions reductions.
Most recently, the ASHRAE 90.1 committee adopted economic criteria to monetize benefits from reduced emissions based on the latest regulatory guidance in 89 FR 16820.[34] This regulatory action contains an approach to monetizing emissions that incorporates feedback on the methodology outlined in previous regulatory guidance 87 FR 74702, including public comments; peer review comments; and recommendations from the Natural Academies of Science, Engineering, and Medicine.

B.1.1 Estimating Monetized Emissions

Avoided emissions will be calculated by multiplying the annual building site energy use savings by corresponding emissions factors. Emissions factors represent the amount of emissions emitted per unit of consumed electricity or fuel and are typically reported in pounds or tons per unit of energy.

The emissions factors will represent the total combined combustion and pre-combustion emissions, often referred to as carbon dioxide equivalent (CO_2e) and represents multiple gasses, including CO_2, CH_4, and N_2O. The fossil fuel emissions factors will use U.S. averages based on the most recent EIA and EPA data. The electricity emissions factors will be based on values in Table B.1, which are derived from 2022 Cambium long-run marginal emission rates and are based on 2021 Cambium data (Gagnon, et al. 2023). The electricity data are site end-use values for the Cambium mid-case scenario, based on a 20-year levelized analysis period, zero discount rate, and a 20-year period. If an alternative source for emissions factors is used, it will be reported.

[34] DOE also adopted this approach to emission reduction monetization in its *Analysis Regarding Energy Efficiency Improvements in the 2024 International Energy Conservation Code (IECC)* found here: https://www.energycodes.gov/determinations

Table B.1. Electricity Emission Factors

eGRID Subregion*	Yearly CO_2e Emissions (lb/MWh)						
	2024	2025	2026	2027	2028	2029	2030
AZNMc	458	439	438	438	446	454	465
CAMXc	132	106	91	75	67	59	53
ERCTc	258	230	216	199	197	195	197
FRCCc	684	691	706	723	747	772	793
MROEc	639	628	628	628	633	638	645
MROWc	420	407	409	412	423	433	442
NEWEc	648	625	608	590	577	565	556
NWPPc	317	283	263	243	235	227	227
NYSTc	210	169	134	99	76	53	40
RFCEc	909	902	901	900	906	912	918
RFCMc	1141	1140	1140	1138	1137	1136	1135
RFCWc	990	977	967	955	947	939	933
RMPAc	485	454	435	417	412	407	410
SPNOc	432	411	408	406	418	431	442
SPSOc	498	472	461	450	452	454	464
SRMVc	964	935	910	881	859	837	816
SRMWc	629	599	581	556	541	527	518
SRSOc	999	1003	1018	1027	1043	1058	1064
SRTVc	1151	1162	1173	1179	1183	1188	1184
SRVCc	548	518	500	479	465	452	438

* The Cambium eGRID subregions are based on balancing area and do not completely align with EPA eGRID subregions, which are based on utility service territory. Look up tables that indicate eGRID subregions by zip code or county are included in the published Cambium 2022 LRMER workbooks available at: https://data.nrel.gov/submissions/206. More details on the Cambium input assumptions and methodology are described in the documentation report, available at: https://www.nrel.gov/docs/fy23osti/84916.pdf.

B.1.2 Net Present Value of Monetized Emissions

The monetary value of avoided emissions will be calculated on an annual basis for each year of the study period using the values in 89 FR 16820, and in alignment with the approach adopted by ASHRAE Standard 90.1. To calculate net present value (NPV), these annual values will be discounted using the same methodology and discount rate as other costs in the LCC analysis. Where a nominal discount rate is used, the annual value of carbon will incorporate a uniform rate of inflation. DOE will use alternative values and methods pursuant to guidance from State or local regulatory agencies requesting an analysis.

The net present value of avoided emissions will be converted into units of $/MWh for electricity and $/MMBTU for fossil fuels based on the applicable emissions factors. Current emissions factors and guidance on values and discount rates associated with avoided emissions will be used and reported with cost-effectiveness analysis results.

For example, using this approach the ASHRAE Standard 90.1 committee established the following monetized emissions cost adjustment factors for electricity and natural gas during the 90.1-2025 development cycle:

Electricity: $0.0650/kWh

Natural Gas: $2.0214/therm

The rates established by the ASHRAE Standard 90.1 committee are based on national average emissions rates determined in accordance with Section B.1.1 of this document, the economic criteria established for the 90.1-2025 development cycle, and the 2023 value of annual carbon estimates at a 2% discount rate.

These NPV costs per unit energy of avoided emissions can be added to the electricity and natural gas fuel costs so that the cost-effectiveness of a proposed code change may include the monetary benefit of reduced emissions. The ASHRAE 90.1 committee processes include the reporting of cost-effectiveness both with and without the monetary benefits of reduced emissions as shown in the following example. In this example, note that the cost-effectiveness of adoption of building energy codes are positive without including any monetized climate benefits. An example cost-effectiveness calculation using the 2023 metrics currently adopted by ASHRAE 90.1-2025 is shown in Table B.2.

