ComStock Measure Scenario Documentation: Upgrade Envelope to Current State Code

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Acknowledgments

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List of Acronyms

ACEEE	American Council for an Energy-Efficient Economy
ANSI	American National Standards Institute
BCAP	Building Codes Assistance Project
BECP	Building Energy Codes Program
Btu	British thermal units
CEC	California Energy Commission
DEER	Database for Energy Efficient Resources
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EUL	effective useful life
IEAD	insulation entirely above deck
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
SHGC	solar heat gain coefficient
tBtu	trillion British thermal units
URDB	Utility Rate Database
VLT	visible light transmittance

Executive Summary

Building on the 3-year End-Use Load Profiles project to calibrate and validate the U.S. Department of Energy's ResStock™ and ComStock™ models, this work produces national datasets that enable cities, states, utilities, and other stakeholders to answer a broad range of questions regarding their commercial building stock.

ComStock is a highly granular, bottom-up model that uses various data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual subhourly energy consumption of the commercial building stock across the United States. The "baseline" model intends to represent the U.S. commercial building stock as it existed in 2018. The methodology of the baseline model is discussed in the ComStock Reference Documentation.

The goal of this work is to develop energy efficiency and demand flexibility measures that cover market-ready technologies and study their mass adoption impact on the baseline building stock, utility bill affordability, and grid reliability. "Measures" refers to various "what-if" scenarios that can be applied to buildings. The results for the baseline and measure scenario simulations are published in public datasets that provide insights into building stock characteristics, operational behaviors, utility bill impacts, and annual and subhourly energy usage by fuel type and end use.

This report describes the modeling methodology for a single ComStock measure scenario—Upgrade Envelope to Current State Code—and briefly introduces key results. The full public dataset can be accessed on the ComStock data lake or via the Data Viewer at comstock.nrel.gov. The public dataset enables users to create custom aggregations of results for their use case (e.g., filter to a specific county or building type).

Key modeling assumptions and technology details are summarized in Table ES-1..

Table ES-1. Summary of Key Modeling Specifications

Package Title	Upgrade Envelope to Current State Code
Technology Description	This measure upgrades the envelope (wall insulation, roof insulation, and windows) to the current code followed by the state where the building is located. Most states adopt residential and commercial building energy codes that align with International Energy Conservation Code (IECC) and/or ASHRAE 90.1 standards. These standards are updated every few years; however, states adopt them at different rates. Some states always adhere to the latest version, whereas other states adopt newer codes more slowly. Building energy codes set minimum standards for new construction and major renovations; however, existing buildings are not typically required to comply with the current code. This measure scenario explores the possible savings for existing commercial buildings that upgrade their envelope to comply with the latest IECC and/or ASHRAE 90.1 code adopted in their state. This measure was published in the ComStock 2025.2 Standard Data Release (August 2025); therefore, the "current code" adopted by each state reflects the data available at the time of the measure development. There are no current plans to regularly update this measure as states adopt newer codes.

Performance Assumptions	This measure assumes state-level code adoption. In reality, cities or local jurisdictions can adopt more stringent standards beyond the state requirement; therefore, by upgrading the envelope to the state-level code, this measure is generally conservative in its savings estimates, as some buildings in the state might be required to adhere to more aggressive targets. There are nine states in the United States that do not adopt building energy codes at the state level. For these cases, research was performed to determine which version of the ASHRAE 90.1 standard best represents the commercial buildings being built in that state. Often, this was based on the codes adopted by large cities and jurisdictions in the state; therefore, the current code assumed for modeling could be overestimating savings for some buildings in these states. For walls and roofs, each building's insulation is upgraded to the R-value defined in the current ASHRAE 90.1 code adopted by the state. For windows, each building is upgraded to the predefined window construction that most closely aligns (based on U-factor and solar heat gain coefficient) with the current ASHRAE 90.1 standard adopted by the state.
Applicability	This measure is applicable to all buildings in the stock where the current envelope does not already meet or exceed the current code adopted by the state where it is located. **100% stock floor area applicable**
Release	2025 Release 2: 2025/comstock_amy2018_release_2/

The national annual results for site energy and utility bills are summarized in Table ES-2. and Table ES-3..

Table ES-2. Summary of Key Results for Annual Site Energy Savings

"Applicable" buildings are those that receive the upgrade based on the criteria defined for this study.

Fuel Type	Percent Savings (All Buildings)	Percent Savings (Applicable Buildings Only)	Absolute Savings (TBtu)
Natural Gas	11.5%	11.5%	179.5
Electricity	5.8%	5.8%	187.4
Other Fuel*	18.9%	18.9%	10.3
Total	7.7%	7.7%	377.1

*Combination of fuel oil and propane annual site energy results

Table ES-3. Summary of Key Results for Annual Utility Bill Savings

Electricity bill savings in this table are calculated using the mean available electricity rate available for each building. Other electricity rate structures are available in this report and in the public dataset. "Applicable" buildings are those that receive the upgrade based on the criteria defined for this study.

End Use/Fuel Type	Percent Savings (All Buildings)	Percent Savings (Applicable Buildings Only)	Absolute Savings (Billion USD, 2022)
Natural Gas	10.6%	10.6%	1.9
Electricity	6.1%	6.1%	6.7
Fuel Oil	26.0%	26.0%	0.2
Propane	15.0%	15.0%	0.2
Total	6.9%	6.9%	8.9

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1 Introduction

Building energy codes play a crucial role in improving energy performance and reducing utility costs in buildings. The most widely adopted model energy codes are the International Energy Conservation Code (IECC) [1] and the ANSI/ASHRAE/IES Standard 90.1 [2] (for simplicity, referred to as "ASHRAE 90.1" throughout this document).[1] The IECC includes residential and some commercial building types, while ASHRAE 90.1 covers commercial and high-rise residential buildings. These codes and standards establish minimum requirements for energy efficiency for insulation, windows, heating and cooling systems, lighting, and more.

Building energy codes are intended for new construction buildings and major renovations. Existing buildings are not required to comply with the most current building energy code adopted by the state; however, this can leave a large portion of the commercial building stock lagging many code cycles in terms of performance. This is especially apparent with the building envelope (wall insulation, roof insulation, and windows) because these components of a building are not frequently replaced or upgraded.

In the United States, each state decides how to adopt and enforce building energy codes. Cities and local jurisdictions can also choose to adopt their own set of codes; however, at a minimum, they must adhere to the state-adopted code [3]. New IECC and ASHRAE 90.1 standards are released every 3 years. Many states choose to quickly adopt the most recent code version, whereas other states lag several code cycles behind. Nine states do not have any statewide commercial building energy codes: Alaska, Arizona, Colorado, Kansas, Mississippi, Missouri, North Dakota, South Dakota, and Wyoming [4]. States can be classified into four categories based on their historical rate of code adoption:

- Aggressive: The state adopts the new code within one code cycle. Future adoption lag = 1 year.
- Moderate: The state adopts the new code within two code cycles. Future adoption lag = 4 years.
- Slow: The state adopts the new code after two code cycles. Future adoption lag = 7 years.
- Not applicable: States with no statewide code [5].

Although most states and local jurisdictions officially adopt IECC codes as law, the IECC recognizes ASHRAE 90.1 as a pathway for compliance with the requirements of the IECC [6]. Furthermore, ASHRAE 90.1 has multiple compliance pathways, typically either prescriptive or performance based. This study considers only the prescriptive pathway, in which our buildings are modeled to comply with the established criteria for the energy-related characteristics of building components (in this case, wall insulation R-value, roof insulation R-value, and window U-value and solar heat gain coefficient [SHGC]) [7]. This measure will use ASHRAE 90.1 when referring to code adoption, as ComStock™ modeling assumptions are largely based around the ASHRAE 90.1 standard. The main exception is California, which follows Title 24, the California Building Energy Code. Title 24 relies on the Database for Energy Efficient Resources (DEER) to

[1] ANSI: American National Standards Institute; IES: Illuminating Engineering Society

set the minimum energy efficiency standards for new buildings [8], [9]; therefore, for California, this measure uses DEER assumptions for California buildings.

The U.S. Department of Energy (DOE) Building Energy Codes Program (BECP) tracks code adoption by state and provides other resources and analysis related to building energy code adoption in the United States [4]. Figure 1 shows the commercial code adoption by state as of December 2024 [4]. The ASHRAE 90.1 standard is used as the basis for assigning a current code efficiency category for each state. California, which uses the DEER standard, is categorized as "greater than or equal to 90.1-2019" for this figure.

In addition, Arizona, despite not having a statewide code, is categorized along with Oklahoma as adhering to a code lower than 90.1-2007. The BECP found that more than 80% of Arizona's population is covered by codes at this level. A similar review of all other states without statewide energy codes will be conducted in subsequent sections to assign the most appropriate/widely followed ASHRAE 90.1 code to these states.

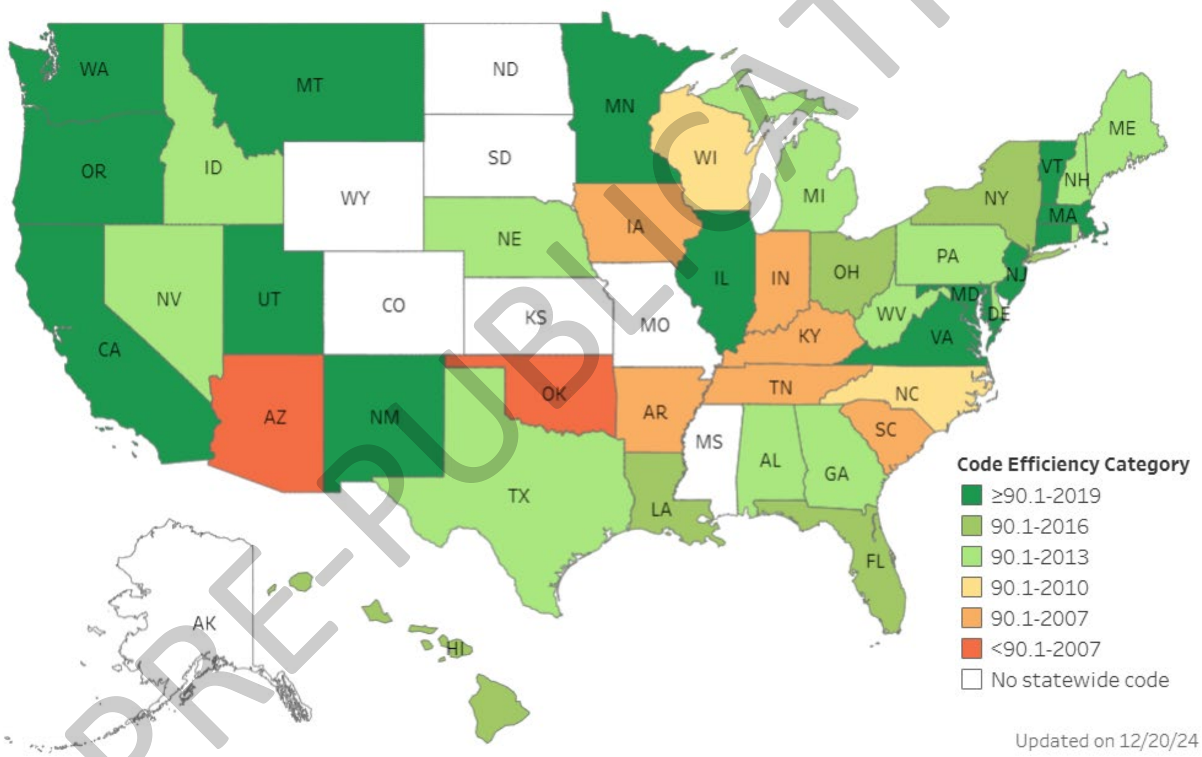

Figure 1. Commercial building energy code adoption by state as of December 2024.

