PNNL-37098

Methodology for Evaluating Residential Energy Code Updates

December 2024

Victor Salcido
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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Preface to 2024 Edition

DOE supports the development of the International Code Council's (ICC) International Energy Conservation Code (IECC), the national residential model energy code as described in the Energy Conservation and Production Act (ECPA), as amended. The IECC is adopted by or forms the basis of residential energy codes promulgated by most U.S. states and local governments. DOE performs various energy and cost-effectiveness analyses of the IECC, at the national, state, and local level (upon request), assessing impacts of one code version to the next, as well as proposed modifications to individual code provisions within a model code.[1] This document represents the methodology DOE uses in performing such analyses.

This document is an update to the Department of Energy's (DOE) cost-effectiveness methodology originally published in August 2015. Changes include correction of a typographical error in lifecycle costing equations and building prototype enhancements; updating the weighting factors for foundation types and system types based on permit data from the U.S. Census and current housing starts data from the U.S. Census and Residential Energy Consumption Survey (RECS), updated representative climate locations for both national and state level aggregations, adding a section on data for measure lifetimes, and the addition of the determination strategy for compiling first costs of measures and economic parameters.[2] New appendices are included to describe the methodologies for the State Code Adoption Map Analyses (Appendix A), and Advanced Benefits Analysis (Appendix B).

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[1] Additionally, DOE is statutorily required to evaluate whether updates to the IECC would result in increased energy savings as compared to the prior version. (42 U.S.C. 6833(a)(5)(A)) The statutorily required determination is based solely on an assessment of energy savings. To the extent a quantitative analysis would be required for such a determination, DOE would rely on the energy savings portion of the methodology.

[2] 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

This report was prepared by Pacific Northwest National Laboratory (PNNL) for the Department of Energy (DOE) Building Energy Codes Program. The authors would like to thank Jeremy Williams, Christopher Perry and Ian Blanding at DOE for providing oversight. This work was truly a team effort, and the authors would like to express their deep appreciation to the PNNL codes team who contributed to its completion, especially Michael Rosenberg, Matt Tyler, and Fan Feng.

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Contents

Figures

Tables

1.0 Introduction

The Department of Energy's (DOE's) Building Energy Codes Program (BECP) has developed and established a methodology for evaluating the energy and economic performance of residential energy codes. This methodology serves three primary purposes. First, as DOE participates in the consensus processes of the International Code Council (ICC), the methodology described herein will be used by DOE to ensure that its proposals are both energy efficient and cost-effective. Second, when a new version of the International Energy Conservation Code (IECC) is published, DOE will evaluate the new code to establish expected energy savings and cost-effectiveness, which will help states and local jurisdictions interested in adopting the new code. DOE's measure of cost-effectiveness balances longer-term energy savings against additions to initial costs through a lifecycle cost (LCC) perspective. Lastly, DOE tracks state energy code adoption efforts and analyzes state specific codes as they go into effect. A quantitative analysis of state specific energy codes provides a framework to compare against latest model energy codes for energy savings and cost-effectiveness.

The DOE methodology estimates the energy impact by simulating the effects of the code change(s) on typical new residential buildings, assuming both the old and new code provisions are implemented fully. The methodology does not estimate rates of code adoption or compliance. Cost-effectiveness is defined primarily in terms of LCC evaluation and can be calculated for various income levels; low-income, middle-income families and first-time homebuyers). The DOE methodology includes several other key metrics intended to be useful to states considering adopting new codes.

This document is arranged into three primary parts covering the following.

1. **Estimating Energy Savings of Code Changes**—by modeling changes to representative building types. The DOE methodology defines single-family and multifamily 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 include four foundation types and four heating equipment types to appropriately account for location-specific construction practices and fuel prices.
2. **Estimating the Cost-effectiveness of Code Changes**—by comparing energy cost savings to incremental construction costs. The methodology defines three metrics to be calculated—LCC, annual consumer cash flow, and simple payback period; establishes sources for the economic parameters to be used in estimating those metrics and defines three geopolitical levels at which those metrics will be reported (state, climate zone, national). Each set of economic parameters can reflect various income levels of homebuyers to illustrate the economic impact of the code changes. Evaluating cost-effectiveness requires three steps: 1) analyzing 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.
3. **Aggregating Energy and Economic Results**—across building types, foundation types, fuel/equipment types, and climate locations. The methodology establishes sources for weighting factors to be used in aggregating location-specific results to the three geopolitical levels, including national, state, and local (upon request).

This document also includes two appendices. Appendix A describes the process DOE uses to populate the Status of State Energy Code Adoption Map on the energycodes.gov website. Appendix B describes how DOE will analyze advanced benefits of a new energy code where appropriate or as requested by states, local jurisdictions, or model code development bodies.

2.0 Estimating Energy Savings of Code Changes

The first step in assessing the impact of a code change or a new code is estimating the energy savings of the associated changes. DOE will employ computer simulation analysis to estimate the energy impact of a code change. In some cases, DOE may rely on extant studies directly addressing the building elements involved in a proposed change if such can be identified. DOE intends to use the most recent edition of EnergyPlus[1] software as the primary tool for its analyses. If necessary, to better capture the nuances of a particular code change, DOE may supplement EnergyPlus with other software tools or performance databases. Such code changes will be addressed case by case.

The energy savings analyses are performed on a national, state, and local level (upon request). These analyses compare the most recent code edition to the previous code edition or a set of code changes based on a national, state, or local set of weighting factors. Code changes affecting a particular climate zone will be simulated in representative weather locations. The state level analysis compares the most recent model energy code to the current state adopted energy code. State analyses inform DOE's Status of State Energy Code Adoption Maps[2] as well as provide state specific cost-effectiveness reports. At least one location is chosen per climate zone in every U.S. state. DOE's methodology includes weighting factors based on recent housing starts data to allow the individual location results to be aggregated to climate-zone and national averages as needed. These methodologies, weighting factors, and other assumptions are described in the sections that follow.

The 2021 IECC introduced a set of additional efficiency measures that increase the level of energy savings beyond prescriptive code requirements and must be included in the building design and construction. This additional efficiency comes in the form of various energy saving measures, such as envelope, HVAC, service water heating, air leakage, and thermal distribution, which can be incorporated in the design to meet the minimum number of measures or credits required. In the 2024 IECC, energy efficiency measures are assigned energy credits based on the total energy savings achieved over the baseline prescriptive energy code for each climate zone and building type. The higher the energy savings associated with each measure, the more energy credits assigned. Since the energy credits provide flexibility to meet the minimum number of credits, various combinations of energy saving measures can be employed to meet the requirement. For the national, state and local level analyses, energy credit measures will be selected 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 Assumptions and Methodology

The energy performance of most energy efficiency measures can be estimated by computer simulation. Prototype buildings will be developed—one designed to comply with the baseline energy code and an otherwise identical building complying with the revised energy code for national level analyses. State level analyses use the prototype buildings with the revised energy code compared to the state adopted energy code. This comparison will be simulated in the relevant climate zones to estimate the overall energy impact of the new code. The inputs and assumptions used in the simulations are discussed in the following sections.

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[1] http://www.energyplus.net/

[2] A detailed description of the State Energy Code Adoption Maps can be found in Appendix A.

2.1.1 Energy Simulation Tool

DOE intends to use an hour-by-hour simulation tool to calculate annual energy consumption for relevant end uses toward a dwelling unit energy use index (EUI). For most situations, the EnergyPlus software will be the tool of choice. EnergyPlus provides for a detailed hour-by-hour (or more frequent) simulation of a home's energy consumption throughout a full year, based on typical weather data for a location. It covers almost all aspects of residential envelopes; heating, ventilation, and air-conditioning (HVAC) equipment and systems; water heating equipment and systems; and lighting systems. Air leakage from the envelope and duct systems is modeled using the EnergyPlus airflow network for more accurate air movement prediction. Depending on how building energy codes evolve, it may be necessary to identify additional tools to estimate the impacts of more specialized changes.

DOE recognizes there are other tools that can produce credible energy estimates. DOE intends to use EnergyPlus as its primary tool, because it includes enhanced simulation capabilities, is under active development, and has the potential to include capabilities either unavailable or less sophisticated in other accepted simulation tools. EnergyPlus has capabilities for detailed simulation of the pressure-related interactions between duct leakage and air infiltration through the building envelope, enhanced capabilities for simulating residential attics and other unconditioned spaces, and the potential for analyzing detailed control strategies and specific hot water piping configurations.

2.1.2 Prototypes

Simulations will be conducted for single-family and multifamily buildings. The prototypes used in the simulations are intended to represent a typical new one- or two-family home or townhouse, and a low-rise (3-story) multifamily building, such as an apartment, cooperative, or condominium. The prototypes will be developed based on analysis using U.S. census data for new construction. Operating schedules and parameters will be obtained from the latest Building America Simulation Protocols.[1] Four foundation types will be examined for all buildings: vented crawlspace, slab-on-grade, heated basement with wall insulation, and unheated basement with insulation in the floor above the basement. All buildings will be evaluated with central air conditioning and each of four heating system types: gas furnace, oil furnace, heat pump, and electric furnace. The multifamily prototypes will be simulated with a central oil-fired boiler instead of individual oil furnaces. If new code provisions relate to other less frequently used foundations or equipment types, supplemental prototype configurations will be developed as necessary.

Prototypes will be configured to meet the provisions of each code's primary prescriptive manifestation. DOE will address any future codes that may not have such primary requirements (e.g., a purely performance code) and codes for which the primary prescriptive path does not represent the likely practical manifestation of the code on a case-by-case basis.

Table 1 shows the characteristics DOE intends to assume for the single-family prototype. Note that any of these characteristics may be modified if impacted by a code change. The single-family prototype is configured as a simple rectangular building and is illustrated by the line drawing in Figure 1.