Table B.2. Example Calculation of Monetized Emissions

	90.1-2025 Energy Prices	90.1-2025 Emissions Adders	Energy Prices with Emissions Adders
Electricity ($/kWh)	$0.1122	$0.0650	$0.1772
Natural Gas ($/therm)	$0.8381	$2.0214	$2.8595

	PV Savings excluding emissions benefits	PV Savings including emissions benefits
Present Value (PV) Construction Costs ($)	-$688	-$688
PV Electricity Savings (150 kWh annually)	$262	$414
PV Natural Gas Savings (30 therms annually)	$428	$1461
Net Present Value (NPV) Total PV Savings + Total PV Costs (>0 = cost effective)	$ 2	$ 1,187

B.1.3 Reporting National and State Cost-Effectiveness

National and state level cost-effectiveness reports for the commercial model energy code will include the following summary tables:

The cumulative (30-year) emissions reduction, calculated in accordance with Section B.1.1, attributed to the adoption of the evaluated model energy code. Emissions reductions attributable to CO_2, CH_4, and N_2O will be reported separately.

The net present value of the monetized emission reductions calculated in accordance with Section B.1.2. The summary table (example shown in Table B.3.) will include the anticipated annual benefit in 2030, the annual benefit in 2040, and the 30-year cumulative benefit. Benefits will also be separately reported for each of the near-term Ramsey discount rates (2.5%, 2%, and 1.5%) and CO_2, CH_4, and N_2O.

Table B.3 provides an example template table that could be used to report national and state cost effectiveness, including monetized emissions.

Table B.3. Example Template for Reporting NPV of Monetized Emissions

Present Value of Monetized Emissions ($millions)			
Emission	Near-Term Ramsey Discount Rate		
	2.5%	2.0%	1.5%
Annual (2030)			
CO_2			
CH_4			
N_2O			
Annual (2040)			
CO_2			
CH_4			
N_2O			
Cumulative 2024 - 2053			
CO_2			
CH_4			
N_2O			

B.2 Jobs Creation

When analyzing updated energy codes, DOE may report on their impact on job creation. Energy-efficient building codes impact job creation through two primary value streams:

1. Dollars returned to the economy through reduction in utility bills and resulting increase in disposable income, and;
2. An increase in construction-related activities associated with the incremental cost of construction that is required to produce a more energy efficient building.

When a building is built to a more stringent energy code, there is the long-term benefit of the ratepayer paying lower utility bills.

- This is partially offset by the increased cost of that efficiency, establishing a relationship between increased building energy efficiency and additional investments in construction activity.
- Since building codes are cost-effective, (i.e., the savings outweigh the investment), a real and permanent increase in wealth occurs that can be spent on other goods and services in the economy, just like any other income, generating economic benefits and creating additional employment opportunities.

The following set of activities were modeled using a separate IMPLAN[35] model for each state as follows:

- Bill savings become new spending by households (+)
- Utilities receive lower revenue from residential sector (-)
- Construction industry spending incrementally more on home construction (+)
- Households incur higher incremental cost of new homes (-)

The modeled activities are all important considerations when looking at workforce impacts because of the interactions that occur. Since some activities will have positive impacts while others will have a negative impact, the net effect of these activities will be reported. The analysis includes assumptions about labor market conditions, impacts on employment, wages and productivity, and also considers factors like consumer behavior and regional economic stability.

B.3 Health Impacts

The assessment of health impacts focuses primarily on the benefit of improved air quality by monetizing reductions in mortality, sick days, health care costs, and diseases related to air pollution. This analysis relies on assumptions about, the link between air quality and health, population demographics, baseline health and air quality data, and economic factors that are location specific. Where requested by a jurisdiction or state, DOE will calculate the health impacts of energy code changes using publicly available and vetted tools including but not limited to EPA Avoided Emissions and Generation Tool (AVERT) [36] and EPA Coalitional Benefits Risk Assessment (COBRA) [37] with documented state or jurisdictional assumptions. DOE may subsequently provide analysis demonstrating the monetary value of health benefits using common industry practices and publicly available data sources.