Image from [4]

As mentioned, states adopt and enforce energy codes; however, cities and jurisdictions can adopt stricter codes if they wish. These intricacies will not be captured in this measure, which simply upgrades the buildings in a state to the statewide code. As a result, savings estimates when upgrading a building's envelope to the state code could be underestimated if a building is located in a jurisdiction with codes that exceed the state code, but this was the most conservative approach.

The city and local adoption of energy codes also occurs in states with no statewide code. For example, Colorado has no statewide code, but Denver has adopted strict building energy codes that align with 90.1-2019 or better [10]; therefore, there will be some limitations in this measure, as it would be extremely difficult to determine and implement local code (e.g., at the city level) adoption in ComStock.

2 ComStock Baseline Approach

2.1 Energy Code Template Assignment

In the ComStock baseline, the energy code assigned to a building is based on the location of the building and the year of construction [11]. As shown in Table 1, much of the commercial building stock was constructed before energy codes became widespread. Forty-eight percent of the floor area modeled in ComStock was built before 1980, and another 30% was built from 1980 to 2000. For this period, the “energy code” is described as either “DOE Ref Pre-1980,” whose assumptions are drawn from Deru et al. [12], or “DOE Ref 1980-2004,” whose assumptions are a combination of ASHRAE 90.1-1989 [13] and Deru et al. [12].

For later vintages, ComStock maps to ASHRAE 90.1 versions. If a state’s code is not a derivative of the ASHRAE 90.1 series, the most similar version of ASHRAE 90.1 was used for that state. The only exception is California, where the Title 24 series of codes (as represented in DEER) [9] was used. This series of codes has key differences from ASHRAE 90.1 and therefore is used to more accurately model the buildings in California. The energy code template assigned to a building informs many performance assumptions in the model, including envelope; heating, ventilating, and air-conditioning (HVAC); and lighting.

Table 1. Breakdown of ComStock Floor by Building Vintage

Building Vintage	Percentage of ComStock Floor Area	Notes [14]
Before 1946	12.6%	
1946 to 1959	9.5%	
1960 to 1969	12.0%	
1970 to 1979	13.8%	1975: First national model energy code covering commercial and residential buildings
1980 to 1989	16.8%	1975 to 2000: National model codes were periodically updated but not on a regular cycle
1990 to 1999	13.4%	
2000 to 2012	17.4%	Early 2000s to present: National model codes began updates on a 3-year cycle
2013 to 2018	4.6%	

The adoption of building codes over time varies for each state—some states are assumed to adopt the latest version of ASHRAE 90.1 within 1–2 years after it is released, whereas other states lag many cycles. Figure 2 shows the current ComStock baseline assumptions for the energy code in force as a function of the state and vintage of the building [11]. The assumptions around the code adoption history were largely derived from the Building Codes Assistance Project (BCAP) [15]. For more information about the assumptions that go into ComStock related to building energy codes, see the *ComStock Reference Documentation* [11].

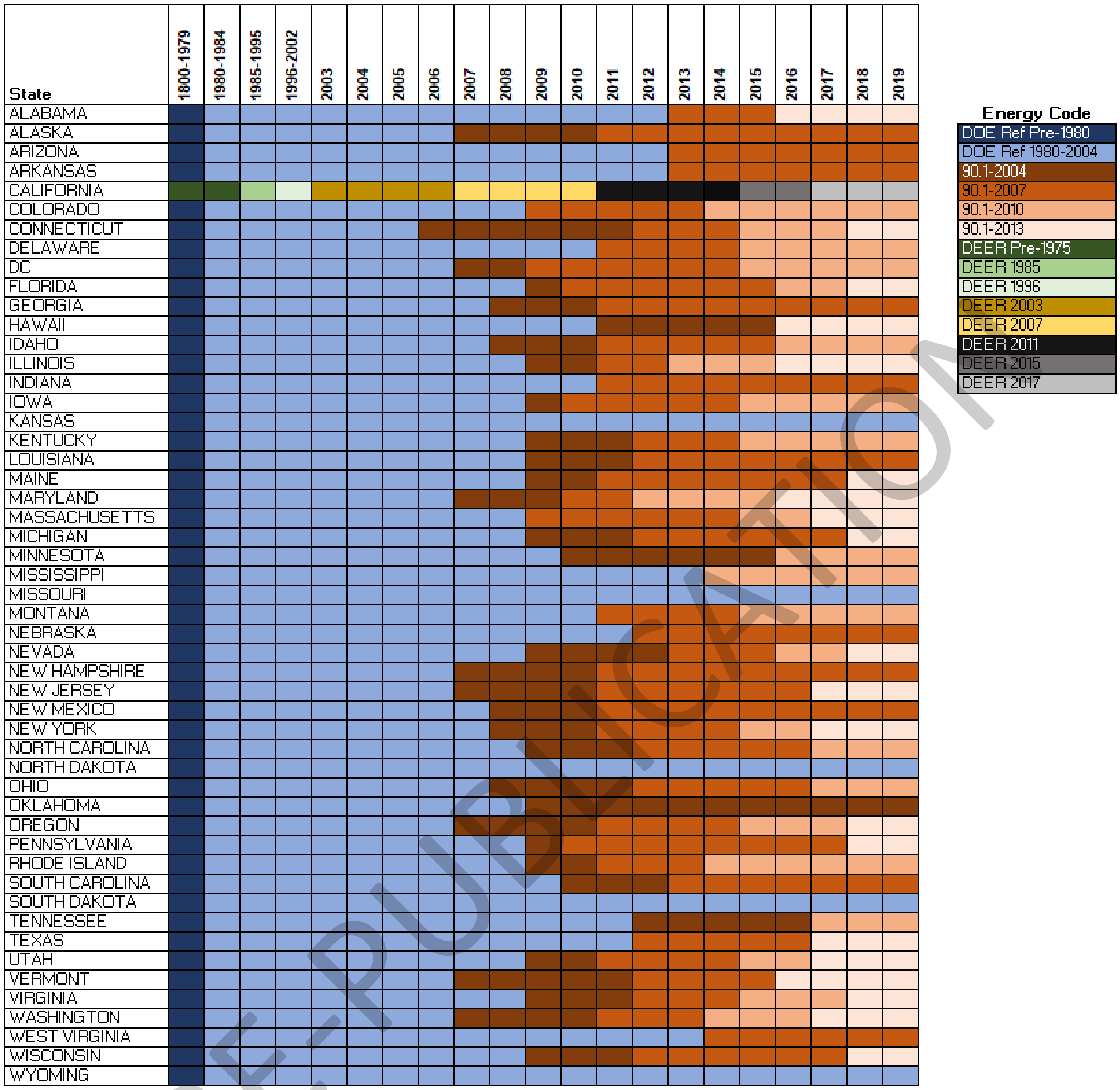

Figure 2. Energy code in force during year of construction by state.

Image from [11]

2.2 Building System Turnover Assumptions

The original, or as-built, energy code assigned to a building in ComStock directly informs the performance of the building systems, such as HVAC efficiency or insulation levels. The as-built code in the model can be updated for different building systems based on equipment turnover and effective useful life (EUL) assumptions. We assume that all major building systems are installed when the building is constructed and that they are replaced periodically over the lifespan of the building. This process modifies the energy code associated with that building system, and therefore the system could be upgraded to a more efficient system if the energy code at the time of replacement is better than the as-built energy code. The metric commonly used by industry to describe the lifespan of a building system or a piece of equipment is the EUL. In real buildings, replacements might be made because of equipment failure, building remodeling, or energy efficiency upgrades. In the ComStock model, we make informed assumptions regarding how often building systems are replaced; the assumptions are based on a combination of internal research and the California Public Utilities Commission DEER model [16]. Although the EUL of different systems can vary across the country, the DEER studies were found to be the best available. Table 2 details the EUL assumptions in ComStock. For more details about this methodology, see the *ComStock Reference Documentation* [11].

Table 2. EUL of Major Commercial Building Systems in ComStock

Major Building System	EUL (Years)
Envelope—wall insulation	200
Envelope—roof insulation	200
Envelope—windows	70
Exterior lighting	15
Interior lighting	10
HVAC	20
Service water heating	15
Interior equipment (plug-and-process loads)	15

2.3 Envelope Baseline Assumptions

The EUL of the envelope components that this measure scenario pertains to (wall insulation, roof insulation, and windows) is very large: 200 years for walls and roofs and 70 years for windows (Table 2); therefore, the vast majority of buildings in ComStock are assumed to have the original walls, roof, and windows from when the building was built. This is often many code cycles behind what is required of new construction buildings in the state where that building is located.

2.3.1 Wall Insulation

In the ComStock baseline, the thermal performance of walls (R-value/U-value) is determined by the energy code template assigned to the building, the climate zone, and the wall construction type. ComStock models four wall types commonly seen in commercial construction: mass, metal building, steel framed, and wood framed. The prevalence of each wall type is a sampled building characteristic that is dependent on the climate zone and the number of stories. These two characteristics were determined to be the biggest drivers of wall construction types based on an extensive analysis detailed in the *ComStock Reference Documentation* [11].

As mentioned, because the EUL assumption for walls is 200 years, the walls in most buildings are assumed to be original. Table 3. shows the average assembly R-value by climate zone, wall construction type, and energy code template for non-California buildings. Table 4. shows the average assembly R-value by climate zone, wall construction type, and energy code template for California buildings. Note that the roof constructions in DEER are categorized by California Energy Commission (CEC) climate zones. The CEC climate zones in California have less climatic variability than the ASHRAE climate zones that span the entire United States; therefore, the range of R-value targets for California buildings tends to be smaller than the range seen in models for the rest of the country.

In some cases, the pre-1980 and/or 1980–2004 wall assembly R-value targets are better than those of the newer 90.1 templates. This is because the pre-1980 and 1980–2004 assumptions are drawn from Deru et al. [12] and a combination of Deru et al. [12] and ASHRAE 90.1-1989, respectively. The envelope performance assumptions from Deru et al. [12] were derived from a Briggs et al. study that estimated envelope thermal properties by construction year for office buildings [17]. For pre-1980 buildings, the performance assumptions from the Briggs study for 1970 were used across all building and construction types, as this study did not differentiate between construction types. For this reason, there is no diversity in R-values across wall construction types for the pre-1980 values. The newer 90.1 templates are drawn directly from the ASHRAE 90.1 standards, so the R-value targets start following a more consistent trend after 90.1-2004. In the later templates, there is variability across construction types.

Table 3. Baseline Wall R-Value by Wall Type, Energy Code, and Climate Zone for Non-California Buildings.