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[1] .https://www.nrel.gov/docs/fy14osti/60988.pdf#:~:text=Space%20conditioning%20equipment%20type%20and%20efficiency%20for,For%20all%20homes%2C%20including%20multifamily%20buildings%20with

Table 1. Single-Family Prototype Characteristics

Parameter	Assumption	Notes
Conditioned floor area	2,376 ft^2 (plus 1,188 ft^2 of conditioned basement, where applicable) 3,564 ft^2 for heated basement	National Association of Home Builders (NAHB)
Footprint and height	39.8-ft-by-29.8 ft, two-story, 8.5-ft-high ceilings	---
Area above unconditioned space	1,188 ft^2	Over a vented crawlspace or unconditioned basement
Area below roof/ceilings	1,188 ft^2	Under a conditioned attic unless specific roof/ceiling measures warrant other (or multiple) roof/ceiling types
Perimeter length	139.2 ft	---
Gross exterior wall area	2,366.4 ft^2	---
Window area (relative to conditioned floor area)	Fifteen percent equally distributed to the four cardinal directions (or as required to evaluate glazing-specific code changes)	---
Door area	42 ft^2	---
Internal gains	86,761 Btu/day 115,035 Btu/day (heated basement)	2021 IECC, Table R405.4.2(1), assuming three bedrooms. May vary if homes of different size than the standard prototype are analyzed.
Heating system	Natural gas furnace, heat pump, electric furnace, or oil-fired furnace	Efficiencies will be based on prevailing federal minimum standards.
Cooling system	Central electric air conditioning	Efficiency will be based on prevailing federal minimum standards.
Water heating	Same as fuel used for space heating, or as required to evaluate domestic hot water-specific code changes	Efficiency will be based on prevailing federal minimum standards.

Btu = British thermal units.
IECC = International Energy Conservation Code.

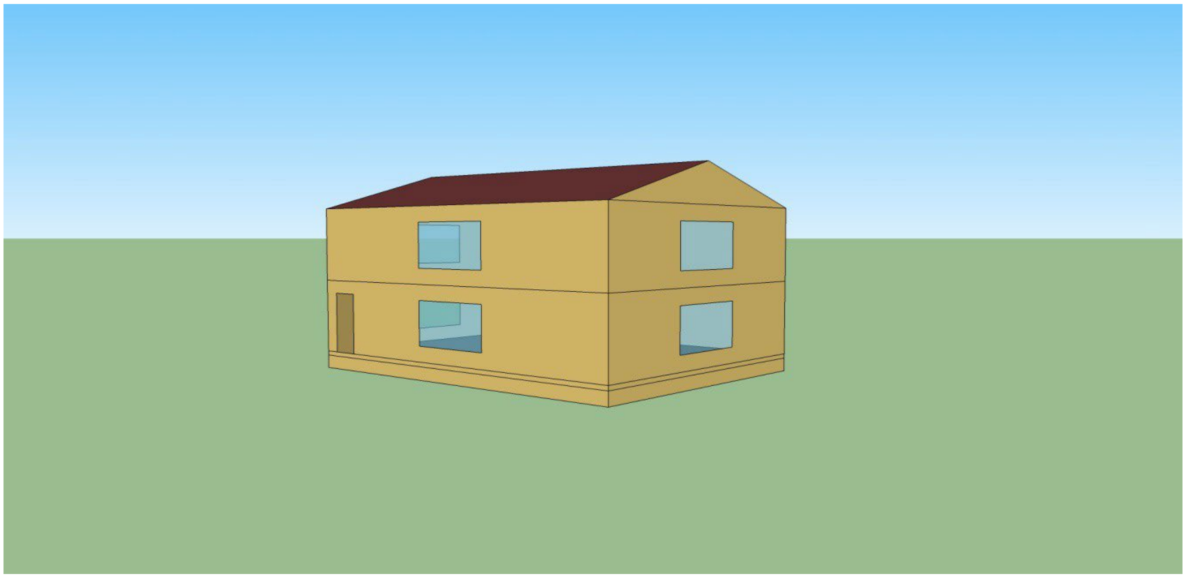

Figure 1. Single-family prototype

DOE will employ a three-story multifamily prototype having six dwelling units per floor, arranged in two rows with an open breezeway in between. The multifamily prototype characteristics to be used for DOE's analyses are shown in Table 2. The heating, cooling, and water-heating system characteristics are the same as for the single-family prototype (each dwelling unit is assumed to have its own separate heating and cooling equipment except when the heating fuel is oil, in which case a centralized oil-fired boiler is assumed). The multifamily prototype is illustrated by the line drawing in Figure 2.

Table 2. Multifamily Prototype Characteristics

Parameter	Assumption	Notes
Conditioned floor area	1,200 ft^2 per unit, or 21,600 ft^2 total (plus 1,200 ft^2 of conditioned basement on ground-floor units, where applicable)	Characteristics of New Housing, U.S. Census Bureau
Footprint and height	Each unit is 40 ft wide by 30 ft deep, with 8.5-ft-high ceilings. The building footprint is 120 ft by 65 ft.	---
Area above unconditioned space	1,200 ft^2 on ground-floor units	Over a vented crawlspace or unconditioned basement
Wall area adjacent to unconditioned space	None	No attached garages or similar
Area below roof/ceilings	1,200 ft^2 on top-floor units	---
Perimeter length	370 ft (total for the building), 10 ft of which borders the open breezeway	---
Gross wall area	5,100 ft^2 per story, 2,040 ft^2 of which faces the open breezeway (15,300 ft^2 total)	---
Window area (relative to gross wall area)	Twenty-three percent of gross exterior wall area, excluding walls facing the interior breezeway (or as required to evaluate glazing-specific code changes)	---
Door area	21 ft^2 per unit (378 ft^2 total)	Assumed to open into the breezeway
Internal gains	54,668 Btu/day per unit (984,024 Btu/day total)	2021 IECC, Table R405.4.2(1), assuming two bedrooms per unit. May vary if buildings/units of different size than the standard prototype are analyzed.
Heating system	Natural gas furnace, heat pump, electric furnace, or centralized oil-fired boiler	Efficiency will be based on prevailing federal minimum standards.
Cooling system	Central electric air conditioning	Efficiency will be based on prevailing federal minimum standards.
Water heating	Same as fuel used for space heating, or as required to evaluate domestic hot water-specific code changes	Efficiency will be based on prevailing federal minimum standards.

Btu = British thermal units.
IECC = International Energy Conservation Code.

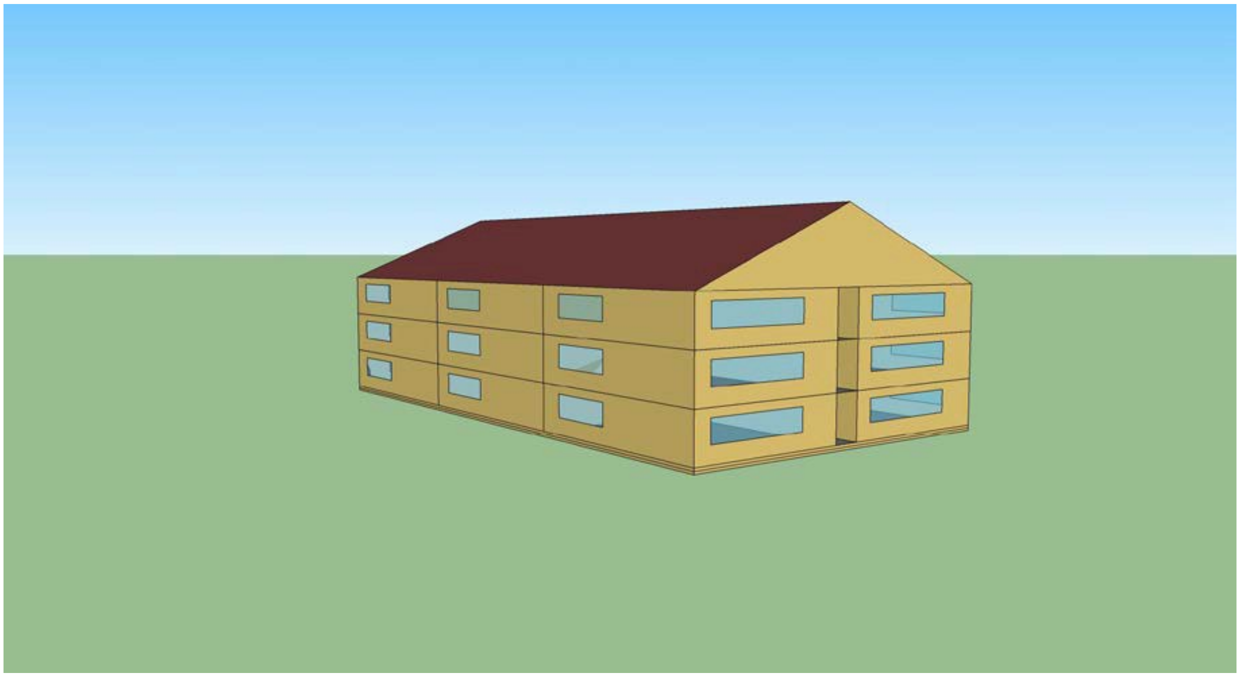

Figure 2. Multifamily prototype

2.1.3 Default Assumptions

Some building components are not addressed by the code and many components may not change from one code to the next. For these components, inputs are identical in both pre- and post-revision simulations. While specific input values for these components are of secondary importance, it is important that they be reasonably typical of the construction types being evaluated. Assumptions and input values for these building components will be set to match shared code requirements (if such exist), shared standard reference design specifications from the codes' performance paths (if such exist), or to best estimates of standard practice. Standard practice assumptions will be taken from various sources, including prototypes and models used by DOE residential programs or other efficiency programs (e.g., Building America, Residential Energy Services Network (RESNET) specifications).