B.4 Resilience Impacts

Where requested by a jurisdiction or state, DOE will calculate resilience impacts of energy code changes. Resilience impacts are indicated by metrics determined from prototype building performance simulation results. Metric values are evaluated during no-power conditions that coincide with extreme heat and cold outdoor conditions. The metrics may include but are not limited to Standard Effective Temperature, Heat Index, and Hours of Safety, which provide a means to quantify habitability and occupant safety benefits of energy codes. Methods will follow published procedures developed to assess resilience impacts associated with increases in building efficiency, including those described in the DOE report “Enhancing Resilience in Buildings through Energy Efficiency” available at the DOE Building Energy Codes Program energy resilience website.[38]

B.5 Grid Impacts

Where requested by a jurisdiction, state, or model code development body, DOE will evaluate the ability for the building to respond to a grid signal resulting from energy code changes. The

[35] IMPLAN is a software tool used to perform economic impact analysis. More detailed information can be found here: https://implan.com/
[36] https://www.epa.gov/avert
[37] https://cobra.epa.gov
[38] https://www.energycodes.gov/energy-resilience

assessment will evaluate building demand responsiveness by simulating building performance and calculating energy operating costs using a time-of-use electricity rate. The applied rate will be provided by the jurisdiction or calculated following procedures developed to calculate national or state representative rates, such as those used to define a national, representative, commercial building time-of-use rate that was approved by the ASHRAE Standard 90.1 Committee for code development purposes.

B.6 Avoided Future Costs

Jurisdictions may consider adopting readiness provisions, which specify code requirements to ease the transition and installation of new technologies, such as electric vehicle charging, on-site solar, and future electrification of equipment and appliances. Readiness provisions may require that buildings be equipped with the underlying infrastructure (e.g., conduit, panel capacity, roof orientation and available space, etc.) to enable future building owners to have the option to fully install these technologies in the future at a much lower cost than retrofitting the building after it’s built. For example, installing electric vehicle readiness infrastructure during construction could reduce costs to owners by as much as 75% when compared to the costs to retrofit the building with electric vehicle charging infrastructure later (Banwell et al. 2022). Each readiness measure has a direct impact on new construction costs and may provide benefits to building occupants. Although these measures may not have immediate energy cost savings that can be analyzed as part of the traditional DOE cost-effectiveness methodology, in many cases they still provide long-term consumer cost savings. Where asked to consider the benefit of readiness measures, in addition to evaluating the potential energy cost savings and grid impacts, the potential avoided cost of installing readiness measures during new construction versus the higher cost of installing as a future retrofit will be quantified.

Readiness measures are considered cost-effective when the cumulative present value of the new construction cost is less than the cumulative present value of the future retrofit cost. The cumulative present value of the new construction and retrofit costs are calculated as described in the following sections. Table B.4 shows an example calculation of avoided future costs.

Table B.4. Example Readiness Measure Installation and Avoided Future Costs

Measure	New Construction Cost	Future Retrofit Cost
EV Readiness*[39]	$1,067	$4,304
Solar Readiness*[40]	$1,228	$4,219
Total Costs*	$2,296	$8,523
Present Value Life-cycle Cost	$2,275	$5,760
Present Value Avoided Life Cycle Cost Savings	$3,485	

*New Construction and Future Retrofit Costs are shown in life cycle cost analysis year-0 dollars.

B.6.1 Calculating new construction costs

The cost of readiness measures installed as part of new construction are analyzed as an additional loan cost. The annual loan costs are calculated using a fixed loan payment function based on the loan interest rate, the down payment percentage, and the mortgage term. Every loan payment is converted to a present value based on the discount rate and the year in which

[39] https://www.energycodes.gov/sites/default/files/2021-07/TechBrief_EV_Charging_July2021.pdf
[40] www.nrel.gov/docs/fy12osti/51296.pdf

payments occur. The present values of all loan payments over the analysis period are summed together into a cumulative present value.

B.6.2 Calculating retrofit costs

The future retrofit costs are calculated for each year of the analysis period by multiplying the total retrofit cost by the probability of implementation in each year over the life of the building. Future retrofit costs are converted to a present value based on the discount rate and the year in which the cost occurred. The present values of all future retrofit costs, over the analysis period, are summed together into a cumulative present value. The cumulative present value represents the total present value of the future retrofit costs of the readiness measure(s). Future retrofit costs are calculated in present dollars on an annual basis using an annual inflation rate. The probability that readiness measures are adopted is based on regression analysis using the best publicly available data. Where supported by supplemental information provided by a local jurisdiction, different probability of adoption assumptions may be used.

Appendix C – Cost-effectiveness Parameters

Following the methodology outlined in this document and previously posted on the BECP web site,[41] DOE has established the following parameters for analysis of 90.1-2022. Current economic parameters are posted at the same web site. These parameters are subject to reevaluation for each analysis and may change if deemed appropriate. The parameters used and their source will be documented in each analysis.