Table from [11]

Whole Wall Assembly R-Value by ASHRAE Climate Zone (ft^2*F*h/Btu) Includes interior and exterior air films																
Wall Type	Energy Code	ASHRAE Climate Zone														
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
Mass	Pre-1980	4.3	4.3	4.3	4.4	4.3	4.5	5.6	5.4	5.7	6.4	6.2	6.9	6.9	7.4	8.0
	1980–2004	1.0	2.9	2.4	3.4	3.4	2.0	8.3	5.3	10.0	10.0	7.1	7.1	14.1	16.4	21.3
	90.1-2004	1.7	1.7	1.7	6.6	6.6	6.6	6.6	6.6	6.6	8.1	8.1	9.6	9.6	11.1	12.5
	90.1-2007	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	14.1
	90.1-2010	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	14.1
	90.1-2013	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	20.8
Metal building	Pre-1980	4.3	4.3	4.3	4.4	4.3	4.5	5.6	5.4	5.7	6.4	6.2	6.9	6.9	7.4	8.0
	1980–2004	1.0	6.7	4.2	7.7	6.3	7.7	11.2	10.0	10.9	12.2	12.2	15.4	13.9	17.2	22.2
	90.1-2004	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	17.5	17.5
	90.1-2007	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	17.5	17.5
	90.1-2010	10.8	10.8	10.8	11.9	11.9	11.9	11.9	11.9	11.9	14.5	14.5	14.5	14.5	17.5	17.5
	90.1-2013	10.6	10.6	10.6	10.6	10.6	10.6	16.7	16.7	16.7	20.0	20.0	20.0	20.0	22.7	25.6
Steel framed	Pre-1980	4.3	4.3	4.3	4.4	4.3	4.5	5.6	5.4	5.7	6.4	6.2	6.9	6.9	7.4	8.0
	1980–2004	1.0	6.7	4.2	7.7	6.3	7.7	11.2	10.0	10.9	12.2	12.2	15.4	13.9	17.2	22.2
	90.1-2004	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	11.9	11.9	11.9	11.9	15.6	15.6
	90.1-2007	8.1	8.1	8.1	11.9	11.9	11.9	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
	90.1-2010	8.1	8.1	8.1	11.9	11.9	11.9	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
	90.1-2013	8.1	11.9	11.9	13.0	13.0	13.0	15.6	15.6	15.6	18.2	18.2	20.4	20.4	20.4	27.0
Wood framed	Pre-1980	4.3	4.3	4.3	4.4	4.3	4.5	5.6	5.4	5.7	6.4	6.2	6.9	6.9	7.4	8.0
	1980–2004	1.0	6.7	4.2	7.7	6.3	7.7	11.2	10.0	10.9	12.2	12.2	15.4	13.9	17.2	22.2
	90.1-2004	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	19.6
	90.1-2007	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	19.6	19.6	19.6	27.8
	90.1-2010	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	19.6	19.6	19.6	27.8
	90.1-2013	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	15.6	19.6	19.6	19.6	19.6	19.6	31.3

Table 4. Baseline Wall R-Value by Wall Type, Energy Code, and Climate Zone for California Buildings.

Table from [11]

Whole Wall Assembly R-Value by CEC Climate Zone (ft^2*F*h/Btu) Includes interior and exterior air films																	
Wall Type	Energy Code	CEC Climate Zone															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mass	DEER pre-1975	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	DEER 1985	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	DEER 1996	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	DEER 2003	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	DEER 2007	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
	DEER 2011	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	5.4	4.0	4.7	5.4	5.4	6.3
	DEER 2014	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	5.4	4.0	4.7	5.4	5.4	6.3
	DEER 2015	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	5.4	4.0	4.7	5.4	5.4	6.3
	DEER 2017	4.0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	5.4	4.0	4.7	5.4	5.4	6.3
Metal building	DEER pre-1975	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	DEER 1985	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
	DEER 1996	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	11.3	11.3	12.5	12.5	12.5	12.5	12.5	12.5
	DEER 2003	12.5	12.5	11.3	11.3	11.3	11.3	11.3	11.3	11.3	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	DEER 2007	12.5	12.5	11.3	11.3	11.3	11.3	11.3	11.3	11.3	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	DEER 2011	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9
	DEER 2014	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9
	DEER 2015	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9
	DEER 2017	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9
Steel framed	DEER pre-1975	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
	DEER 1985	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	DEER 1996	8.0	8.0	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.4	8.0	8.0	8.0	8.0	8.0	8.0
	DEER 2003	8.0	8.0	7.4	7.4	7.4	7.4	7.4	7.2	7.2	7.2	8.0	8.0	8.0	8.0	8.0	8.0
	DEER 2007	8.0	8.0	7.4	7.4	7.4	7.4	7.4	7.2	7.2	7.2	8.0	8.0	8.0	8.0	8.0	8.0
	DEER 2011	10.2	16.1	12.2	16.1	16.1	10.2	10.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
	DEER 2014	10.2	16.1	12.2	16.1	16.1	10.2	10.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
	DEER 2015	10.2	16.1	12.2	16.1	16.1	10.2	10.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
	DEER 2017	10.2	16.1	12.2	16.1	16.1	10.2	10.2	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1
Wood framed	DEER pre-1975	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	DEER 1985	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3	11.3
	DEER 1996	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	11.3	11.3	12.5	12.5	12.5	12.5	12.5	12.5
	DEER 2003	12.5	12.5	11.3	11.3	11.3	11.3	11.3	11.3	11.3	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	DEER 2007	12.5	12.5	11.3	11.3	11.3	11.3	11.3	11.3	11.3	12.5	12.5	12.5	12.5	12.5	12.5	12.5
	DEER 2011	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9
	DEER 2014	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9
	DEER 2015	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9
	DEER 2017	12.5	16.9	11.3	16.9	11.3	11.3	11.3	11.3	16.9	16.9	16.9	16.9	16.9	16.9	23.8	16.9

2.3.2 Roof Insulation

In the ComStock baseline, the thermal performance of roofs (R-value/U-value) is determined by the energy code assigned to the building, the climate zone, and the roof construction type. Our research indicated that more than 90% of commercial floor space has flat or shallow pitch roofs; therefore, ComStock assumes flat roofs for modeling simplicity.

For all states except California, ComStock models three roof types commonly seen in commercial construction: insulation entirely above deck (IEAD), metal building, and attic/other. In California, roof constructions are based on the DEER prototypes, and they include mass, wood-framed, and IEAD roofs. The roof construction assigned to a building is fixed based on the building type. More details can be found in the *ComStock Reference Documentation* [11].

As mentioned, because the EUL assumption for roofs is 200 years, the roofs in most buildings are assumed to be original. Table 5. shows the average assembly R-value by climate zone, roof construction type, and energy code template for non-California buildings. Note that metal buildings are not modeled for pre-1980 [11]. Table 6 shows the average assembly R-value by climate zone, roof construction type, and energy code template for California buildings. Note that the roof constructions in DEER are categorized by CEC climate zones.

Table 5. Baseline Roof R-Value by Roof Type, Energy Code, and Climate Zone for Non-California Buildings.

Table from [11]

Whole Roof Assembly R-Value by ASHRAE Climate Zone (ft²*F*h/Btu) Includes interior and exterior air films																	
Roof Type	Energy Code	ASHRAE Climate Zone															
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Attic and other	Pre-1980	10	10	10	10	10	10	12	11	12	14	13	13	17	17	17	17
	1980–2004	14	15	22	14	21	11	17	17	16	19	20	20	22	20	25	32
	90.1-2004	29	29	29	29	29	29	29	29	29	29	29	29	37	37	37	37
	90.1-2007	29	37	37	37	37	37	37	37	37	37	37	37	37	37	37	48
	90.1-2010	29	37	37	37	37	37	37	37	37	37	37	37	37	37	37	48
	90.1-2013	37	37	37	37	37	37	48	48	48	48	48	48	48	48	59	59
IEAD	Pre-1980	10	10	10	10	10	10	12	11	12	14	13	13	17	17	17	17
	1980–2004	14	15	22	14	21	11	17	17	16	19	20	20	22	20	25	32
	90.1-2004	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	21
	90.1-2007	16	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
	90.1-2010	16	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
	90.1-2013	21	26	26	26	26	26	31	31	31	31	31	31	31	31	36	36
Metal building	1980–2004	10	10	10	10	10	10	12	11	12	14	13	13	22	20	25	32
	90.1-2004	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20
	90.1-2007	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20
	90.1-2010	15	18	18	18	18	18	18	18	18	18	18	18	20	20	20	29
	90.1-2013	24	24	24	24	24	24	27	27	27	27	27	27	32	32	34	38

Table 6. Baseline Roof U-Value by Roof Type, Energy Code, and Climate Zone for California Buildings.

Table from [11]

Whole Roof Assembly R-Value by CEC Climate Zone (ft²*F*h/Btu) Includes interior and exterior air films																	
Roof Type	Energy Code	CEC Climate Zone															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
IEAD	DEER pre-1975	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
	DEER 1985	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	DEER 1996	18	18	18	18	18	13	13	13	13	13	18	18	18	18	18	18
	DEER 2003	18	18	18	18	18	13	13	13	13	18	18	18	18	18	18	18
	DEER 2007	20	20	20	20	20	13	13	13	13	20	20	20	20	20	20	20
	DEER 2011	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2014	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2015	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2017	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
Mass	DEER pre-1975	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
	DEER 1985	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
	DEER 1996	18	18	18	18	18	13	13	13	13	13	18	18	18	18	18	18
	DEER 2003	18	18	18	18	18	13	13	13	13	18	18	18	18	18	18	18
	DEER 2007	20	20	20	20	20	13	13	13	13	20	20	20	20	20	20	20
	DEER 2011	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2014	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2015	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2017	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
Wood framed	DEER pre-1975	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
	DEER 1985	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
	DEER 1996	18	18	18	18	18	13	13	13	13	13	18	18	18	18	18	18
	DEER 2003	18	18	18	18	18	13	13	13	13	18	18	18	18	18	18	18
	DEER 2007	20	20	20	20	20	13	13	13	13	20	20	20	20	20	20	20
	DEER 2011	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2014	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2015	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26
	DEER 2017	20	26	26	26	20	13	15	15	26	26	26	26	26	26	26	26

2.3.3 Windows

Unlike walls and roofs, which are simply modeled to meet the R-value or U-value required by the building's energy code, windows in the ComStock baseline are modeled based on market-representative product distributions, reflecting the realistic performance characteristics of actual window technologies rather than idealized code-minimum values. ComStock models 12 different window assemblies, whose properties are based on commercially available products, as described in a collaborative Lawrence Berkeley National Laboratory and National Renewable Energy Laboratory study [18]. Window performance in ComStock is defined by three metrics: U-value, SHGC, and visible light transmittance (VLT). The 12 window constructions modeled in ComStock, along with their performance characteristics, are shown in Table 7 [11].

Table 7. Window Constructions and Associated Performance Characteristics Modeled in ComStock.