2.1.4 Provisions Requiring Special Consideration

New code provisions that expand the code to include previously unaddressed building components may require special treatment. For example, editions of the IECC prior to 2009 had no duct testing requirement and hence analysis requires establishing a meaningful baseline leakage rate against which newer versions of the code can be compared. In these cases, rather than comparing one code to another, a new code must be compared to an unstated prior condition. In DOE's proposal to add duct testing requirements to the 2009 IECC, energy savings was approximated based on findings from extant post-occupancy studies of duct leakage rather than by simulation. That prior condition can sometimes be based on the average or typical pre-code level used by builders, but this can sometimes understate the energy savings of the new code requirement. Returning to the example of a new requirement for testing the duct leakage rate, consider Figure 3. The curve represents a hypothetical distribution of leakage rates prior to the code's regulation of leakage rates. Even if the new code requirement was set equal to or worse than the pre-change average rate, savings would accrue from houses that would have had higher leakage rates. Data to establish such a pre-code distribution is often unavailable, so DOE intends to evaluate scope expansions on a case-by-case basis to determine the most appropriate way to estimate energy savings given the data available.

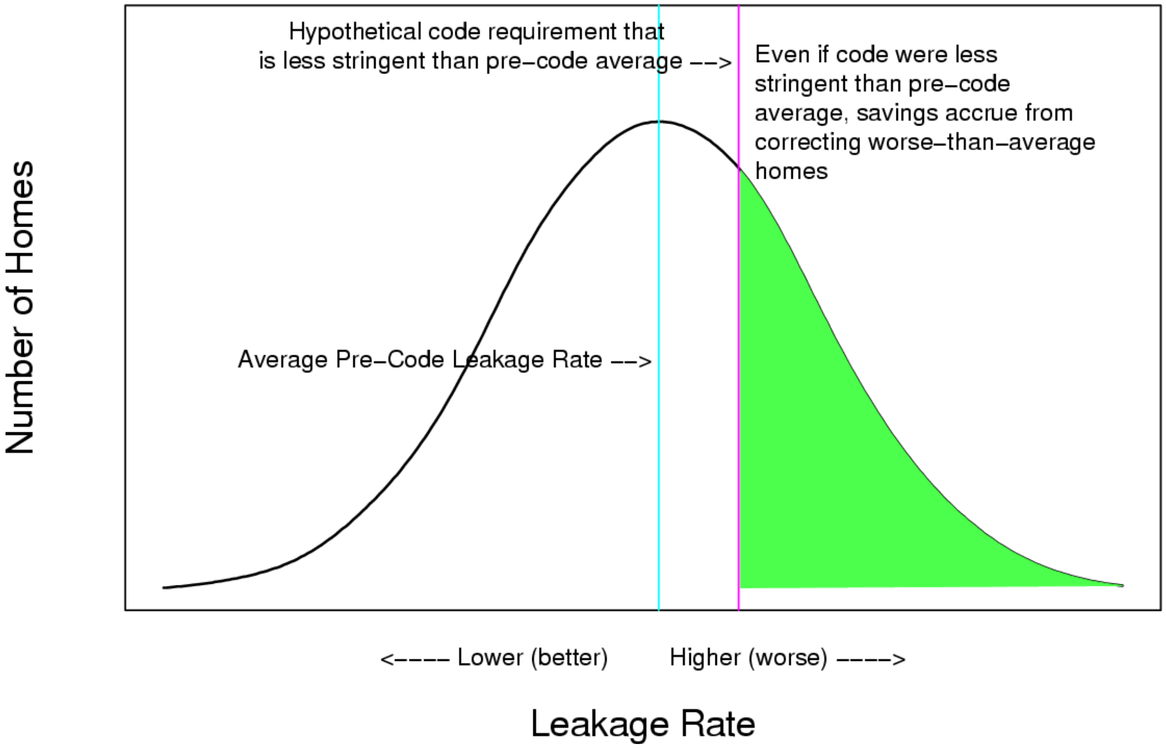

Figure 3. Illustration of energy savings from a hypothetical code change that improves the worst- performing homes.

3.0 Estimating the Cost-effectiveness of Code Changes

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 costs against energy savings over time. The DOE methodology accounts for the benefits of energy-efficient home construction that accrue to homeowners over 30 years. The methodology and assumptions are described in this section.

3.1 Economic Metrics to be Calculated

DOE intends to calculate three metrics in evaluating the economics of code change proposals and in assessing new editions of residential building energy codes:

1. Lifecycle cost
2. Simple payback period
3. Cash flow

LCC is the primary metric DOE will use to evaluate whether a particular code change is cost-effective. The payback period and cash flow analyses provide additional information that DOE believes is helpful to others participating in the code-change processes and to states and jurisdictions considering adoption of new codes. These metrics are discussed further in the following sections.

3.1.1 Lifecycle Cost

LCC[1] is a robust cost-benefit metric that sums the costs and benefits of a code change over a specified time period. Any code change resulting in a net LCC less than or equal to zero (i.e., monetary benefits exceed costs) will be cost-effective. The methodology considers only direct costs (and savings) to the consumer. Externalities, such as impacts on manufacturers, are not considered. DOE will use LCC for determining the cost-effectiveness of code change proposals, and for the code as a whole, as it is the most straightforward approach to achieving the desired balance of first costs and longer-term energy savings.

The key feature of LCC analysis is the summing of costs and benefits over multiple years, which requires cash flows in different years to be adjusted to a common year for comparison. This is done with a *discount rate* that accounts for changes in the value of money over time (i.e., the “time value” of money). Like most LCC implementations, DOE’s methodology sums cash flows in year-zero dollars (the present year), which allows the use of standard discounting formulas. Cash flows adjusted to year zero are termed *present values*. The procedure described herein combines concepts from two ASTM International standard practices, E917[2] and E1074.[3] The

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[1] LCC analysis is sometimes referred to as *net present value* analysis or *engineering economics*, and sometimes expressed in terms of *life-cycle savings*.

[2] ASTM International. “Practice for Measuring Life-Cycle Costs of Buildings and Building Systems.” 2020. E917, *Annual Book of ASTM Standards: 2020*, Vol. 4.11. ASTM International, West Conshohocken, Pennsylvania.

[3] ASTM International. “Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems.” 2020. E1074, *Annual Book of ASTM Standards: 2020*, Vol. 4.11. ASTM International, West Conshohocken, Pennsylvania.

resultant procedure is both straightforward and comprehensive and is in accord with the methodology recommended and used by the National Institute of Standards and Technology.[1]

Present values can be calculated in either *nominal* or *real* terms. In a nominal analysis, all compounding rates (e.g., discount rate, mortgage interest rate, fuel price escalation rate) include the effect of general inflation, and cash flows in future years are assumed to rise with the general rate of inflation. An exception is mortgage payments, which remain constant from year to year regardless of inflation. In a real analysis, inflation is assumed to be zero, and all compounding rates are adjusted to remove the effect of inflation. The relationship between a nominal rate $R_{nominal}$ and a real rate R_{real} is expressed as a function of the inflation rate $R_{inflation}$:

$$(1 + R_{nominal}) = (1 + R_{real}) \times (1 + R_{inflation}) \quad (1)$$

Consequently:

$$R_{nominal} = (1 + R_{real}) \times (1 + R_{inflation}) - 1 \quad (2)$$

$$R_{real} = \left[\frac{(1 + R_{nominal})}{(1 + R_{inflation})}\right] - 1 \quad (3)$$

The two approaches are algebraically equivalent. DOE intends to conduct economic analyses of residential energy codes in nominal terms, because accounting for mortgage cash flows and associated income tax effects is more straightforward. Consumers are generally familiar with nominal rates, because, for example, mortgage interest rates are generally quoted in nominal terms.

The net LCC of a code change is defined formally as the present value (*PV*) of all costs and benefits summed over the period of analysis.[2] Because it is defined in terms of costs, the net LCC of a code change must be zero or negative for the change to be considered cost-effective, as shown in Equation 4.

$$LCC = PV(Costs) - PV(Benefits) \quad (4)$$

A future cash flow (positive or negative) is brought into the present (i.e., time zero) by assuming a discount rate (R_d or simply *d*). The discount rate is an annually compounding rate[3] by which future cash flows are discounted in value. It can be thought of as representing the minimum rate of return demanded of the investment in energy-saving measures. It is sometimes referred to as an alternative investment rate and chosen to approximate a homeowner’s best alternative investment with risk similar to that of energy efficiency measures. Thus, the present value of a cash flow in year *y* (CF_y) is defined as:

$$PV = \frac{CF_y}{(1 + d)^y} \quad (5)$$

---

[1] For a detailed discussion of LCC and related economic evaluation procedures specifically aimed at private sector analyses, see Ruegg and Petersen (Ruegg RT and SR Petersen. 1987. *Comprehensive Guide to Least-Cost Energy Decisions*, NBS Special Publication 709. National Bureau of Standards, Gaithersburg, Maryland).

[2] In this methodology, the term LCC is generally used to mean a net life-cycle cost because we are comparing the energy impacts of two scenarios rather than simply summing the total cost of ownership of a single scenario.

[3] The analysis can be done for other compounding periods (e.g., monthly), but for simplicity DOE uses annual periods for the subject analyses.

The present value of a stream of annual cash flows over the period of analysis, *N* years, is then the sum of all of those discrete cash flows:

$$PV = \sum\nolimits_{y=0}^{N} \left[\frac{CF_y}{(1+d)^y}\right] \tag{6}$$

For an annualized stream of cash flows *A* that is the same from year to year, such as a mortgage payment with a term of *N* years, Equation 6 is equivalent to:

$$PV = A \times \left[\frac{(1+d)^N - 1}{d \times (1+d)^N}\right] \tag{7}$$

For an annualized stream of cash flows that is escalating with time, such as the energy cost savings (ES), that increases (or decreases) from year to year because of escalations in fuel prices, Equation 8 can be used (*e* is the fuel price escalation rate, *N* is the number of years):

$$PV = ES \times N \tag{8}$$

DOE will compute and publish annual cash flow impacts, as well as the net LCC at time zero.

Equation 6 will generally be preferred to Equations 7 and 8, because it allows presentation and analysis of all the yearly cash flows during the LCC analysis period. Equations 7 and 8 are algebraically equivalent to 6, and useful when year-by-year cash flows are not needed.