Table C.1. Summary of 90.1-2022 Economic Parameter Estimates

Parameter	Symbol	Scenario 1 (Publicly Owned Method)	Scenario 2 (Privately Owned Method)	Scenario 3 (ASHRAE 90.1-2022 Scalar Method)
Period of Analysis	L	30 years*	30 years*	40 years*
Energy Prices	Latest national annual average prices based on current DOE EIA data**			$0.1099/kWh $0.983/therm blend†
Energy Escalation Rates		Price escalation rates taken from 2022 *NIST Handbook 135 Supplement*	NIST year-by-year rates (same as scenario 1)	NIST rates (same as scenario 1) plus 2.90% inflation (heating) and 2.25% (cooling)
Loan Term	M_L	N/A	$M_L = L$ (same as period of analysis)	$M_L = L$ (same as period of analysis)
Loan Interest Rate	I	N/A	8.00%	5.0%
Nominal Discount Rate	D_n	N/A	8.00% (same as loan rate)	8.1%
Real Discount Rate	D_r	3.0%	5.19%	5.64%
Inflation Rate	R_{INF}	N/A	2.67% annual	2.33% annual

* Study period shown is for full code or standard analysis, for individual measures, measure life may be used as the study period.
** Average EIA prices from EIA. State prices from EIA are used for individual state analysis. National analysis of Standard 90.1 may use the Scenario 3 prices established by ASHRAE.
† The ASHRAE Scalar Method identifies a fossil fuel rate that is primarily applied to heating energy use. For this reason, the fossil fuel rate is a blended heating rate and includes proportional (relative to national heating fuel use) costs for natural gas, propane, heating oil, and electric heat. Heating energy use in the prototypes for fossil fuel equipment is calculated in therms based on natural gas equipment, but in practice, natural gas equipment may be operated on propane, or boilers that are modeled as natural gas may use oil in some regions.

[41] See https://www.energycodes.gov/methodology

Appendix D – Supplemental Range of Results Method

In some cases, it may be desirable to understand the range of results that might occur in a cost-effectiveness analysis, given potential variation in some of the parameters. This type of analysis shows the sensitivity of the cost-effectiveness to each parameter and the range of results that can occur. This analysis can be conducted using either a Monte Carlo or discrete probability method. This example uses a discrete probability or decision analysis method. This type of analysis may be helpful in demonstrating cost-effectiveness of a code or standard as a whole in a particular domain when some individual building type and climate zone combinations do not individually meet cost-effectiveness criteria.

D.1 Evaluating Multiple Mixed Cost-effectiveness Results

To demonstrate the Range of Results Method, two discrete probability analyses are conducted. The first shows the impact of variation in energy cost savings and construction costs and the second adds variation in economic parameters. For these examples, preliminary results of the analysis of ASHRAE Standard 90.1-2013 compared to 90.1-2010 are used. Note that this is intended to provide an example of the method, not a finished result. In a finished analysis, more research into each variable and the associated probabilities would be undertaken, and more documentation of that research, the data and expert sources used, and the range of each input parameter would be provided.

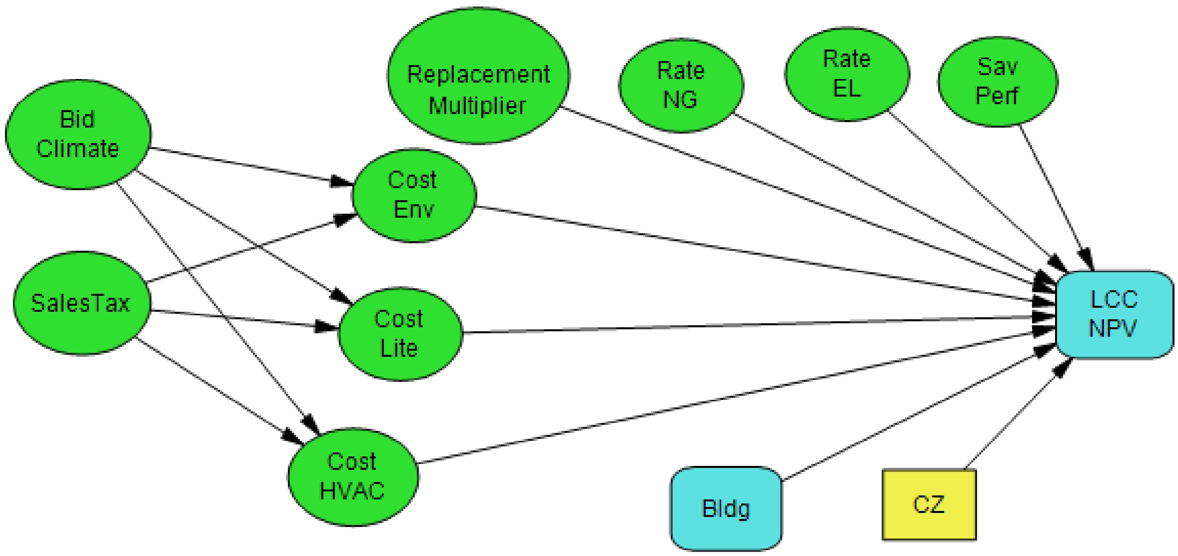
When conducting a national analysis, many parameters will vary from region to region and state to state. Variable parameters in the cost-effectiveness analysis include the following:

- **Construction costs.** Separate location cost factors for building envelope (walls and windows), lighting, and HVAC can be applied. In addition, sales tax varies from location to location. Specific construction bids (bid climate) also affect costs beyond average location multipliers. Replacement costs include a large cost increase multiplier and variation can be included for that cost as well. A variable reflecting bid climate is also included as the number of active construction projects can have a large impact on local construction costs.
- **Energy cost savings.** A range of energy prices can be applied, along with multipliers on the escalation factors. In addition, a savings range can be applied, as there will be variation in savings in actual buildings compared with the prototype buildings.
- **Economic parameters.** While economic parameters have been established by federal statute or committee consensus process, there is variability in discount rates for various sectors and in the escalation rates for energy prices.

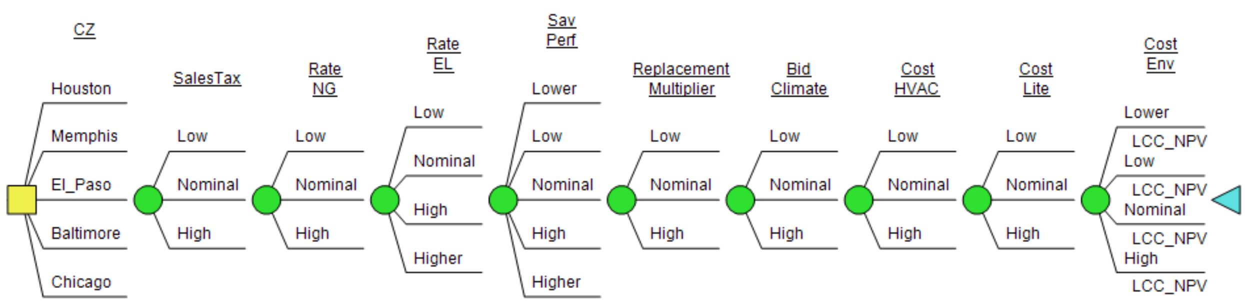
In a discrete probability analysis, a high, nominal, and low value for each factor is used (sometimes additional discrete states are added). Where a good set of data is available, these values and the probability of their occurrence can be determined fairly precisely, as is the case with occurrence of different state energy prices or sales taxes. In other cases, expert judgment can be applied to arrive at a reasonable range of values that are generally acceptable, and a reasonable set of probabilities can be applied. Even without a complete set of data-based inputs, a valid range of results can be shown, as individual high and low values tend to average out, and probabilities often match a standard distribution. The value of the analysis is not predicting a precise expected value but rather seeing the range of results that occurs with the given inputs and a good estimate for the expected value of the overall group result based on the given range of inputs. The expected value is similar to a weighted average based on probability.

D.2 Example of Variable Costs and Energy Parameters

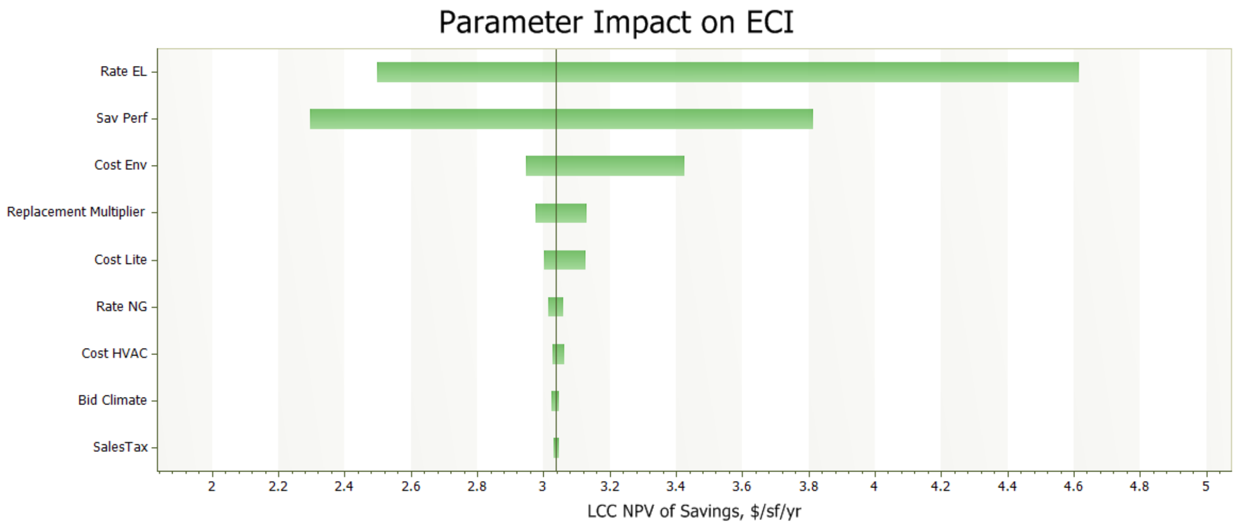
For this analysis, a weighted average NPV savings of the six building types is used in Scenario 1. Variation in energy cost savings and construction cost values are analyzed. An influence diagram shows the relationship of the parameters in this analysis.