Content of table derived from [11]

Panes	Glazing Type	Frame Material	Low-e Coating	U-Value IP (Btu/h-ft^2-F)	U-Value SI (W/m^2-K)	SHGC	VLT
Single	Clear	Aluminum	No	1.01	6.689	0.744	0.754
Single	Tinted/reflective	Aluminum	No	1.01	6.689	0.579	0.455
Single	Clear	Wood	No	0.91	5.167	0.683	0.723
Single	Tinted/reflective	Wood	No	0.91	5.167	0.525	0.436
Double	Clear	Aluminum	No	0.746	4.236	0.646	0.671
Double	Tinted/reflective	Aluminum	No	0.749	4.253	0.484	0.411
Double	Clear	Aluminum	Yes	0.559	3.174	0.386	0.591
Double	Clear	Aluminum with thermal break	Yes	0.499	2.833	0.378	0.591
Double	Tinted/reflective	Aluminum	Yes	0.557	3.163	0.274	0.359
Double	Tinted/reflective	Aluminum with thermal break	Yes	0.496	2.816	0.266	0.359
Triple	Clear	Aluminum with thermal break	Yes	0.3	1.703	0.328	0.527
Triple	Tinted/reflective	Aluminum with thermal break	Yes	0.299	1.698	0.224	0.32

These window constructions and performance characteristics were developed after thorough analysis of several commercial building window databases that characterize existing installations. WINDOW modeling software was used to set the U-value, SHGC, and VLT associated with each window construction [19]. More details about this methodology can be found in the *ComStock Reference Documentation* [11] and the commercial window market report study [18].

The prevalence of each window construction was determined to be dependent on the climate zone and the energy code of the building. Again, ComStock assumes a 70-year lifespan for windows, so some of the oldest buildings in the stock might assume that the window energy code template was updated since construction; however, most buildings are still modeled with their original windows.

Building energy codes such as ASHRAE 90.1 define a maximum U-value and a maximum SHGC as the window performance characteristics for code compliance. For each combination of climate zone and energy code, we determined which window constructions most closely complied with code. (For example, although triple-pane windows technically comply with all energy code templates based on U-value and SHGC, it is not realistic to assume that buildings used triple-pane windows to align with pre-2004 energy code requirements.) Each combination of climate and energy code included anywhere from 2–12 window constructions that met those criteria. A probability distribution (based on the data on existing installations) was incorporated in the sampling to assign a window construction to each model.

Figure 3 shows the breakdown for floor area by window construction type for each climate zone. In general, the warmer climate zones have a larger prevalence of single-pane windows than the colder climates. This is based on the datasets of existing window installations as well as energy code requirements, which typically become more aggressive in colder climate zones. As of the ComStock 2025 Release 2 dataset [20], 49% of the baseline stock received single-pane windows, 51% received double-pane windows, and less than 1% received triple-pane windows. See the *ComStock Reference Documentation* for more information [11].

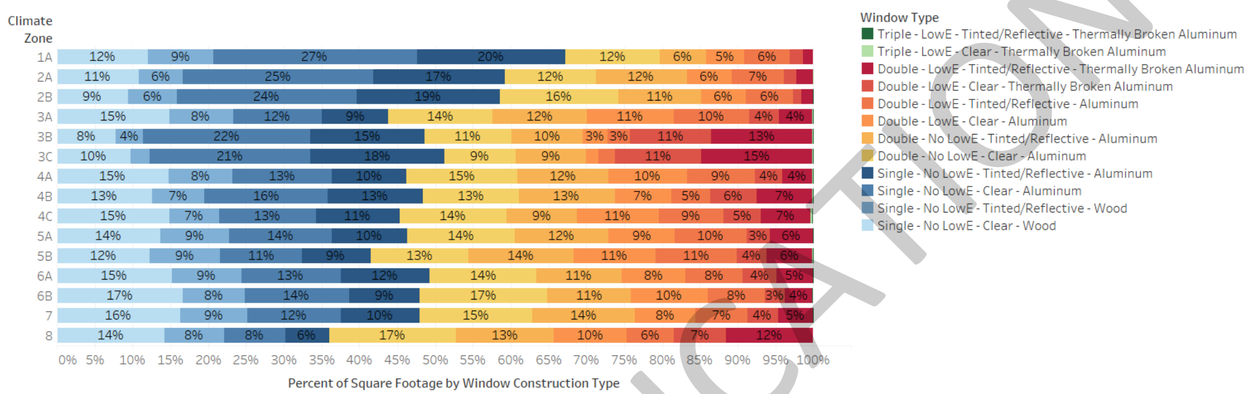

Figure 3. Breakdown of window construction by Climate Zone in the ComStock baseline.

Data from ComStock 2025 Release 2 [20]

3 Modeling Approach

3.1 Applicability

The measure has three components: wall insulation, roof insulation, and windows. The measure will cycle through each component and upgrade any building whose energy code for those systems is lagging the current code adopted by the state where that building resides. In practice, this means that for each building simulated, the measure will load the following model inputs:

- energy_code_followed_during_latest_walls_replacement
- energy_code_followed_during_latest_roof_replacement
- energy_code_followed_during_latest_windows_replacement.

These inputs are determined during the model distribution sampling process and are a function of a building's location, the year of original construction, and the equipment EUL assumptions. The measure will also load a new input called "current_energy_code_in_force", which is a function of the building's location. This new input will determine whether a building's existing wall, roof, or window codes are lagging the current code in force in that state. If the current code in force is newer than the building's current code for any of these three building systems, the energy code will be updated; hence, a model is considered "applicable" if one or more of the wall, roof, or window codes are updated in the measure.

This measure is applicable to 100% of the floor area in ComStock.

3.2 Measure Scenario Modeling Methodology

3.2.1 Determining Current Code in Force by State

An important assumption for this measure is the current energy code followed by each state, which will drive the wall, roof, and window performance metrics that are assigned to a building. The BECP regularly updates a database of current residential and commercial energy codes by state [4]. Although most states officially adopt IECC codes as law for commercial buildings, the IECC recognizes ASHRAE 90.1 as a pathway for compliance with the requirements of the IECC. The BECP database includes both an IECC code version and the equivalent ASHRAE 90.1 code versions for each state (with a few exceptions). ComStock, which is built around ASHRAE 90.1 performance metrics, will use the ASHRAE 90.1 code versions.

Table 8. lists all the states and their current commercial building energy code efficiency category as of December 2024 when the BECP database was last updated [4]. The states that are highlighted in blue will be further investigated, as they either have no statewide energy code, do not follow ASHRAE 90.1, or their energy code listed in BECP is inconsistent with other sources. Each of these 15 states will be individually discussed to determine the most appropriate energy code to be assigned for this measure. For the remaining 38 states (plus the District of Columbia), the measure will assume the BECP assumption [4].

Table 8. Commercial Energy Code Efficiency Category According to BECP as of December 2024.

Data from [4]. States highlighted in blue will be further investigated, as they either have no statewide energy code, do not follow ASHRAE 90.1, or their energy code listed in BECP is inconsistent with other sources.

State	Current ASHRAE 90.1 Energy Code Followed
Alabama	90.1-2013
Alaska	No statewide code
Arizona	<90.1-2007
Arkansas	90.1-2007
California	>=90.1-2019
Colorado	No statewide code
Connecticut	>=90.1-2019
Delaware	90.1-2013
District of Columbia	>=90.1-2019
Florida	90.1-2016
Georgia	90.1-2013
Hawaii	90.1-2016
Idaho	90.1-2013
Illinois	>=90.1-2019
Indiana	90.1-2007
Iowa	90.1-2007
Kansas	No statewide code
Kentucky	90.1-2007
Louisiana	90.1-2016
Maine	90.1-2013
Maryland	>=90.1-2019
Massachusetts	>=90.1-2019
Michigan	90.1-2013
Minnesota	>=90.1-2019
Mississippi	No statewide code
Missouri	No statewide code
Montana	>=90.1-2019
Nebraska	90.1-2013
Nevada	90.1-2013
New Hampshire	90.1-2013
New Jersey	>=90.1-2019
New Mexico	>=90.1-2019
New York	90.1-2016
North Carolina	90.1-2010
North Dakota	No statewide code
Ohio	90.1-2016
Oklahoma	<90.1-2007
Oregon	>=90.1-2019
Pennsylvania	90.1-2013
Rhode Island	90.1-2013
South Carolina	90.1-2007
South Dakota	No statewide code
Tennessee	90.1-2007
Texas	90.1-2013
Utah	>=90.1-2019
Vermont	>=90.1-2019
Virginia	>=90.1-2019
Washington	>=90.1-2019
West Virginia	90.1-2013
Wisconsin	90.1-2010
Wyoming	No statewide code

3.2.1.1 Alaska

Alaska has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. According to BCAP, commercial buildings in Alaska follow the 2018 IECC, enhanced with amendments to cater to Alaska's harsh climate [15]; therefore, we assume 2018 IECC or ASHRAE 90.1-2016 for the state of Alaska.

3.2.1.2 Arizona

Arizona has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. According to BECP, a review of the codes in place in jurisdictions across the state indicates that more than 80% of the population of Arizona is covered by codes at the 90.1-2007 level [4]. According to an American Council for an Energy-Efficient Economy (ACEEE) database, the Southwest Energy Efficiency Project found that most new construction activity occurs in jurisdictions that have adopted the 2012 IECC or the 2018 IECC [21]. For this measure, we conservatively assume ASHRAE 90.1-2007 for the state of Arizona.

3.2.1.3 California

California follows the Title 24 series of codes (as represented in DEER) [8], [9]. This series of codes is known to be significantly different from ASHRAE 90.1; therefore, ComStock models California buildings using DEER assumptions. For this measure, California buildings are assumed to follow DEER 2020, which is the latest DEER code version available in ComStock.

3.2.1.4 Colorado

Colorado has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. The Colorado Energy Office publishes a database of local code adoptions across the state [10]. From the map in Figure 4, Colorado's major cities (Denver, Colorado Springs, Fort Collins, and Pueblo), comply with IECC 2021 (or ASHRAE 90.1-2019). These major cities, which comprise is known as the Front Range Urban Corridor, comprise more than 85% of Colorado's population [22]. Many other mountain towns in the western part of the state also follow IECC 2021; therefore, we assume ASHRAE 90.1-2019 for the state of Colorado, with the understanding that a small fraction of the buildings in more rural parts of the state might be lagging this code level.