The primary cash flows relevant to LCC analysis of energy code changes are detailed below.

- The down payment cost associated with the code changes is the down payment rate (RDP) multiplied by the total cost of the code changes (C, or the “first cost”) and is incurred at the onset (year zero):

$$down\,payment = R_{DP} \times C \tag{9}$$

- On top of the down payment is a mortgage fee, which represents the additional cost of obtaining credit due to the additional cost of efficiency measures. It is the cost of the code changes (C) multiplied by the mortgage fee rate (RMF). The mortgage fee is not tax deductible. Some mortgages involve other up-front fees used to buy down the mortgage interest rate. These payments, often referred to as “points,” are tax deductible because they are essentially prepaid interest on the loan. DOE’s methodology assumes that all interest payments are accounted for in the mortgage interest rate, so there are no tax deductible up-front costs. The mortgage fee is calculated as:

$$mortgage\,fee = R_{MF} \times C \times (1 - R_{DP}) \tag{10}$$

- Property tax occurs every year, beginning with year one and continuing through the analysis period P. It represents additional tax paid as a result of efficiency measures giving the home a higher value. It is the property tax rate (RPT) multiplied by the cost of efficiency measures C, and further adjusted annually by a factor EH representing the home price escalation rate. This assumes the initial tax appraisal of the house increases directly with the amount of the code-related cost increase, and that the year-to-year tax assessment increases in step with the escalating home price. The property tax cost in year y is calculated as:

$$property\ tax_y \ = \ R_{PT} \times C \times (1 + E_H)^y \tag{11}$$

- Energy cost savings occur every year, starting at year one and continuing through the analysis period P. They are equal to the modeled energy cost savings at year zero (ES0), adjusted annually by a fuel price escalation factor EF. The energy savings in year y are given by:

$$ES_y \ = \ ES_0 \times (1 + E_F)^y \tag{12}$$

- Mortgage payments occur every year throughout the mortgage term T, and are unchanging (i.e., unaffected by inflation). The annual mortgage payment is calculated dividing the additional loan amount by a standard uniform series present worth factor using the mortgage interest rate (RMI) as the discounting factor. The additional loan amount is simply the initial cost of efficiency measures less the down payment. However, because mortgage interest rates are generally quoted as annual rates but used to calculate monthly payments, we calculate annual mortgage payments as 12 times a standard monthly payment. The annual mortgage payment is given by:

$$mortgage\ payment \ = \ \frac{(1 - R_{DP}) \times C \times 12}{\left[\dfrac{\left(1 + \frac{R_{MI}}{12}\right)^{12T} - 1}{\frac{R_{MI}}{12} \times \left(1 + \frac{R_{MI}}{12}\right)^{12T}}\right]} \tag{13}$$

- Tax deductions for mortgage interest payments and property tax payments begin in year one and continue through the end of the analysis period P. They are calculated as the marginal income tax rate (RIT) multiplied by the sum of mortgage interest payments and property tax payments each year. Property tax payments are calculated as shown above. Mortgage interest payments are the mortgage interest rate (RMI) multiplied by the loan balance each year. The loan balance is simply the present value (at year y) of the remaining stream of mortgage payments, discounted at the mortgage interest rate. Thus, the tax deduction in year y is given by:

$$tax\ deduction_y \ = \ R_{IT} \times \left\{ \begin{matrix} property\ tax_y + mortgage\ payment \times \\ R_{MI} \times \left[\dfrac{(1 + R_{MI})^{T-y+1} - 1}{R_{MI} \times (1 + R_{MI})^{T-y+1}}\right] \end{matrix} \right\} \tag{14}$$

- The methodology accounts for replacement costs of efficiency measures that have an expected useful life L less than the analysis period. It is assumed that a failed measure is replaced with an identical measure at the same first cost and efficiency level, escalated per the home price escalation rate (EH). For a measure m with a service life L that is less than the analysis period P, a replacement cost RCm,y is incurred at the end of any year when the service life expires. That is:

$$RC_{m,y} \ = \ \begin{cases} 0, & y \bmod L \ \neq 0 \\ (1 + E_H)^y \times FC_{m,} & y \bmod L \ = 0 \end{cases} \tag{15}$$

Where FC_m is the first cost of measure *m* and "*y* mod *L*" refers to the *modulo* operator, which gives the remainder after dividing y by *L*. The measure life *L* in equation 16 is taken from Table 3.

Table 3. Measure Lifetimes for Cost Effectiveness Analysis[1]

Measure	Lifetime (years)
Service hot water equipment	12
Lighting equipment	15
HVAC equipment	20
Windows/Doors	25
Thermal envelope/Insulation	60

- Finally, there is a residual value for efficiency features with remaining useful life at the end of the analysis period. This is related to the replacement costs in that a feature replaced shortly before the end of the analysis period would have a higher residual value than one nearing the end of its service life. At the end of the analysis period P, the residual value of each efficiency measure is based on straight-line "depreciation" of its inflated first cost based on the number of years left in its useful life. That is, the residual value for measure m (RVm) is a beneficial cash flow occurring at the end of year P and is given by:

$$RV_m = (1 + E_H)^P \times FC_m \times \left(1 - \frac{P \bmod L}{L}\right) \tag{16}$$

Each of the cash flow components above is discounted to a time-zero present value and the results summed to compute the net LCC.

3.1.2 Simple Payback Period

The simple payback period is a straightforward metric including only the costs and benefits directly related to the implementation of energy-saving measures associated with a code change. It represents the number of years required for the energy savings to pay for the cost of the measures, without regard for changes in fuel 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*), divided by the annual marginal benefit from compliance (ES_0, the energy cost savings in year zero), as shown in Equation 18:

$$P = \frac{C}{ES_0} \tag{17}$$

The simple payback period is a metric useful for its ease of calculation and understandability. Because it focuses on the two primary characterizations of a code change—cost and energy performance—it allows an assessment of cost-effectiveness easy to compare with other investment options and requires a minimum of input data. The simple payback period is used in many contexts and is written into some state laws governing the adoption of new energy codes. However, because simple payback ignores many of the longer-term factors in the economic

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[1] International Association of Certified Home Inspectors Standard Estimated Life Expectancy Chart for Homes. https://www.nachi.org/life-expectancy.htm

performance of an energy efficiency investment, DOE does not use the payback period as a primary indicator of cost-effectiveness for its own decision-making purposes.

3.1.3 Cash Flow Analysis

In the process of calculating LCC, year-by-year cash flows are computed. These can be useful in assessing a code change's impact on consumers and will be shown by DOE for the code changes it analyzes. The cash flow analysis simply shows each year's net cash flow (benefits minus costs) separately (in nominal dollars), including any time-zero cash flows, such as a down payment. Two aspects of cash flow analysis are of particular interest to consumers. First, the net annual cash flow shows how annual cost outlays are compensated by annual energy savings. This value ignores the mortgage down payment and other up-front costs, focusing instead on a new code's impact on consumers' ability to make monthly mortgage payments. Second, the number of years to positive cash flow shows the time required for cumulative energy savings to exceed cumulative costs, including both increased mortgage payments and the down payment and other up-front costs.

3.2 Economic Parameters and Other Assumptions

Calculating the metrics described in Section 3.1 requires defining various economic parameters. Table 4 shows the primary parameters of interest and how they apply to the three metrics. The current values are presented at the end of this section.

Table 4. Economic Parameters for Cost-Effectiveness Metrics

Parameter	Needed For
First costs Fuel prices	Payback Cash flow LCC
Fuel price escalation rates Mortgage parameters Inflation rate Tax rates (property, income) Period of analysis Residual value	Cash flow LCC
Discount rate	LCC

The actual values chosen for these parameters are considered by DOE to be representative of a typical middle income homebuyer with a 30-year mortgage. DOE will consult and cite authoritative sources to establish assumptions for each of these financial, economic, and fuel price parameters. Whenever possible, DOE will use sources discussed in the following sections. Where multiple sources for any parameter are identified, DOE will use those deemed best documented and reliable. Most economic parameters vary with time. DOE will periodically review its parameter estimates and update them to account for changing economic conditions, availability of updated data or projections from the selected sources, or identification of better data sources.

3.2.1 First Cost

A key 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 the change. For DOE's analyses, it refers to the retail cost (the cost to a homebuyer) prior to amortizing that cost over multiple years through the home mortgage. It includes the price paid by the home buyer, including materials, labor, overhead, and profit, minus any tax rebates or other incentives generally available to home buyers when the new code takes effect.

Where costs differ among the sources or there are otherwise questions about the currency of any measure data, DOE will choose measure costs based on the specifics of the analysis (e.g., location, time period of interest), by seeking corroborating estimates from various sources (e.g., *RS Means Residential Cost Data*,[1] national home hardware suppliers such as Lowes and The Home Depot), and/or by consulting recent studies by others (DOE's own Building America[2] program, those generated from the ENERGY STAR[3] program, and buildings-oriented research publications such as American Society of Heating, Refrigerating and Air-Conditioning Engineers' [ASHRAE] Transactions).

DOE anticipates that as building energy codes advance and incorporate more energy features, the traditional cost sources may be insufficient for estimating the first costs of code changes. Where new technologies or techniques are involved, current cost data are often unreliable indicators of the long-term costs of such measures after taking into account economies of scale and builder/contractor learning curves. DOE will address such measures on a case-by-case basis and document any cost adjustments along with the relevant analysis.

3.2.2 Mortgage Parameters

The majority of homes purchased are financed. The 2021 Characteristics of New Housing report from the Census Bureau reports that 94% of new homes were purchased using a loan while only 6% were purchased with cash.[4] Accordingly, DOE calculates cost-effectiveness assuming the home buyer finances the purchase through a 30-year mortgage.