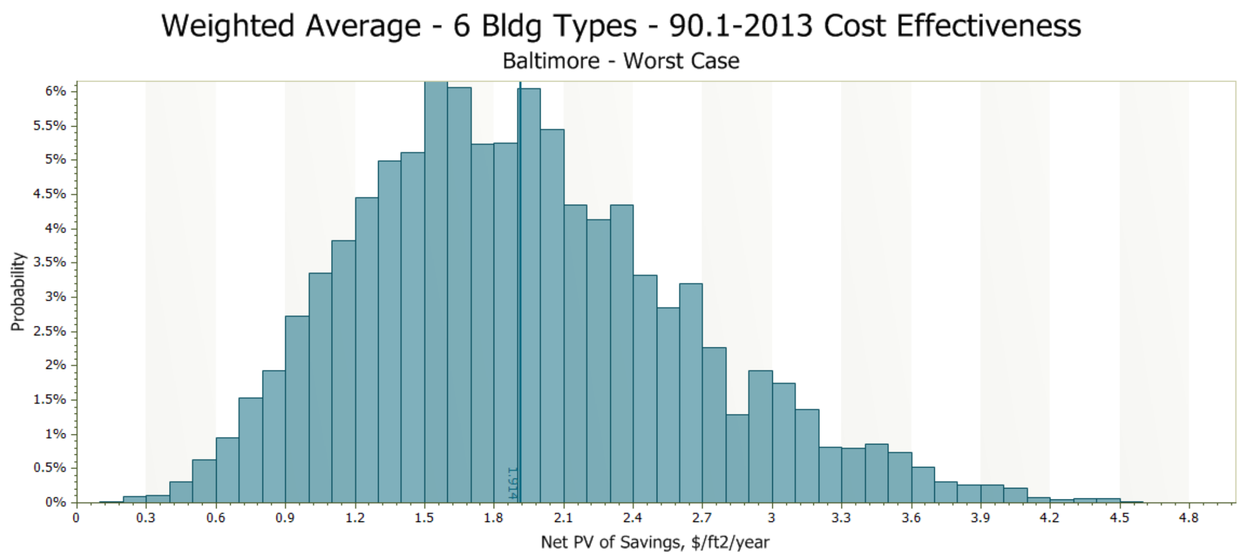
That relationship can also be seen as a decision tree, where the discrete states for each parameter are shown:



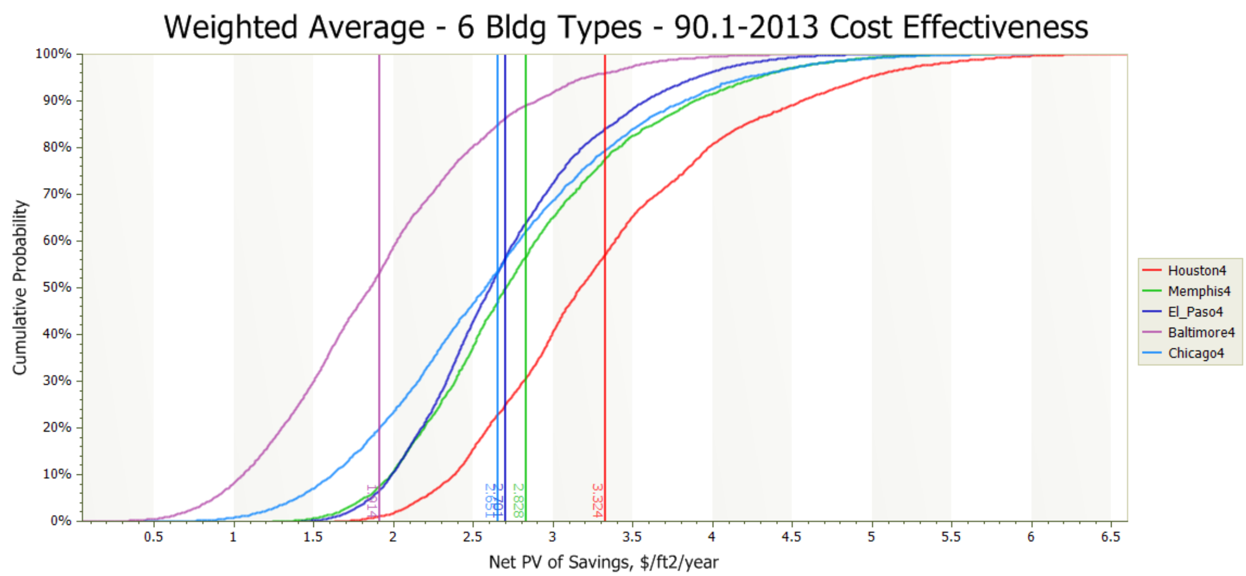
When the impact of the influencing parameters on the final NPV of savings is evaluated, we can see the range of impact each parameter has when the other parameters are held at their nominal state. The range of impact can be displayed in a tornado diagram. The vertical line represents the NPV of savings for the Houston climate zone with all parameters equal to the nominal position. The width of each bar shows the high and low result that each parameter's range of values will produce when other influencing parameters are held at their nominal value. Reviewing the tornado diagram indicates that the electric rate and savings performance variation have the largest impact on the NPV of savings.