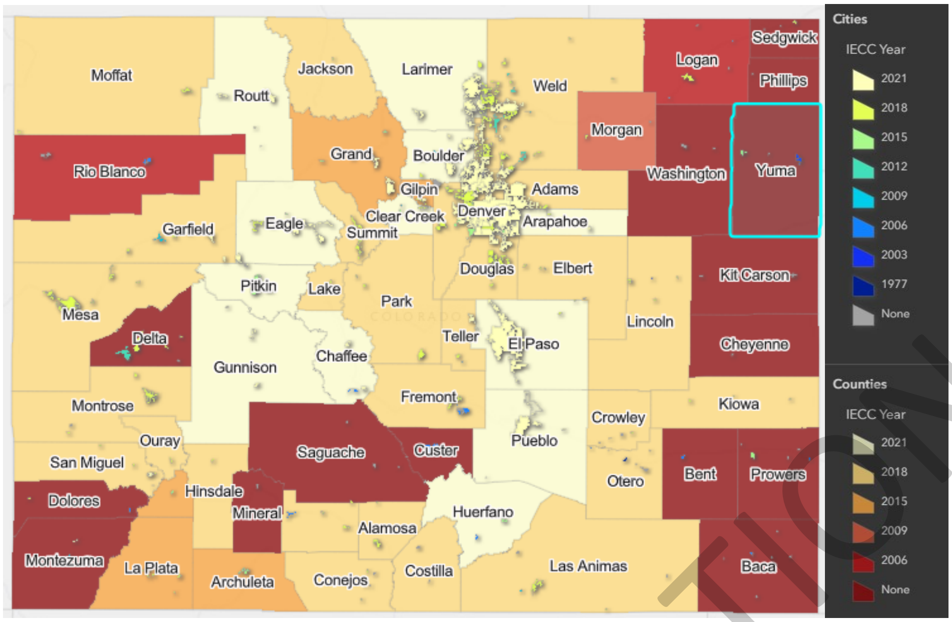

Figure 4. Energy code adoption in Colorado.

Image from [10]

3.2.1.5 Hawaii

According to BECP, Hawaii does not have a statewide energy code, but a review of codes in place in jurisdictions across the state indicates that more than 80% of the population is covered by codes at the 90.1-2016 level [4]. According to an ACEEE database, all four counties in the state have adopted IECC 2018 [21]. As such, we assume ASHRAE 90.1-2016 for the state of Hawaii.

3.2.1.6 Iowa

According to BECP, Iowa follows 90.1-2007 [4]; however, our existing ComStock baseline assumptions set Iowa's current code as 90.1-2010, which was derived from chronological tracking of BCAP [11]. Due to this inconsistency, we did additional research to confirm which code year should be assigned to Iowa. According to an ACEEE database, the Iowa State Energy Code for commercial buildings must comply with the 2012 IECC, with reference to ASHRAE 90.1–2010 [21]. Because ACEEE and the current ComStock assumption align, we assume ASHRAE 90.1-2010 for the state of Iowa.

3.2.1.7 Kansas

Kansas has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. According to ACEEE, the 2006 IECC became the applicable standard for new commercial structures, but it is not mandated [21]. In the absence of other information, we assume ASHRAE 90.1-2004 for the state of Kansas.

3.2.1.8 Kentucky

According to BECP, Kentucky follows 90.1-2007 [4]; however, our existing ComStock baseline assumptions set Kentucky's current code as 90.1-2010, which was derived from chronological tracking of BCAP [11]. Due to this inconsistency, we did additional research to confirm which code year should be assigned to Kentucky. According to an ACEEE database, the projects constructed under the 2013 Kentucky Building Code must comply with the 2012 IECC and ASHRAE 90.1-2010 [21]. Because ACEEE and the current ComStock assumption align, we assume ASHRAE 90.1-2010 for the state of Kentucky.

3.2.1.9 Mississippi

Mississippi has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. According to ACEEE, building energy codes are mandatory for commercial buildings. In 2023, the Mississippi Legislature passed a law to set the mandatory energy code standard for commercial buildings to be ASHRAE 90.1-2016 [21]; therefore, we assume ASHRAE 90.1-2016 for the state of Mississippi.

3.2.1.10 Missouri

Missouri has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. Although state-owned buildings are required to comply with the latest version of IECC, other commercial buildings do not have a mandatory code. According to ACEEE, approximately 50% of the state's population is covered by the 2009, 2012, 2015, or 2018 IECC or equivalent codes [21]. In the absence of other information, we conservatively assume ASHRAE 90.1-2007, for the state of Missouri.

3.2.1.11 North Dakota

North Dakota has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. According to ACEEE, approximately 91% of the state's population lives in a jurisdiction that has adopted the North Dakota State Building Code, which includes the 2021 IECC [21]; therefore, we assume ASHRAE 90.1-2019 for the state of North Dakota.

3.2.1.12 Oklahoma

According to BECP, Oklahoma's commercial energy code is "<90.1-2007", so we did additional research to confirm which code year should be assigned to Oklahoma [4]. According to ACEEE, Oklahoma has a technical commission called the Oklahoma Uniform Building Code Commission, which reviews and recommends buildings codes for new construction. The energy-related chapter of this code references the 2006 IECC. Many jurisdictions in Oklahoma have set their own codes and standards, but after review, many of the codes adopted by jurisdictions are not IECC or ASHRAE 90.1 [21]; therefore, in the absence of other information, we conservatively assume ASHRAE 90.1-2004, for the state of Oklahoma.

3.2.1.13 South Dakota

South Dakota has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. According to ACEEE, most jurisdictions have adopted codes based on the 2015 IECC [21]; therefore, we assume ASHRAE 90.1-2013 for the state of South Dakota.

3.2.1.14 Tennessee

According to BECP, Tennessee follows 90.1-2007 [4]; however, our existing ComStock baseline assumptions set Tennessee's current code as 90.1-2010, which was derived from chronological tracking of BCAP [11]. Due to this inconsistency, we did additional research to confirm which code year should be assigned to Tennessee. According to an ACEEE database, Tennessee adopted the 2012 IECC for commercial and state-owned buildings, which took effect in 2016 [21]. Because ACEEE and the current ComStock assumption align, we assume ASHRAE 90.1-2010 for the state of Tennessee.

3.2.1.15 Wyoming

Wyoming has no statewide building energy code, so we need to assume an appropriate ASHRAE 90.1 version for this measure. According to BCAP, many of the most populous cities in Wyoming—including Cheyenne, Casper, Gillette, Laramie, and Teton—have adopted commercial energy codes ranging from IECC 2009 to IECC 2015 [15]. In the absence of other information, we conservatively assume ASHRAE 90.1-2007 for the state of Wyoming.

3.2.2 Final List of Current Code Assumptions by State

Considering all the assumptions from the previous section, Table 9 and Figure 5 represent the final list of current commercial energy code assumptions by state that will be implemented in this measure.

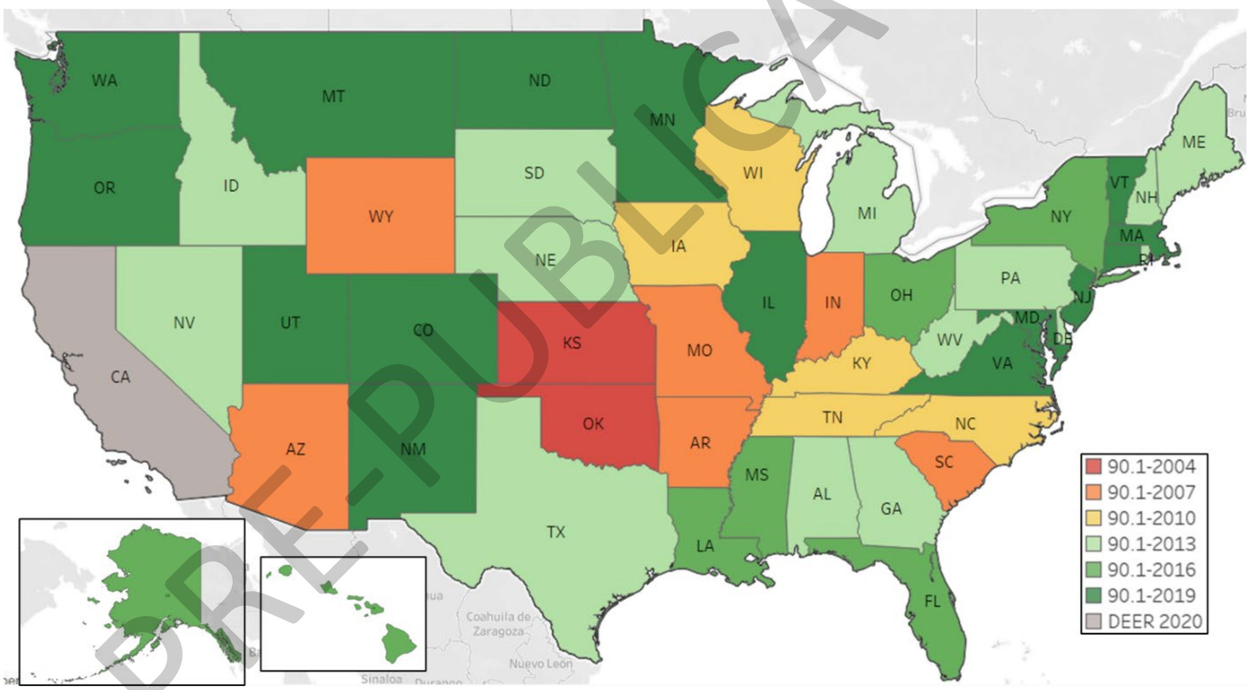

Figure 5. Final assumptions for current code in force by state

Table 9. Final Assumptions for Current Code in Force by State

State	Current Energy Code in Force
Alabama	90.1-2013
Alaska	90.1-2016
Arizona	90.1-2007
Arkansas	90.1-2007
California	DEER 2020
Colorado	90.1-2019
Connecticut	90.1-2019
Delaware	90.1-2013
District of Columbia	90.1-2019
Florida	90.1-2016
Georgia	90.1-2013
Hawaii	90.1-2016
Idaho	90.1-2013
Illinois	90.1-2019
Indiana	90.1-2007
Iowa	90.1-2010
Kansas	90.1-2004
Kentucky	90.1-2010
Louisiana	90.1-2016
Maine	90.1-2013
Maryland	90.1-2019
Massachusetts	90.1-2019
Michigan	90.1-2013
Minnesota	90.1-2019
Mississippi	90.1-2016
Missouri	90.1-2007
Montana	90.1-2019
Nebraska	90.1-2013
Nevada	90.1-2013
New Hampshire	90.1-2013
New Jersey	90.1-2019
New Mexico	90.1-2019
New York	90.1-2016
North Carolina	90.1-2010
North Dakota	90.1-2019
Ohio	90.1-2016
Oklahoma	90.1-2004
Oregon	90.1-2019
Pennsylvania	90.1-2013
Rhode Island	90.1-2013
South Carolina	90.1-2007
South Dakota	90.1-2013
Tennessee	90.1-2010
Texas	90.1-2013
Utah	90.1-2019
Vermont	90.1-2019
Virginia	90.1-2019
Washington	90.1-2019
West Virginia	90.1-2013
Wisconsin	90.1-2010
Wyoming	90.1-2007

Figure 6 shows the breakdown of ComStock floor area by current code in force after applying these final code assumptions by state. This does *not* represent the breakdown of current code followed by existing buildings in the United States, as state-mandated codes only apply to new construction. Rather, this graphic represents what the breakdown of floor area by code would be if all existing buildings upgraded their envelope to meet the current code enforced by their state for new construction.

States representing more than 78% of the U.S. commercial floor area are now enforcing 90.1-2013 or higher for new construction buildings. This includes California (following DEER 2020), which, according to BECP, is equivalent to or more aggressive than 90.1-2019 [4]. This measure will upgrade the envelope of all buildings in ComStock to meet the current code in force in the state.