3.2.2.1 Mortgage Interest Rate (R_{MI})

DOE bases the mortgage interest rate on the 1-year and 5-year average historic rates. To capture a relatively constant long-term mortgage interest rate over time that is appropriate for the study period, DOE intends to use the 1-year and 5-year rate to calculate a weighted average mortgage interest rate for each analysis as shown in Equation 19.

$$Mortgage\ Interest\ Rate\ = (1\ yr\ ave\ x\ 0.2) + (5\ yr\ ave\ x\ 0.8) \tag{18}$$

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[1] RSMeans Reed Construction Data. 2024. Accessed May, 2024 at http://www.rsmeans.com/

[2] U.S. Department of Energy, Energy Efficiency & Renewable Energy. 2022. Building America –Resources for Energy Efficient Homes. Accessed August, 2022, at https://www.energy.gov/eere/buildings/building-america.

[3] ENERGY STAR. 2022. News Room. Available online at http://www.energystar.gov/

[4] U.S. Census Bureau. 2021. Characteristics of New Single-Family Houses Sold – Financing. Accessed June, 2022 at https://www.census.gov/construction/chars/sold.html

This methodology for calculating the mortgage interest rate used in the analysis weights the 5-year average mortgage rate at 80% while the 1-year mortgage rate is weighted at 20%. This weighted mortgage rate reflects the historic mortgage interest rates going back 5 years to help predict the mortgage rate for the cost-effectiveness analysis.

For January of 2024, Freddie Mac reports that conventional 30- year real estate loans have averaged about 5% since the beginning of 2009[1] (though historical rates have been higher. The Federal Housing Finance Agency reports similar rates).[2] The current mortgage interest rate according to Freddie Mac is 6.69% but has seen a peak of 7.79% due to the Federal Reserve's efforts to curb inflation. The one-year average mortgage interest rate according to Freddie Mac is 6.84% while the five-year average mortgage rate is 4.59%. Using equation 19, the weighted average rate is calculated to be 5.04%. DOE will therefore currently use a mortgage rate of 5%.

3.2.2.2 Loan Term (T)

For real estate loans, 30 years is by far the most common term and is the value DOE uses in its analyses. DOE bases the loan term on the latest available American Housing Survey. According to the Characteristics of Primary Mortgages in the 2021 American Housing Survey (U.S. Census), approximately 72% of all home loans have a term between 28 and 32 years, with 30 being the median.

3.2.2.3 Down Payment (R_{DP})

DOE bases the down payment on the latest available data from the American Housing Survey, National Association of Realtors or research from Zillow or other websites. The 2021 American Housing Survey reports a wide range of down payment amounts for loans for new homes (see Table 5).[3] According to the National Association of Realtors, the median down payment on a home for all home buyers is 13% while for buyers aged 23 to 41, the rate drops to 8-10%[4]. First time home buyers prefer a smaller downpayment and the average rate varies by age group.

DOE assumes a down payment of 10%. Among the possible rates, this is probably most representative of first-time home buyers who have little significant equity to bring forward from a previous home. It is among the more common ranges for down payments (13.0% of all mortgages have down payments in the 6-10% range). American Family Insurance survey results state that the average down payment on a new home is 5%.[5]

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[1] Freddie Mac. 2022. 30-Year Fixed-Rate Mortgages Since 1971. Accessed January, 2024, at http://www.freddiemac.com/pmms/pmms30.htm.

[2] Federal Housing Finance Agency. Periodic Summary Table. Accessed January, 2024, at http://www.fhfa.gov/Default.aspx?Page=252.

[3] 2021 American Housing Survey. 2021. Accessed February, 2024 at https://www.census.gov/programs-surveys/ahs.html

[4] https://themortgagereports.com/60543/average-down-payment-on-a-house-and-low-down-payment-benefits

[5] https://www.amfam.com/resources/articles/money-matters/how-much-to-save-for-house

Table 5. Down Payment - 2021 American Housing Survey

Percent of Purchase Price	Percentage of Homes (%)
No down payment	12.2
1-3 percent	4.1
3-5 percent	11.1
6-10 percent	13.0
11-15 percent	5.1
16-20 percent	14.4
21-40 percent	9.3
41-99 percent	4.7
Bought outright	5.9
Not reported	20.2

3.2.2.4 Points and Loan Fees (R_{MF})

Points represent an up-front payment to buy down the mortgage interest rate and are tax deductible. DOE assumes all interest is accounted for by the mortgage rate and so points are taken to be zero. The loan fee is likewise paid up-front in addition to the down payment and varies from loan to loan. DOE bases the loan fees on the latest available market data from Freddie Mac. DOE assumes the loan fee to be 0.9% of the mortgage amount, based on recent data from Freddie Mac Weekly Primary Mortgage Market Survey.[1]

3.2.3 Discount Rate (R_d)

The purpose of the discount rate is to reflect the time value of money. Because DOE's economic perspective is that of a homeowner, that time value is determined primarily by the owner's best alternative investment at similar risk to the energy features being considered—in this case a typical homeowner who holds a home throughout a 30-year mortgage term. DOE sets the discount rate equal to the mortgage interest rate in nominal terms. Because mortgage prepayment is an investment available to consumers who purchase homes using financing, the mortgage interest rate is a reasonable estimate of a consumer's alternative investment rate.

3.2.4 Period of Analysis (P)

DOE's economic analysis is intended to examine the costs and benefits impacting all the consumers who live in the house. Energy efficiency features generally last longer than the average length of home ownership, so a longer analysis period is used. Assuming a single owner keeps the house throughout the analysis period accounts for long-term energy benefits without requiring complex accounting for resale values at home turnover.

DOE uses a 30-year period of analysis to capture long-term energy savings, and to match the typical mortgage term. Although 30 years is less than the overall life of the home, some efficiency measures, equipment in particular, require replacement during that period. It will be assumed that replacements are of equivalent efficiency and cost. The impact of the selection of

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[1] Freddie Mac. 2024. Weekly Primary Mortgage Market Survey® (PMMS®). Accessed January 2024 at http://www.freddiemac.com/pmms/.

any particular analysis term is ameliorated by the effect of the discount rate in aligning future costs and benefits with present values.

3.2.5 Property Tax Rate (R_{PT})

Property taxes vary widely within and among states. DOE bases the national property tax rate on the median property tax reported by the latest American Housing Survey. DOE bases the national property tax rate on the median property tax reported by the latest American Housing Survey. The median property tax reported by the 2021 American Housing Survey (U.S. Census Bureau 2019) for all homes is $3,000 for $350,000 in home value. Therefore, for purposes of code analysis, DOE assumes a property tax rate of 0.86%. For state-level analyses, state-specific rates will be used, as appropriate.

3.2.6 Income Tax Rate (R_{IT})

The marginal income tax rate paid by the homeowner determines the value of the mortgage tax deduction. DOE bases the income tax rate from the income characteristics of a median household income level by the latest American Housing Survey. The 2021 American Housing Survey on “income characteristics” reports a median household income of $62,000 (U.S. Census Bureau 2020). The Internal Revenue Service Statistics of Income Tax Stats, Table 1 for 2021 (latest year available) reported that most taxpayers in this income bracket itemize deductions (e.g., over 90% in this bracket took a deduction for cash contributions).[1] DOE accounts for income tax deductions for mortgage interest. A family earning $62,000 in 2024, with a married-filing-jointly filing status, would have a marginal tax rate of 22%,[2] which is DOE’s current assumption. Where state income taxes apply, rates will be taken from state sources or collections of state data, such as provided by the Federation of Tax Administrators.[3]

3.2.7 Inflation Rate (R_{INF})

The inflation rate R_{INF} is necessary only to give proper scale to the mortgage payments so that interest fractions can be estimated for tax deduction purposes. It does not affect the present values of cash flows, because all other rates are expressed in nominal terms (i.e., are already adjusted to match the inflation rate). The assumed inflation rate must be chosen to match the assumed mortgage interest rate (i.e., be estimated from a comparable time period). DOE bases the inflation rate on the latest available data from the Office of Management and Budget (OMB). Estimates of the annual inflation rate are derived from the 30-year nominal and real discount rates for cost-effectiveness, lease purchase and related analysis from the OMB.[4]

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. The estimate of the annual inflation rate is derived from the 30-year nominal discount rate and the 30-year discount rate

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[1] Internal Revenue Service. 2022. Tax Statistics - Produced by the Statistics of Income Division and Other Areas of the Internal Revenue Service. Accessed January, 2024 at https://www.irs.gov/statistics/soi-tax-stats-individual-income-tax-returns-complete-report-publication-1304-basic-tables-part-2

[2] Internal Revenue Service. 2024. Tax Bracket Marginal Rates - https://www.irs.gov/newsroom/irs-provides-tax-inflation-adjustments-for-tax-year-2023

[3] Federation of Tax Administrators. Accessed January, 2024, at www.taxadmin.org.

[4] Office of Management and Budget Memorandum – 2023 Discount Rates for OMB Circular No. A-94. Accessed February, 2024, at www.whitehouse.gov/wp-content/uploads/2023/02/M-23-12-Appendix-C-Update_Discount-Rates.pdf

from the OMB. The difference between the nominal discount rate and the real discount rate is the interest rate. The 30-year nominal discount rate is reported at 4.2% while the 30-year real discount rate is reported at 2.0%. The difference is calculated as 2.2% which will be used by DOE as the inflation rate.

3.2.8 Residual Value (*RV*)

The residual value of energy features is the value assumed to be returned to the home buyer upon sale of the home (after 30 years). As previously shown, it is calculated assuming straight-line depreciation of each measure's value against the useful life of that measure.

3.2.9 Home Price Escalation Rate (E_H)

DOE assumes that home prices have a real escalation rate of 0%. That is, the rate of home value appreciation is assumed to equal the general rate of inflation. While many homes do experience non-zero increases in value over time, the factors that influence future home prices (location, style, availability of land, etc.) are too varied and situation-specific to warrant direct accounting in this methodology.

3.2.10 Resale Value Fraction (R_R)

DOE will assume that energy efficiency measures have a residual value calculated from strait-line depreciation based on an assumed useful life. Most measures are assumed to last for the life of the home, which is assumed to be 60 years. Measures that need replacement at some point during the 30-year analysis period will have a residual value based on the remaining life per Equation 17.