The range of NPV savings results can be viewed for individual climate zones. A histogram for the weighted average of six building types in Baltimore, the location with the lowest (worst) NPV of savings result, is shown below.



The histograms for each analyzed climate zone can be converted into a plot of cumulative probability so they can be easily overlaid on one graph. Each “S” shaped line shows the range of results for a climate zone. The vertical lines show the expected value for each climate zone, given the range and probabilities for all the input parameters.

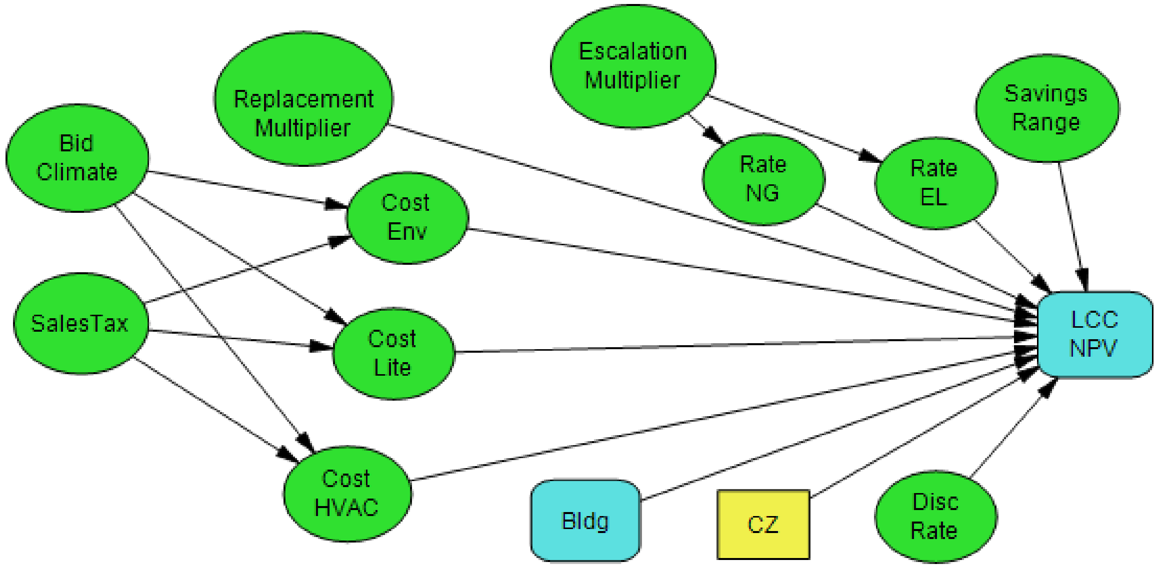


The results across the entire range and combination of parameter inputs in each climate zone were all cost-effective in this example. In a case where some combinations fell below zero NPV savings, a code upgrade would be declared cost-effective in aggregate if the expected value of NPV savings was greater than zero.

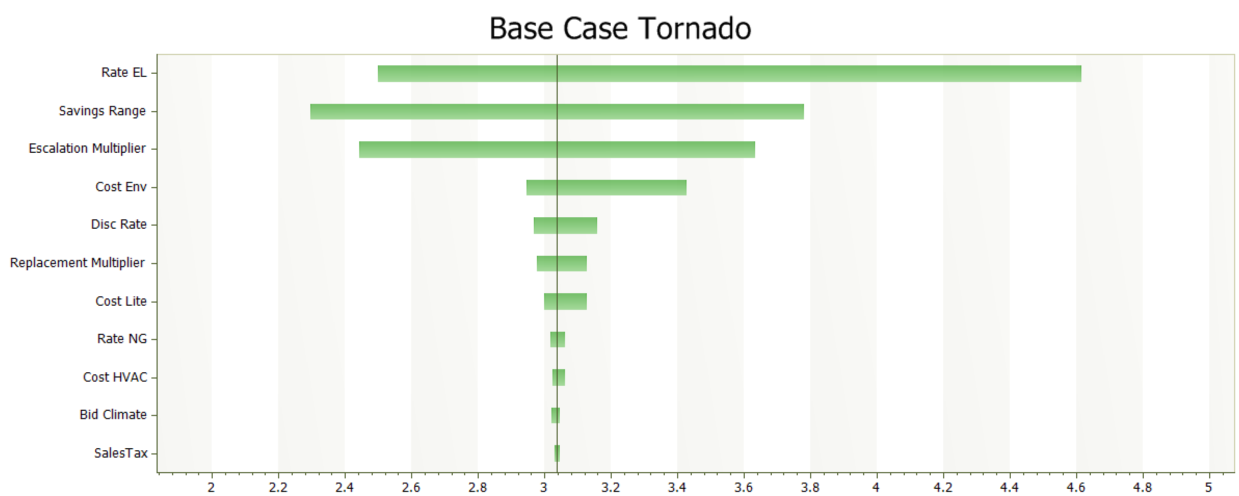
D.3 Example Including Variable Economic Parameters