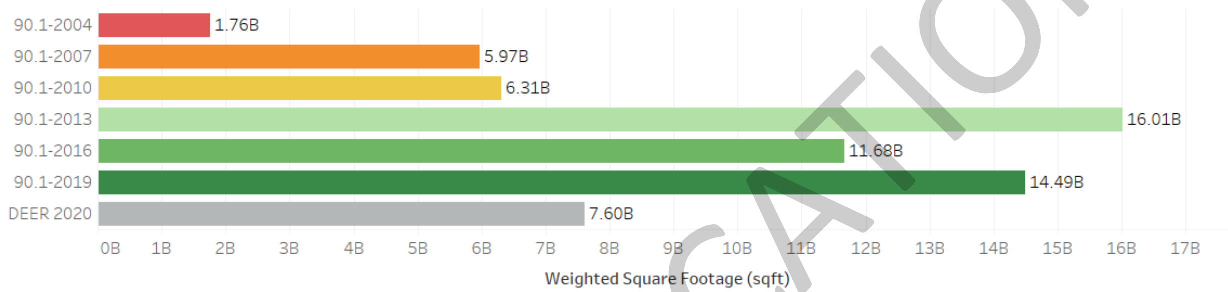

Figure 6. Square footage by current code in force.

Data from ComStock 2024 Release 2 Standard Data Release [20]

3.2.3 Wall Insulation Upgrade Methodology

This measure upgrades the wall insulation for each building to the assigned code in force for the state where the building is located. The R-value of the wall assembly is upgraded to the new R-value for the assigned code, which can be found in

Table 10 (non-California) and Table 11 (California). If the wall insulation of a building is already at the desired code level, no changes are made.

Note that these tables contain some duplicative information to the tables in Section 2.3.1; however,

Table 10 does not include the pre-1980 and 1980–2004 templates, but it does include the 90.1-2016 and 90.1-2019 templates. This is because in the upgrade scenario, the building's current code template will be set to a template ranging from 90.1-2004 to 90.1-2019, depending on what state it is in. In Table 11, only the DEER 2020 template is shown because all California buildings will be set to this code level in the upgrade scenario. The data for 90.1-2016, 90.1-2019, and DEER 2020 are derived from the openstudio-standards database [23], as these templates are not represented in the baseline of ComStock (and therefore not included in the *ComStock Reference Documentation* [11]).

Table 10. Upgrade Wall R-Value by Wall Type, Energy Code, and Climate Zone for Non-California Buildings.

Data from [11], [23]

Whole Wall Assembly R-Value by ASHRAE Climate Zone (ft²*F*h/Btu) Includes interior and exterior air films																
Wall Type	Energy Code	ASHRAE Climate Zone														
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	6A	6B	7	8
Mass	90.1-2004	1.7	1.7	1.7	6.6	6.6	6.6	6.6	6.6	6.6	8.1	8.1	9.6	9.6	11.1	12.5
	90.1-2007	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	14.1
	90.1-2010	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	14.1
	90.1-2013	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	20.8
	90.1-2016	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	20.8
	90.1-2019	1.7	6.6	6.6	8.1	8.1	8.1	9.6	9.6	9.6	11.1	11.1	12.5	12.5	14.1	20.8
Metal building	90.1-2004	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	17.5	17.5
	90.1-2007	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	17.5	17.5
	90.1-2010	10.8	10.8	10.8	11.9	11.9	11.9	11.9	11.9	11.9	14.5	14.5	14.5	14.5	17.5	17.5
	90.1-2013	10.6	10.6	10.6	10.6	10.6	10.6	16.7	16.7	16.7	20.0	20.0	20.0	20.0	22.7	25.6
	90.1-2016	10.6	10.6	10.6	10.6	10.6	10.6	16.7	16.7	16.7	20.0	20.0	20.0	20.0	22.7	25.6
	90.1-2019	10.6	10.6	10.6	10.6	10.6	10.6	16.7	16.7	16.7	20.0	20.0	20.0	20.0	22.7	25.6
Steel framed	90.1-2004	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	11.9	11.9	11.9	11.9	15.6	15.6
	90.1-2007	8.1	8.1	8.1	11.9	11.9	11.9	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
	90.1-2010	8.1	8.1	8.1	11.9	11.9	11.9	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
	90.1-2013	8.1	11.9	11.9	13.0	13.0	13.0	15.6	15.6	15.6	18.2	18.2	20.4	20.4	20.4	27.0
	90.1-2016	8.1	11.9	11.9	13.0	13.0	13.0	15.6	15.6	15.6	18.2	18.2	20.4	20.4	20.4	27.0
	90.1-2019	8.1	11.9	11.9	13.0	13.0	13.0	15.6	15.6	15.6	18.2	18.2	20.4	20.4	20.4	27.0
Wood framed	90.1-2004	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	19.6
	90.1-2007	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	19.6	19.6	19.6	27.8
	90.1-2010	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	19.6	19.6	19.6	27.8
	90.1-2013	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	15.6	19.6	19.6	19.6	19.6	19.6	31.3
	90.1-2016	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	15.6	19.6	19.6	19.6	19.6	19.6	31.3
	90.1-2019	11.2	11.2	11.2	11.2	11.2	11.2	15.6	15.6	15.6	19.6	19.6	19.6	19.6	19.6	31.3

Table 11. Upgrade Wall R-Value by Wall Type, Energy Code, and Climate Zone for California Buildings.

Data from [23]

Whole Wall Assembly R-Value by CEC Climate Zone (ft²*F*h/Btu) Includes interior and exterior air films																	
Wall Type	Energy Code	CEC Climate Zone															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mass	DEER 2020	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Metal building	DEER 2020	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Steel framed	DEER 2020	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7
Wood framed	DEER 2020	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

3.2.4 Roof Insulation Upgrade Methodology

This measure upgrades the roof insulation for each building to the assigned code in force for the state where the building is located. The R-value of the roof assembly will be upgraded to the new R-value for the assigned code, which can be found in Table 12 (non-California) and Table 13 (California). If the roof insulation of a building is already at the desired code level, no changes will be made.

Note that these tables contain some duplicative information to the tables in Section 2.3.2; however, Table 12 does not include the pre-1980 and 1980–2004 templates, but it does include the 90.1-2016 and 90.1-2019 templates. This is because in the upgrade scenario, the building's current code template will be set to a template ranging from 90.1-2004 to 90.1-2019, depending on what state it is in. In Table 13, only the DEER 2020 template is shown because all California buildings will be set to this code level in the upgrade scenario. The data for 90.1-2016, 90.1-2019, and DEER 2020 are derived from the openstudio-standards database [23], as these templates are not represented in the baseline of ComStock (and therefore not included in the *ComStock Reference Documentation* [11]).

Table 12. Upgrade Roof R-Value by Roof Type, Energy Code, and Climate Zone for Non-California Buildings.

Data from [11], [23]

Whole Roof Assembly R-Value by ASHRAE Climate Zone (ft²*F*h/Btu) Includes interior and exterior air films																	
Roof Type	Energy Code	ASHRAE Climate Zone															
		1A	2A	2B	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	7	8
Attic and other	90.1-2004	29	29	29	29	29	29	29	29	29	29	29	29	37	37	37	37
	90.1-2007	29	37	37	37	37	37	37	37	37	37	37	37	37	37	37	48
	90.1-2010	29	37	37	37	37	37	37	37	37	37	37	37	37	37	37	48
	90.1-2013	37	37	37	37	37	37	48	48	48	48	48	48	48	48	59	59
	90.1-2016	37	37	37	37	37	37	48	48	48	48	48	48	48	48	59	59
	90.1-2019	37	37	37	37	37	37	48	48	48	48	48	48	48	48	59	59
IEAD	90.1-2004	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	21
	90.1-2007	16	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
	90.1-2010	16	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
	90.1-2013	21	26	26	26	26	26	31	31	31	31	31	31	31	31	36	36
	90.1-2016	21	26	26	26	26	26	31	31	31	31	31	31	31	31	36	36
	90.1-2019	21	26	26	26	26	26	31	31	31	31	31	31	31	31	36	36
Metal building	90.1-2004	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20
	90.1-2007	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20
	90.1-2010	15	18	18	18	18	18	18	18	18	18	18	18	20	20	20	29
	90.1-2013	24	24	24	24	24	24	27	27	27	27	27	27	32	32	34	38
	90.1-2016	24	24	24	24	24	24	27	27	27	27	27	27	32	32	34	38
	90.1-2019	24	24	24	24	24	24	27	27	27	27	27	27	32	32	34	38

Table 13. Upgrade Roof R-Value by Roof Type, Energy Code, and Climate Zone for California Buildings.

Data from [23]

Whole Roof Assembly R-Value by CEC Climate Zone (ft²*F*h/Btu) Includes interior and exterior air films																	
Roof Type	Energy Code	CEC Climate Zone															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
IEAD	DEER 2020	25	29	29	29	26	15	20	20	29	29	29	29	29	29	29	29
Mass	DEER 2020	25	29	29	29	26	15	20	20	29	29	29	29	29	29	29	29
Wood framed	DEER 2020	25	29	29	29	26	15	20	20	29	29	29	29	29	29	29	29

3.2.5 Window Upgrade Methodology

This measure upgrades the windows in each building to a window technology that complies with the assigned code in force for the state where the building is located. Building energy codes and standards such as ASHRAE 90.1 set assembly U-value and SHGC targets by climate zone for windows. The energy codes specify several types of windows, including fixed, operable, and skylights. For ComStock, we use the "Metal framing, fixed" category to assign U-value and SHGC targets, as we assume that windows in ComStock are inoperable and that a vast majority have metal framing.

As discussed in more detail in Section 2.3.3, windows in ComStock are modeled on a technology basis, meaning each building is assigned a window assembly rather than just assigning the U-value/SHGC from the building's energy code; therefore, when we upgrade the windows in this measure, we want to assign a new window assembly that meets or exceeds the U-value and the SHGC of the current code in force.

Table 14 shows the maximum U-value and SHGC for each combination of ASHRAE 90.1 energy code and ASHRAE climate zone [2]. Only 90.1-2004 through 90.1-2019 are shown because this is the range of energy codes currently in force in this upgrade scenario. DEER 2020 is also shown, which corresponds to the current code in force for California buildings [8], [9]. For each code/climate zone, we found the window assembly (or assemblies) that closely meet the code U-value. If there are two window assemblies with very similar U-values that meet the code, we then looked at the SHGC and chose the window technology with the closest SHGC to the code. If the existing window U-value of a building already meets the desired code level, no changes will be made.

Table 14. Maximum U-Value and SHGC for Whole Window Assembly by Energy Code and ASHRAE Climate Zone, Mapped to the Closest Window Technology That Meets or Exceeds Code (Non-California Buildings).