3.2.11 Fuel Prices

Fuel prices are needed to determine the energy cost savings from improved energy efficiency. Both current fuel prices and fuel price escalation rates are needed to establish estimated fuel prices in future years.

DOE will use the most recently available national average residential fuel prices from the DOE Energy Information Administration. If fuel prices from the most recent year(s) are deemed unusually high or low, DOE may consider using a longer-term average of past fuel prices. However, reported fuel price escalation rates (see below) may be tied to specific recent-year prices, so departures from the recent-year prices will be approached with caution. For space heating, winter prices will be used. Fuel price escalation rates will be obtained from the most recent Annual Energy Outlook to account for projected changes in energy prices.

Table 6 summarizes the values discussed above. These values are current as of this publication date. DOE will update these values as needed over time.

Table 6. Summary of Current Economic Parameter Estimates

Parameter	Symbol	Current Estimate
Mortgage Interest Rate	I	5%
Loan Term	M_L	30 years
Down Payment Rate	R_D	10% of home price
Points and Loan Fees	R_M	0.9% (non-deductible)
Discount Rate	D	5% (equal to Mortgage Interest Rate)
Period of Analysis	L	30 years
Property Tax Rate	R_P	0.86% of home price/value
Income Tax Rate	R_I	22% federal, state values vary
Home Price Escalation Rate	E_H	Equal to Inflation Rate
Inflation Rate	R_{INF}	2.2% annual
Fuel Prices and Escalation Rates	Latest national average prices based on current Energy Information Administration data and projections[1]; price escalation rates taken from latest Annual Energy Outlook.	

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[1] Department of Energy. 2024a. Electric Power Monthly. DOE/EIA-0226, Washington, D.C.
Department of Energy. 2024b. Natural Gas Monthly. DOE/EIA-0130, Washington, D.C.

4.0 Aggregating Energy and Economic Results

DOE will report its energy and cost analysis results at different levels:

1. **National**—When assessing the overall impact of new codes, DOE will report results aggregated to a national average and national average by climate zone. At this level, only energy savings (site and source), energy cost savings and emissions savings are reported.
2. **State**—Energy and cost-effectiveness assessments of a new code are often needed by states considering adoption of the code. For such purposes, DOE will report energy savings and cost-effectiveness results aggregated to the individual state level and by climate zone within each state. At this level, DOE will report all major analysis results, including energy savings, net LCC, annual cash flows, simple payback periods, emissions and jobs created.
3. **Climate Zone**—DOE will aggregate its energy and economic analysis results to the climate zone level. The IECC's requirements vary by climate zone, so this is the natural aggregation for evaluation of proposed changes. At this level, DOE will report energy savings, net LCCs, and annual cash flows.
4. **City**—DOE will aggregate its energy and economic analysis results to the city level. At this level, DOE will report energy savings, net LCCs, simple payback periods and annual cash flows considering local construction costs and energy prices. On request by the city, emissions and jobs created can be reported.

Aggregating to national, state, city and climate zone levels involves a weighted averaging of results across several variables, including building type, foundation type, heating system/fuel type, and housing starts by climate location. Unless otherwise noted, the weighted averaging scheme assumes that those variables are independent, which means the weighting factors can be applied in arbitrary order. However, to facilitate reporting at the levels above, the weighting scheme is applied to climate location last. That is, energy simulation results (or computed LCCs) for a given location are first averaged across the foundation type, system type, and building type variables, then the weighted location-specific results are aggregated to the desired geographical regions. Because location weights are based on housing starts (permits) and those data differ between single-family and multifamily, the building-type weighting occurs after the foundation and system type weightings.

4.1 Aggregation across Foundation Types

Residential buildings typically have one of three foundation types: basement, crawlspace, or slab-on-grade. The 2020 Census data indicates that 65% of new single-family homes have slab-on-grade, 22% have a basement, and 12% have a crawlspace. The number of homes with slab-on-grade construction has grown from 52% in 2010 to 65% in 2020. For DOE's analyses, basements are divided into two categories: heated and unheated. According to the Residential Energy Consumption Survey (RECS) 2020 data, 59% of basements are heated while 41% are unheated. Therefore, four foundation configurations are examined:

1. Crawlspace
2. Slab-on-grade
3. Heated basement
4. Unheated basement

Data from the 2020 RECS will be used to establish foundation shares. The RECS database provides data for 4 divisions and 10 regions, with each region consisting of either a single state or a combination of a few states. The advantage of the RECS database is that it provides data for 27 regions, with each region consisting of either a single state or a combination of a few states. The disadvantage of RECS is that it covers existing housing of all vintages, including both older and newer buildings. However, the RECS data suggest the type of foundation used by region has been relatively stable over time. For the foundation shares used in the cost-effectiveness analysis, data from 2010 to 2019 will be used. If statistically valid state data on foundation shares from DOE field studies is available, field study data will be used to determine foundation shares.

Table 7 shows the assumptions about foundation type used in the aggregation of results. These percentages will be used for both single-family and multifamily.

Table 7. Foundation Type Shares (percent) by State

State	Slab	Heated Basement	Unheated Basement	Crawlspace
Connecticut, Rhode Island, Vermont, New Hampshire, Maine	5.8	14.7	79.5	0.0
Massachusetts	11.4	45.1	43.5	0.0
New York	15.4	46.0	38.6	0.0
New Jersey	34.8	44.9	9.2	11.1
Pennsylvania	18.9	47.0	29.6	4.5
Illinois	0.0	74.6	25.4	0.0
Ohio and Indiana	21.5	37.1	33.5	7.9
Michigan	19.7	40.9	39.4	0.0
Wisconsin	9.4	72.1	18.4	0.0
Minnesota, Iowa, North Dakota, South Dakota	33.7	39.3	18.4	8.7
Kansas and Nebraska	23.5	56.0	9.8	10.7
Missouri	25.4	38.9	22.9	12.7
Virginia	10.9	35.1	15.0	39.0
Maryland, Delaware, and West Virginia	24.4	47.6	13.1	14.8
Georgia	73.7	4.5	8.0	13.8
North Carolina and South Carolina	61.1	3.7	4.4	30.8
Florida	95.9	0.0	0.0	4.1
Alabama, Mississippi, Kentucky	71.1	10.4	2.6	15.9
Tennessee	40.0	7.9	0.0	52.0
Arkansas, Louisiana, and Oklahoma	91.8	2.2	0.0	6.1
Texas	98.1	0.0	1.1	0.8
Colorado	29.7	16.5	25.6	28.3
Utah, Wyoming, Montana, Idaho	30.6	25.1	8.1	36.2
Arizona	95.6	0.0	0.0	4.4
Nevada and New Mexico	90.9	2.9	3.6	2.7
California	82.5	5.9	0.0	11.6
Washington, Oregon, Alaska, Hawaii	20.8	2.9	0.6	75.7

4.2 Aggregation across Heating Equipment and Fuel Types

Residential buildings have a variety of different of space heating equipment types. According to U.S. Census data for new construction in 2021, the most common types of heating fuels in homes are natural gas (including liquefied petroleum gas) with a 48% share, electricity with a 52% share, and oil with less than 1% share (Census Characteristics of New Housing).[1] Heating system types are 54% warm-air furnace, 40% heat pump, 2% hot water or steam and 3% other. 87% of the heat pumps are electric, 13% are gas.

Four combinations of HVAC equipment and fuel are examined:

1. Natural gas with a forced air furnace
2. Fuel oil with a forced air furnace
3. Electric resistance with a forced air furnace
4. Electric heat pump with forced air distribution

Central electric air conditioning is assumed for all geographic locations and all four heating types. According to Census data, 96% of single-family homes and 96% of new multifamily units built in 2021 had central air conditioning installed.[2]

Heating system shares used in DOE's analyses are taken from the U.S. Census Survey of Construction (SOC) latest 5 years of data. The SOC data provides data by 10 census divisions. The percent shares by heating type for new construction in each of the 10 regions from the SOC data are shown in Table 8 and 9. If statistically valid state data on heating system shares from DOE field studies is available, field study data will be used to determine the heating system shares.

Table 8. Heating System Shares by Census Division, Single Family (percent)

Census Division	Electric Heating	Gas Heating	Heat Pump	Oil Heating
East North Central	4.1	88.6	7.3	0.01
East South Central	9	19.2	71.8	0.02
Middle Atlantic	3.2	87.1	8.7	1.02
Mountain North	3.2	83.9	12.9	0.09
Mountain South	3.2	83.9	12.9	0.09
New England	1.3	87.4	9	2.32
Pacific	5.7	79	15.2	0.07
South Atlantic	4.1	21.5	74.3	0.01
West North Central	11.9	76	12.1	0.00
West South Central	19.8	52.1	28.1	0.01

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[1] United States Census Bureau. Characteristics of New Single-Family Houses Completed. Accessed February, 2024 at http://www.census.gov/construction/chars/completed.html.

[2] United States Census Bureau. Characteristics of Units in New Multifamily Buildings Completed. Accessed February, 2024 at http://www.census.gov/construction/chars/mfu.html.

Table 9. Heating System Shares by Census Division, Multifamily (percent)

Census Division	Electric Heating	Gas Heating	Heat Pump	Oil Heating
East North Central	4.1	88.6	7.3	0.01
East South Central	9	19.2	71.8	0.02
Middle Atlantic	3.2	87.1	8.7	1.02
Mountain North	3.2	83.9	12.9	0.09
Mountain South	3.2	83.9	12.9	0.09
New England	1.3	87.4	9	2.32
Pacific	5.7	79	15.2	0.07
South Atlantic	4.1	21.5	74.3	0.01
West North Central	11.9	76	12.1	0.00
West South Central	19.8	52.1	28.1	0.01

4.3 Aggregation across Building Type (Single-family and Multifamily) and Climate Zone

To facilitate climate-specific energy estimates, DOE will be using a number of weather locations that give reasonable climate coverage at both the climate-zone and state level. One weather location per climate zone in each state is used, including all unique combinations of the zone (temperature-oriented zone designation in the IECC), moisture regime (moist, dry, marine), and warm-humid designation (equivalent to ASHRAE’s definition of warm-humid climates). This results in 129 weather locations to be used in the DOE state level analyses.