The previous example—based on preliminary results of the Scenario 1 analysis of Standard 90.1-2013 compared to 90.1-2010—can be expanded to include variation in the energy price escalation rates and discount rate used. Again, this analysis is intended to provide an example of the method, not a finished result. In a finished analysis, more research into each variable and the associated probabilities would be undertaken, and more documentation of that research and the selected range of parameter inputs would be provided.

There are often uncertainties regarding the predicted energy escalation rates and the discount rates used in the analysis. While these are established by federal regulation for federal projects, a view of the impact of varying those rates may be helpful from the private investment view. For illustration, the previous analysis was revised to include influence of varying the energy price escalation rates from 80% to 120% of their value as established by the Energy Information Administration and look at real discount rates from 0.5% to 7.0% rather than just 3.0%. The revised influence diagram is shown below.

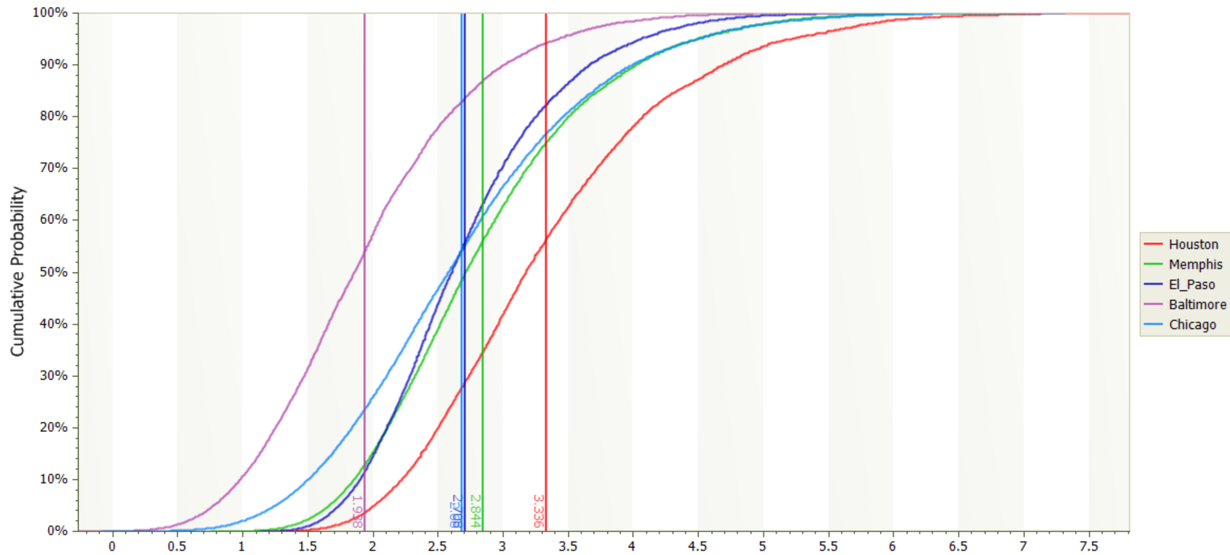


When a sensitivity analysis is run for the Houston climate zone, the energy price escalation multiplier does have a large impact, and the discount rate variation has a lesser impact.



Looking at the cumulative probability diagram for the weighted results of all six building types, we can see that the purple line for the Baltimore climate zone just barely extends below zero NPV. This is because there are a small number of combinations of the tested parameters that result in a NPV of savings less than zero. In fact, the probability is so low that NPV is less than zero it is difficult to see the tail of the line for Baltimore on the chart. The preponderance of cases still has a positive net savings. The expected values of NPV savings shown by the vertical lines for all climate zones are greater than zero. Thus, a conclusion can be made that the code in aggregate is cost-effective, even with variations in energy cost savings, construction cost, and economic parameters.

Weighted Average – 6 Building Types – 90.1-2013 Cost-Effectiveness



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