Data from [2], [8], [9]

Whole Window Assembly U-Value (Btu/ft^2*F*h) and SHGC by ASHRAE Climate Zone				Closest Mapped Window Technology by U-Value (Btu/ft^2*F*h) and SHGC (Meets or Exceeds Code)		
Energy Code	Climate Zone	Max U-value	Max SHGC	Window Technology Name	U-value	SHGC
90.1-2004	1	1.22	0.25	Single - no low-e - tinted/reflective - aluminum	1.01	0.579
	2	1.22	0.25	Single - no low-e - tinted/reflective - aluminum	1.01	0.579
	3	0.57	0.39	Double - low-e - clear - aluminum	0.559	0.386
	4	0.57	0.39	Double - low-e - clear - aluminum	0.559	0.386
	5	0.57	0.49	Double - low-e - clear - aluminum	0.559	0.386
	6	0.57	0.49	Double - low-e - clear - aluminum	0.559	0.386
	7	0.57	0.49	Double - low-e - clear - aluminum	0.559	0.386
	8	0.46	NR[a]	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
90.1-2007	1	1.2	0.25	Single - no low-e - tinted/reflective - aluminum	1.01	0.579
	2	0.75	0.25	Double - no low-e - tinted/reflective – aluminum	0.749	0.484
	3	0.65	0.25	Double - low-e - tinted/reflective - aluminum	0.557	0.274
	4	0.55	0.4	Double - low-e - clear - thermally broken aluminum	0.499	0.378
	5	0.55	0.4	Double - low-e - clear - thermally broken aluminum	0.499	0.378
	6	0.55	0.4	Double - low-e - clear - thermally broken aluminum	0.499	0.378
	7	0.45	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	8	0.45	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
90.1-2010	1	1.2	0.25	Single - No low-e - tinted/reflective - aluminum	1.01	0.579
	2	0.75	0.25	Double - No low-e - tinted/reflective – aluminum	0.749	0.484
	3	0.65	0.25	Double - low-e - tinted/reflective - aluminum	0.557	0.274
	4	0.55	0.4	Double - low-e - clear - thermally broken aluminum	0.499	0.378
	5	0.55	0.4	Double - low-e - clear - thermally broken aluminum	0.499	0.378
	6	0.55	0.4	Double - low-e - clear - thermally broken aluminum	0.499	0.378
	7	0.45	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	8	0.45	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
90.1-2013	1	0.57	0.25	Double - low-e - tinted/reflective - aluminum	0.557	0.274
	2	0.57	0.25	Double - low-e - tinted/reflective - aluminum	0.557	0.274
	3	0.5	0.25	Double - low-e - tinted/reflective - thermally broken aluminum	0.496	0.266
	4	0.42	0.4	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	5	0.42	0.4	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	6	0.42	0.4	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	7	0.38	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	8	0.38	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
90.1-2016	1	0.5	0.22	Double - low-e - tinted/reflective - thermally broken aluminum	0.496	0.266
	2	0.57	0.25	Double - low-e - tinted/reflective - aluminum	0.557	0.274
	3	0.54	0.25	Double - low-e - tinted/reflective - thermally broken aluminum	0.496	0.266
	4	0.45	0.25	Triple - low-e - tinted/reflective - thermally broken aluminum	0.299	0.224
	5	0.38	0.36	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	6	0.38	0.38	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	7	0.36	0.4	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	8	0.33	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328

90.1-2019	1	0.5	0.22	Double - low-e - tinted/reflective - thermally broken aluminum	0.496	0.266
	2	0.5	0.23	Double - low-e - tinted/reflective - thermally broken aluminum	0.496	0.266
	3	0.45	0.25	Triple - low-e - tinted/reflective - thermally broken aluminum	0.299	0.224
	4	0.42	0.25	Triple - low-e - tinted/reflective - thermally broken aluminum	0.299	0.224
	5	0.36	0.36	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	6	0.36	0.38	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	7	0.34	0.38	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	8	0.29	0.4	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
DEER 2020[b]	CEC 1	0.42	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	CEC 2	0.42	0.44	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	CEC 3-9	0.64	0.54	Double - low-e - clear - aluminum	0.559	0.386
	CEC 10-13	0.42	0.44	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	CEC 14-15	0.42	0.43	Triple - low-e - clear - thermally broken aluminum	0.3	0.328
	CEC 16	0.42	0.45	Triple - low-e - clear - thermally broken aluminum	0.3	0.328

[a] No requirement
[b] In the DEER standard, there are different U-value and SHGC requirements for north- and non-north-facing windows and the percentage of wall surface covered by windows. For simplicity, we assume the U-value and SHGC that correspond to the non-north-facing 0%–10% surface covered by windows.

3.3 Utility Bills

ComStock provides utility bill estimates for several fuel types in buildings: electricity, natural gas, propane, and fuel oil. The current implementation represents utility bills circa 2022, which is the most current year of utility data available from the U.S. Energy Information Administration (EIA). This section provides a high-level overview of the methodology behind utility bills in ComStock, but more detailed information is available in the *ComStock Reference Documentation* [11]. Summary statistics from this implementation are shown in Table 15. Note that ComStock does not currently estimate utility bills for district heating and cooling.

Table 15. Summary Statistics of Utility Bill Implementation in ComStock by Fuel Type

Fuel Type	Minimum Price ($)	Average Price ($)	Maximum Price ($)
Natural gas	$0.070/kBtu	$0.012/KBtu	$0.048/kBtu
Propane	$0.022/kBtu	$0.032/kBtu	$0.052/kBtu
Fuel oil	$0.027/kBtu	$0.033/kBtu	$0.036/kBtu
Electricity	$0.003/kBtu	$0.035/kBtu	$3.530/kBtu

Natural gas bills are estimated using 2022 EIA averages by state. The 2022 U.S. EIA Natural Gas Prices - Commercial Price and U.S. EIA Heat Content of Natural Gas Delivered to Consumers are used to create an energy price in dollars per kBtu [24].

Propane and fuel oil bills are estimated using 2022 EIA averages by state. Residential No. 2 Distillate Prices by Sales Type and U.S. EIA residential Weekly Heating Oil and Propane Prices (October–March) and EIA-assumed heat content for these fuels are used to create an energy price in dollars per kBtu [25]. Residential prices are used because commercial prices are only available at the national resolution. Additionally, most commercial buildings using these fuels are assumed to be smaller buildings where a residential rate is likely realistic. For states where state-level pricing was available, these prices are used directly. For other states, Petroleum Administration for Defense District-average pricing is used. For states where Petroleum Administration for Defense District-level pricing is not available, national average pricing is used.

The primary resource for ComStock electric utility rates is the Utility Rate Database (URDB), which includes rate structures for approximately 85% of the buildings and 85% of the floor area in ComStock [26]. The URDB rates include detailed cost features, such as time-of-use pricing, demand charges, and ratchets. ComStock uses only URDB rates that were entered starting in 2013, and a cost adjustment factor is applied such that the rates reflect 2022 U.S. dollars.

URDB rates are assigned to ComStock models at the census tract level. The URDB can include several rate structures for a census tract. Instead of attempting to presume any single rate, multiple rates from the model's census tract are simulated; the ComStock dataset includes the minimum, median, mean, and maximum simulated rates for each model.

Many precautions are implemented to prevent less reasonable rates from being applied. This includes removing noncommercial rates, rates with non-building-load keywords (e.g., security light, irrigation, snow, cotton gin), rates where the load profile does not follow any potential min/max demand or energy consumption qualifiers, and rates that cause uncharacteristically low (<$0.01/kWh) or high (>$0.45/kWh) blended averages. Additionally, any bill that is lower than 25% of the median or higher than 200% of the median is eliminated to avoid extreme bills.

For buildings with no URDB electric utility assigned, or for buildings where none of the stored rates are applicable, the annual bill is estimated using the 2022 EIA Form-861 average prices based on the state each model is located in [27]. Although this method does not reflect the detailed rate structures and demand charges, it is a fallback for the 15% of buildings in ComStock with no utility assigned.

3.4 Limitations and Concerns

This measure intends to analyze the impact of upgrading the envelope of the existing building stock to the current code levels required for new construction. The main assumption made in this measure is to assign current codes at the state level. Although statewide code adoption is common across most states, there are many intricacies in the way building energy codes are adopted and enforced that cannot be captured in this measure.

First, as described in Section 3.2.1, some states do not adopt codes at the state level; rather, they rely on cities and jurisdictions to implement their own codes, or they simply do not require commercial buildings to comply with energy codes. For these states, we did additional research to choose the most suitable energy code for the state, often based on the code of the large population centers in the state.

Second, in states that do have statewide codes, there are often cities and jurisdictions that adopt more stringent codes than the state code. It would require a substantial research effort beyond the scope of this study to track down all the local codes enforced across the United States and implement such level of granularity into this measure; therefore, state-level codes are used for this measure.

We recognize that this means that some parts of the stock might not be set to the exact code level followed in that specific location. It is difficult to quantify the effects of these inconsistencies; however, given that jurisdictions might only set their local codes to a *more stringent* standard than the state code [3], we believe the results of this measure will be conservative and not estimate overly optimistic savings. In states with no statewide energy code, there could be some buildings where the statewide code selected for this measure is overly optimistic. For example, in Colorado, we assigned a code based on large cities that follow ASHRAE 90.1-2019+ codes; however, we might be overestimating savings in rural buildings in Colorado that do not enforce ASHRAE 90.1-2019. At the same time, we could be assuming in the baseline that these rural buildings are at a higher code level than they are, hence underestimating savings. At the aggregate level, this will likely have minimal impacts, given that most buildings are in the urban population centers and therefore have more influence on the energy consumption and energy savings of a state. We recognize that there could be some rare cases where savings in certain regions are overestimated; however, in most states, we can be confident that the savings estimated by this measure are conservative because we assume state-level code adoption.

Another limitation introduced by this measure is due to the new sampling methodology that was implemented starting with ComStock 2024 Release 2 [20]. In this new sampling methodology, detailed in the *ComStock Reference Documentation* [11], a building is sampled in one location, but then it can be reallocated to multiple locations within a specific geographic region. The reallocated buildings are not rerun in ComStock; instead, the results from the original sampled model are simply reused and scaled accordingly. So, a building is sampled in one state, assigned a target energy code in this measure, and then simulated, and the results are generated. During postprocessing, that building could then be reallocated to a neighboring state, meaning the energy code assigned could be incorrect in the reallocated building.

The map in Figure 7 shows the sampling regions used in ComStock for reallocation. The sampling regions are collections of counties grouped together. Both climate zone and code adoption history were considered when developing these regions to ensure that a building is not reallocated into a region with completely different building characteristics and climate. As shown, many of the sampling region boundaries fall along state lines, but there are some regions that span multiple neighboring states that could have different energy codes. There is no viable solution for this limitation at this time because the reallocation process occurs in postprocessing; therefore, the building cannot be rerun with the correct energy code assignment. Based on the results, approximately 26% of the weighted building floor area is reallocated into a different state from the original model. Of that 26%, 4% were reallocated to a state with the same code in force; therefore, the reallocation does not impact those results. This leaves 22% of the stock floor area where the model is reallocated to a state with a different code in force, so there will be imperfections in the results. But at the aggregate level, we believe this measure still provides a good estimate of the anticipated savings if all existing buildings upgrade their envelope to the current code in force in their state.