Census building permit data at the county level for 2020[1] will be used to estimate single-family and multifamily shares and to give appropriate weight to each climate location within a state and/or larger code zone.

4.3.1 Estimate of Low-Rise Multifamily Construction

The IECC’s residential provisions limit multifamily buildings to structures that are three stories or less above grade. High-rise multifamily buildings are considered commercial buildings within the IECC and are not considered in this analysis. As building permit data do not differentiate high-rise from low- rise, 2020 Census data (Characteristics of New Housing[2]), will be used to estimate the number of housing units in structures with three stories or less. These data indicate that recent construction trends have favored high-rise multifamily buildings. In the late 1990s, less than 10% of new multifamily dwelling units were in buildings of four or more stories. During the 2000s, high rise multifamily construction grew from 14% to almost 50%. In new buildings in 2021, 61% of multifamily units were in buildings of four or more stories. Therefore, a 5-year average of the Census data (2017-2021) was used to estimate the proportion of multifamily units that are in low-rise buildings. Table 10 shows the percentage of building permits that are

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[1] United States Census Bureau. Building Permits. Accessed February, 2024, at https://www2.census.gov/econ/bps/County/

[2] United States Census Bureau. Characteristics of Units in New Multifamily Buildings Completed. Accessed February, 2024, at http://www.census.gov/construction/chars/mfu.html.

assumed to fall under the scope of residential buildings in the IECC. These estimates are assumed to hold for each state in the specified region.

Table 10. Proportion of Multifamily Dwelling Units with Three or Fewer Stories

Census Region	Percentage of multifamily dwelling units that are three stories or less
Northeast	24.1
Midwest	47.3
South	45.3
West	40.2

4.3.2 State-Level Aggregations

Forty-one of the 50 U.S. states contain more than one IECC climate zone within their borders. To determine average impacts of the IECC within each state, the share of residential construction permits within each climate zone must be identified for states containing more than one climate zone. 2020 Census building permit data at the county level for 2020 will be used to determine these shares at the state level.[1] County level permit data is rolled up to the state level based on the shares within each climate zone.

4.3.3 Representative Weather Locations

Table 11 shows the single-family and multifamily building permit data by climate zone for each state, along with the weather location used to represent the associated climate zone. The EnergyPlus building energy simulations are run using the latest Typical Meteorological Year weather files (TMY3).[2] There are 1,020 locations nationwide with TMY3 weather data, including Guam, Puerto Rico, and the U.S. Virgin Islands. Nonetheless, there are a few state/zone combinations that do not contain a TMY3 weather file. In these cases, a best representative TMY3 data location outside the state is chosen.

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[1] United States Census Bureau. Building Permits. Accessed February, 2024, at https://www2.census.gov/econ/bps/County/

[2] National Solar Radiation Data Base. 1991-2005 Update: Typical Meteorological Year 3. Accessed January, 2024, at http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/.

Table 11. Housing Permits and Weather Data by Climate Zone in Each State

State	Climate Zone[1]	TMY3 Location	Single-Family Permits	Multifamily Permits
Alabama	2A	Mobile	3,268	315
Alabama	3A	Montgomery	7,722	1,008
Alabama	3A,WH	Birmingham	1,134	140
Alaska	5C	Ketchikan	51	3
Alaska	6A	Juneau	99	20
Alaska	7	Anchorage	868	88
Alaska	8	Fairbanks	54	4
Arizona	2B	Phoenix	22,015	3,506
Arizona	3B	Kingman	1,340	24
Arizona	4B	Prescott	1,253	92
Arizona	5B	Flagstaff	722	98
Arkansas	3A	Little Rock	3,735	755
Arkansas	3A,WH	Shreveport	74	20
Arkansas	4A	Springfield	3,199	458
California	2B	Tucson	237	38
California	3B	Los Angeles	37,154	10,915
California	3C	San Francisco	7,302	5,103
California	4B	Sacramento	827	15
California	4C	Arcata	205	41
California	5B	Reno	376	14
California	6B	Eagle	48	3
Colorado	4B	Trinidad	42	2
Colorado	5B	Colorado Springs	17,485	4,815
Colorado	6B	Eagle	649	65
Colorado	7	Gunnison	890	91
Delaware	4A	Wilmington	4,608	334
District of Columbia	4A	Baltimore	314	1,801
Florida	1A	Miami	2709	538
Florida	2A	Tampa	4608	334
Georgia	2A	Savannah	4,557	435
Georgia	3A	Atlanta	26,069	4,450
Georgia	3A,WH	Albany	1,664	154
Hawaii	1A,WH,T	Honolulu	1,139	569
Hawaii	1A,WH,SC	Honolulu	1,139	0
Idaho	5B	Boise	6,842	852
Idaho	6B	Pocatello	2,039	185
Illinois	4A	St Louis	1,684	230
Illinois	5A	Peoria	8,176	3,775

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[1] The suffixes A, B, and C represent moisture regimes moist, dry, and marine, respectively. “WH” indicates the zone/regime is a warm humid location. “T” indicates the location is in the Tropical zone. “SC” indicates the location is in the Tropical zone and applies to special provisions for homes that are semi-conditioned and meet other special conditions required for the 2021 IECC’s alternative Tropical zone requirements.

State	Climate Zone[1]	TMY3 Location	Single-Family Permits	Multifamily Permits
Indiana	4A	Evansville	5,770	1,009
Indiana	5A	Indianapolis	8,682	1,305
Iowa	5A	Des Moines	7,208	1,513
Iowa	6A	Mason City	448	59
Kansas	4A	Topeka	5,535	1,131
Kansas	5A	Goodland	25	10
Kentucky	4A	Lexington	7,367	1,633
Louisiana	2A	Baton Rouge	11,135	597
Louisiana	3A	Monroe	2,055	135
Louisiana	3A,WH	Shreveport	23	2
Maine	6A	Portland	3,400	168
Maine	7	Caribou	69	2
Maryland	4A	Baltimore	10,651	2,448
Maryland	5A	Harrisburg	154	8
Massachusetts	5A	Boston	6,919	1,790
Michigan	5A	Lansing	10,666	1,535
Michigan	6A	Alpena	2,051	133
Michigan	7	Sault Ste Marie	107	8
Minnesota	5A	Winona	154	18
Minnesota	6A	Minneapolis	9,697	3,825
Minnesota	7	Duluth	1,613	200
Mississippi	2A	Mobile	154	18
Mississippi	3A	Jackson	9697	3825
Mississippi	3A,WH	Tupelo	1613	200
Missouri	3A	Memphis	22	2
Missouri	4A	St	10,212	2,520
Missouri	5A	Kirksville	197	15
Montana	6B	Helena	2,708	616
Nebraska	5B	Omaha	5,055	1,255
Nevada	3B	Las	7,780	1,228
Nevada	4B	Tonopah	440	28
Nevada	5B	Winnemucca	1,896	575
New Hampshire	5A	Manchester	1,730	193
New Hampshire	6A	Concord	821	50
New Jersey	4A	Newark	8,054	2,678
New Jersey	5A	Allentown	2,797	942
New Mexico	3B	Lubbock	1,396	104
New Mexico	4B	Albuquerque	1,589	180
New Mexico	5B	Flagstaff	1,390	95
New York	4A	New York City	2,727	4,792
New York	5A	Albany	6,610	1,264
New York	6A	Binghamton	1,976	151
North Carolina	3A	Wilmington	34,122	6,374

State	Climate Zone[1]	TMY3 Location	Single-Family Permits	Multifamily Permits
North Carolina	3A,WH	Charlotte	5,660	597
North Carolina	4A	Raleigh-Durham	3,035	403
North Carolina	5A	Elkins WV	598	66
North Dakota	6A	Bismarck	2,297	943
North Dakota	7	Minot	445	251
Ohio	4A	Cincinnati	5,167	2,321
Ohio	5A	Columbus	9,362	905
Oklahoma	3A	Oklahoma	9,617	773
Oklahoma	4B	Ponca	5	0
Oklahoma	4A	Amarillo	318	23
Oregon	4C	Portland	7,385	2,394
Oregon	5	Redmond	1,967	159
Pennsylvania	4A	Philadelphia	8,602	1,344
Pennsylvania	5A	Harrisburg	7,943	457
Rhode Island	5A	Providence	7,385	2,394
South Carolina	2A,WH	Beaufort	1,592	116
South Carolina	3A	Columbia	15,246	1,134
South Carolina	3A,WH	Charleston	8,299	986
South Dakota	5A	Sioux City	299	48
South Dakota	6A	Pierre	2,843	883
Tennessee	3A	Memphis	11,440	3,168
Tennessee	4A	Nashville	11,132	1,253
Texas	1A,WH	Brownsville	4,743	480
Texas	2B	Houston	1,246	177
Texas	2A,WH	Laredo	79,241	21,537
Texas	3B	Wichita	6,258	1,012
Texas	3A	El	860	131
Texas	3A,WH	Fort	17,376	2,870
Texas	4B	Amarillo	745	112
Utah	3B	Saint	1,810	117
Utah	5B	Salt	11,266	2,403
Utah	6B	Vernal	996	102
Vermont	6A	Burlington	1,110	148
Virginia	3A	Norfolk	3,218	846
Virginia	4A	Richmond	17,129	3,566
Virginia	5A	Elkins	40	0
Washington	4C	Seattle	13,555	5,893
Washington	5B	Spokane	5,211	768
Washington	5C	Quillayute	1,428	108
Washington	6B	Kalispell	213	1
West Virginia	4A	Charleston	1,885	137
West Virginia	5A	Elkins	409	110
Wisconsin	6A	Madison	6,116	2,131

State	Climate Zone[1]	TMY3 Location	Single-Family Permits	Multifamily Permits
Wisconsin	7	Duluth	4,637	590
Wyoming	5B	Scottsbluff	378	61
Wyoming	6B	Cheyenne	1,055	103
Wyoming	7	Jackson Hole	298	13

4.3.4 Representative Weather Locations for Abbreviated Analyses

When conducting analyses at the national level (i.e., not requiring state-level aggregations of results) or when conducting exploratory or iterative analyses, DOE may use an abbreviated set of climate locations. The abbreviated set, designed to cover all climate zones, moisture regimes, and other climate designations by which requirements vary in the IECC, includes 19 distinct locations,[1] as shown in Table 12. Permits data used for aggregation weights are developed by summing the weights from Table for all locations in the same climate zone/regime. Analyses at the local and climate zone level will use the nearest representative city within the state.

Table 12. Housing Permits and Weather Data by Climate Zone in Abbreviated Climate Locations

Climate Zone[2]	TMY3 Location	Single-Family Permits	Multifamily Permits
1A	Miami	11,004	5,115
1A,T	Honolulu	1,139	569
1A,SC	Honolulu	1,139	0
2A	Tampa	170,630	34,516
2B	Tucson	23,498	3,722
3A	Atlanta	116,918	18,946
3A, WH	Montgomery	55,736	13,399
3B	El Paso	7,302	5,103
3C	San Diego	35,249	4,858
4A	New York	107,389	28,080
4B	Albuquerque	4,902	429
4C	Seattle	21,146	8,329
5A	Buffalo	86,791	17,915
5B	Denver	47,533	9,840
5C	Port Angeles	1,479	110
6A	Rochester	29,379	6,970
6B	Great Falls	7,709	1,075
7	International Falls	4,291	653
8	Fairbanks	54	4

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[1] There are actually 18 locations with Honolulu being used twice, once each for normal and semi-conditioned homes in the Tropical climate zone.

[2] The suffixes A, B, and C represent moisture regimes moist, dry, and marine, respectively. “WH” indicates the zone/regime is a warm humid location. “T” indicates the location is in the Tropical zone. “SC” indicates the location is in the Tropical zone and applies to special provisions for homes that are semi-conditioned and meet other special conditions required for the 2021 IECC’s alternative Tropical zone requirements.

5.0 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.

6.0 References

Banwell, et al. 2022. *Cracking the Code to EV Readiness in New Buildings*. 2022 ACEEE Summer Study Proceedings.

Gagnon P, B Cowiestoll, and M Schwarz. 2023. Cambium 2022 *Scenario Descriptions and Documentation*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-84916. https://www.nrel.gov/docs/fy23osti/84916.pdf

IWG - Interagency Working Group on Social Cost of Carbon. 2021. *Social Cost of Carbon, Methane, and Nitrous Oxide. Interim Estimates under Executive Order 13990*. United States Government. Available at https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

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. [1] 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.[2]

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, REScheck 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 residential energy index represents the ratio between the whole-building site energy intensity (kBtu/ft2-yr) based on a weighted statewide average of the state code and that of the 2006 IECC 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 building specific results across building, foundation, and system types across climate zones using state specific weighting factors based on new housing permits, as described in Section 4.0 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 residential 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 ost recent model energy codes, as applied in the state.

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

[2] 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-dwelling unit intensities (kBtu/unit-yr), which are aggregated across building types, foundation types, system types, and climate zones using weighting factors based on new-housing permits. The energy index represents the ratio between the site energy intensity of a state energy code and that of the 2006 IECC. As defined, the energy indices for the 2006 IECC (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 the 2006 IECC. The energy index of the state adopted code is compared to the baseline (2006 IECC) 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 the 2021 IECC is 36.7, the state adopted code is deemed equivalent to the 2021 IECC.

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 the 2018 IECC with only strengthening amendments could possibly be characterized as equivalent to the 2021 IECC. 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 code with an air leakage requirement of seven air changes per hour and field studies show new homes typically performing at four air changes per hour, the analysis will use seven air changes per hour 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. There are also instances where state codes remove the envelope and duct leakage testing requirements that have been included in the model energy code since 2012. In these instances, a prescribed envelope or duct leakage rate cannot be verified, and DOE assumes leakage rates consistent with the 2009 IECC, as detailed here:

- Envelope Leakage Assumption: the latest editions of model energy codes require that a blower door test is conducted on every home and a prescribed leakage rate is achieved. For states that require a blower door test and specify a prescriptive air leakage rate (e.g., 3 ACH50), DOE sets the leakage rate to that prescriptive number. However, when a state does not require a blower door test, even if a leakage rate is specified, DOE assumes a leakage rate of 7 ACH50, consistent with 2009 IECC levels.

- Duct Leakage Assumption: Similar to envelope leakage, later editions of the model energy codes require a duct pressure test be conducted and a prescribed duct leakage rate be achieved. For states that do not require a duct blaster test, DOE assumes a leakage rate of 12 cfm/100 sq. ft., consistent with 2009 IECC levels.

Where a state adopts code provisions that are not currently considered in the prototype buildings (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[1] 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[2] 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 4 shows the residential state code adoption map.

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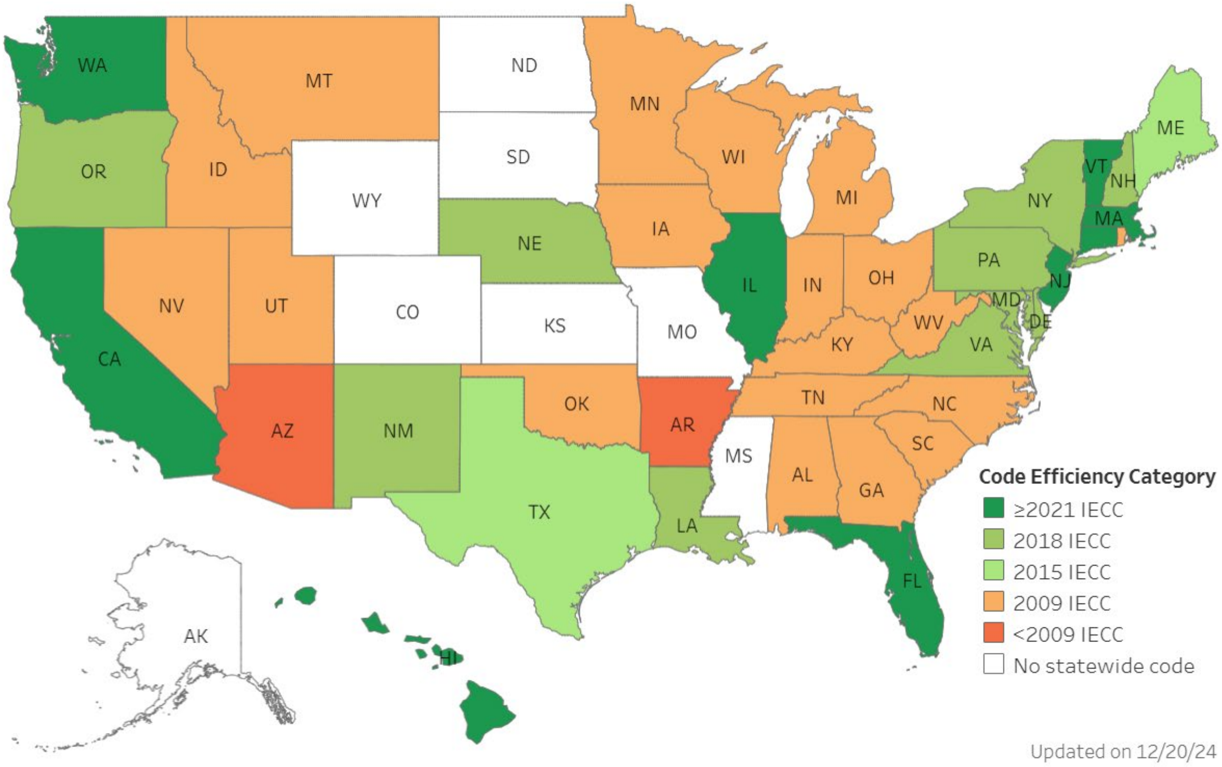
[1] https://www.energycodes.gov/state-portal

[2] https://www.energycodes.gov/infographics



Updated on 12/20/24

Figure 4 - Residential 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 residential building code regarding energy efficiency, and as necessary, update their codes to meet or exceed the updated edition.

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 published in 89 FR 16820[1]. 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 7 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.

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[1] 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 emissions 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 emissions monetization metrics currently adopted by ASHRAE 90.1 is shown in Table 8.

Table B.2 Example Calculation of Monetized Emissions

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

	PV Savings excluding benefits	PV Savings including 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 residential 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 societal benefit of 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 9 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:

- Dollars returned to the economy through reduction in utility bills and resulting increase in disposable income, and;
- 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 energy codes are typically shown to be 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[1] 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 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 which 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)[2] and EPA Coalitional Benefits Risk Assessment (COBRA)[3] 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 conditions. The metrics, which might 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.[4]

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[1] IMPLAN is a software tool used to perform economic impact analysis. More detailed information can be found here: https://implan.com/

[2] https://www.epa.gov/avert

[3] https://cobra.epa.gov

[4] https://www.energycodes.gov/energy-resilience

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 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 homes be equipped with the underlying infrastructure (e.g., conduit, panel capacity, roof orientation and available space, etc.) to enable future homeowners to have the option to fully install these technologies at a much lower cost than retrofitting the home after its built. For example, installing electric vehicle readiness infrastructure during construction could reduce costs to a homeowners 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 do 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 10 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[1]	$1,067	$4,304
Solar Readiness[2]	$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 as life cycle cost analysis year-0 dollars.

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[1] https://www.energycodes.gov/sites/default/files/2021-07/TechBrief_EV_Charging_July2021.pdf

[2] www.nrel.gov/docs/fy12osti/51296.pdf

B.6.1 Calculating new construction costs

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

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