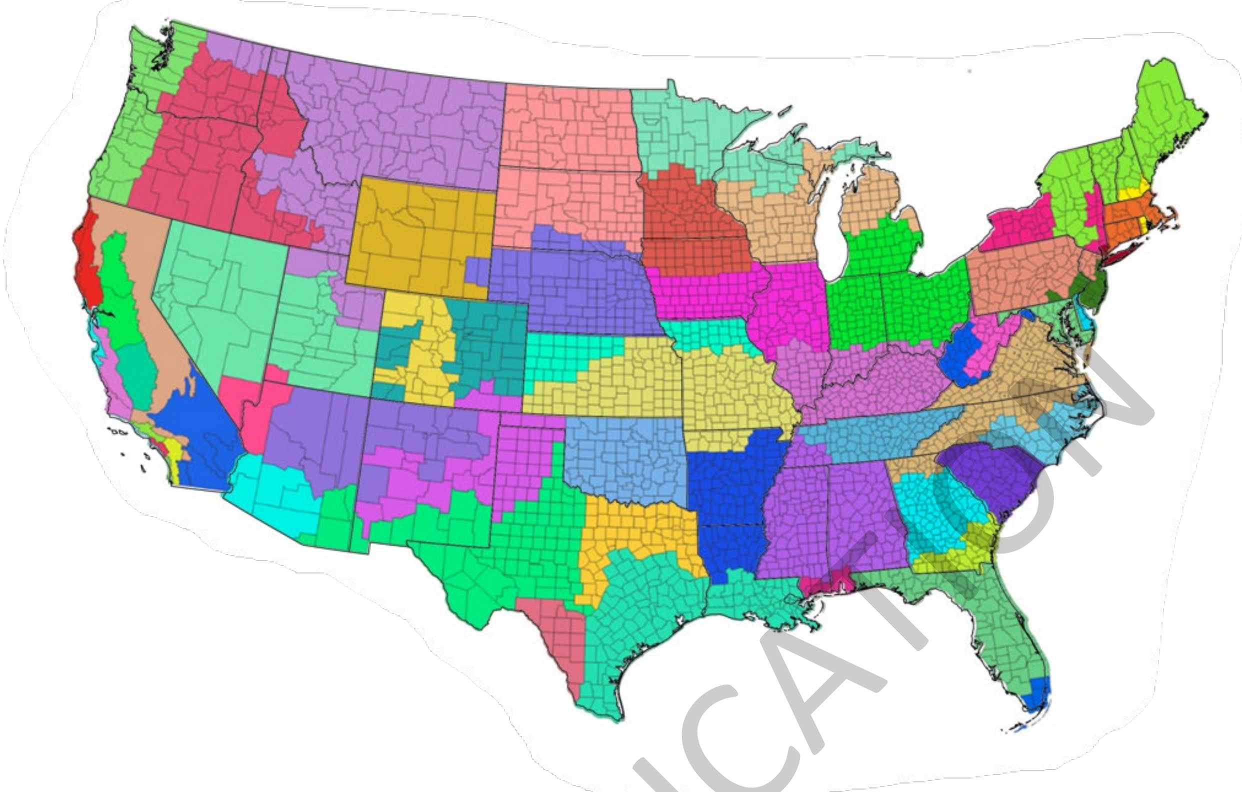

Figure 7. Map of sampling regions used by ComStock.

Image from [11].

Alaska and Hawaii, not shown, are each a single sampling region.

Another minor limitation of this measure is that it does not modify roof absorptance. In ComStock, all roofs are modeled with an absorptance of 0.7 (hence, a reflectance of 0.3). ASHRAE 90.1 requires that roofs in climate zones 0 through 3 have a minimum reflectance of 0.55 or, alternatively, adhere to stricter roof insulation requirements in these climate zones [2]. This requirement is not reflected in either the baseline or upgrade scenarios in ComStock. We anticipate this omission to have a trivial impact on results.

4 Output Variables

Table 16 includes a list of output variables that are calculated in ComStock. These variables are important in terms of understanding the differences between buildings with and without the Upgrade Envelope to Current State Code measure applied. These output variables can also be used for understanding the economics of the upgrade (e.g., return on investment) if cost information (i.e., material, labor, and maintenance costs for technology implementation) is available.

Table 16. Output Variables Calculated From the Measure Application

Envelope Component	Variable Name	Description
Windows	Window-to-wall ratio	Ratio of window area to exterior wall area for the building model (same in baseline and upgrade scenarios)
	Window type	Name of window construction from building model in baseline (window type after upgrade not reported; see Table 14 for assigned window type)
	Average window SHGC	Average SHGC of all the windows in the building model before (use baseline scenario) and after (use upgrade scenario) upgrade is applied
	Average window U-value	Average thermal conductance of all the windows in the building model before (use baseline scenario) and after (use upgrade scenario) upgrade is applied (Btu/ft^2*F*h)
	Average window VLT	Average visible light transmittance of all the windows in the building model before (use baseline scenario) and after (use upgrade scenario) upgrade is applied
	Exterior window area	Total window area replaced by the upgrade (ft^2)
Walls	Energy code followed during last wall replacement	Energy code followed during last wall replacement before the upgrade was applied (energy code after upgrade not reported; see Table 9 for assigned energy code by state)
	Wall construction type	Wall construction type (same in baseline and upgrade scenarios)
	Average wall U-value	Average thermal conductance of all the walls in the building model before (use baseline scenario) and after (use upgrade scenario) upgrade is applied (Btu/ft^2*F*h)
	Exterior wall area	Total wall area modified by the upgrade (ft^2)
Roof	Energy code followed during last roof replacement	Energy code followed during last roof replacement before the upgrade was applied (energy code after upgrade not reported; see Table 9 for assigned energy code by state)
	Average roof absorptance	Roof absorptance in the building model (same in baseline and upgrade scenarios)

	Average roof U-value	Average thermal conductance of the roof in the building model before (use baseline scenario) and after (use upgrade scenario) upgrade is applied (Btu/ft^2*F*h)
	Exterior roof area	Roof area modified by the upgrade (ft^2)

5 Results

This section presents the results both at the stock level and for individual buildings through savings distributions. Stock-level results include the combined impact of all the analyzed buildings in ComStock, including buildings that are not applicable to this measure; therefore, they do not necessarily represent the energy savings of a particular or average building. Stock-level results should not be interpreted as the savings that a building might realize by implementing the measure.

The total site energy savings are also presented in this section. The total site energy savings can be a useful metric, especially for quality assurance/quality control, but this metric on its own can have limitations for drawing conclusions. Further context should be considered, as site energy savings alone do not necessarily proportionally translate to savings for a particular fuel type (e.g., gas or electricity), source energy savings, or cost savings. This is especially important when a measure impacts multiple fuel types or causes decreased consumption of one fuel type and increased consumption of another. Many factors should be considered when analyzing the impact of an energy efficiency strategy, depending on the use case.

5.1 Single-Building Measure Tests

This section demonstrates the impacts of the Upgrade Envelope to Current State Code measure on a 175,000-ft^2 large hotel test model in Billings, Montana, which is climate zone 6B. This section walks through the checks that were done to ensure that the measure is properly applied and the resulting wall, roof, and window properties are as expected.

The model began with the DOE Ref Pre-1980 template. The baseline model's roof is a typical IEAD roof with an R-value of 16.67. The walls are steel framed with an R-value of 6.9. These values coincide with the expected R-values for the pre-1980 template and climate zone 6B (Table 3. and Table 5.). The baseline model's windows are single-pane, clear glazing, wood-framed windows with no low-e coating, which corresponds to a U-value of 0.91, an SHGC of 0.68, and a VLT of 0.723 (Table 7).

When the measure was applied, the wall insulation, roof insulation, and windows were upgraded to comply with ASHRAE 90.1-2019, which is the current state energy code for new construction buildings in Montana (Table 9). The upgraded model has an IEAD roof with an R-value of 31.25 and steel-framed walls with an R-value of 20.41. These values are consistent with the expected R-values for the specified construction type for 90.1-2019 and climate zone 6B (

Table 10 and Table 12). The upgraded model has triple-pane windows with clear glazing, thermally broken aluminum frames, and low-e coating, which have a U-value of 0.3, an SHGC of 0.328, and a VLT of 0.527 (Table 7). This is consistent with the expected window construction for 90.1-2019 and climate zone 6 (Table 14). This confirms that the measure successfully applied the correct roof, wall, and window properties to comply with ASHRAE 90.1-2019.

When evaluating the energy impacts of this upgrade for this single-building test model, we see an approximate 5% reduction in the annual site energy and energy use intensity. The natural gas heating end use is reduced by 9%, and the cooling end use is reduced by 2%. In a colder climate such as Montana's, it is expected that the insulation improvements will result in a larger reduction in heating energy than cooling energy, given the lower average outdoor air temperatures for much of the year. Notably, the annual peak is reduced by nearly 12% when applying the envelope improvements, demonstrating the potential for this measure to reduce stress on the electric grid. Table 17 summarizes the inputs, outputs, and percentage change for relevant building parameters for this single model example.

Table 17. Inputs and Outputs for Single Model Example Before and After Applying Upgrade Envelope to Current State Code Measure Scenario

Field	Baseline Model	Upgraded Model	Percentage Change
Wall insulation	R-6.9	R-20.41	196% increase
Roof insulation	R-16.67	R-31.25	87% increase
Windows	Single - clear - wood - no low-e	Triple - clear - thermally broken aluminum - low-e	N/A
	U-0.91	U-0.3	67% reduction
	SHGC-0.68	SHGC-0.328	52% reduction
Annual site energy (MBtu)	21,288.8	20,286.4	4.7% reduction
Energy use intensity (kBtu/sqft)	121.7	115.9	4.8% reduction
Annual electricity peak (kW)	508.6	447.9	11.9% reduction
Natural gas heating (therm)	97,799.8	88,913.7	9.1% reduction
Cooling electricity (kWh)	393,155.6	384,491.7	2.2% reduction

5.2 Stock Energy Impacts

The Upgrade Envelope to Current State Code measure demonstrates 7.7% total site energy savings (377.1 trillion British thermal units [TBtu]) for the U.S. commercial building stock modeled in ComStock. The savings contributions by end use and fuel type are summarized in Table ***18*** and illustrated in Figure 8. Because this measure is applicable to 100% of the stock, the savings for the full stock and applicable buildings are the same.

Table *18*. Summary of Site Energy Savings From Upgrade Measure Application Versus the ComStock Baseline

End Use/Fuel Type	Percentage Site Energy Savings (All Buildings)	Percentage Site Energy Savings (Applicable Buildings Only)	Absolute Site Energy Savings (TBtu)
Total natural gas	11.5%	11.5%	179.5
Total electricity	5.8%	5.8%	187.4

Total heating	18.8%	18.8%	252.2
Total cooling	12.7%	12.7%	103.0
Gas heating	18.1%	18.1%	179.5
Electric heating	21.4%	21.4%	57.4
Electric cooling	13.2%	13.2%	98.6
Electric fans	5.1%	5.1%	29.6

As shown in Figure 8, the Upgrade Envelope to Current State Code measure primarily shows the annual site energy savings for cooling electricity, natural gas heating, heating electricity, and fan electricity. The improvements to the envelope components (increased wall/roof insulation, high-performance windows) help buildings better maintain their interior temperature throughout the year, reducing heating loads in winter and cooling and loads in summer. In addition, the envelope improvements help prevent unwanted solar heat gains during the summer, reducing cooling loads. With decreased loads, the HVAC system runs less, and thus there are fan savings as well. There could be other end uses with minimal impacts; however heating, cooling, and fans comprise the vast majority of the energy savings from this measure.

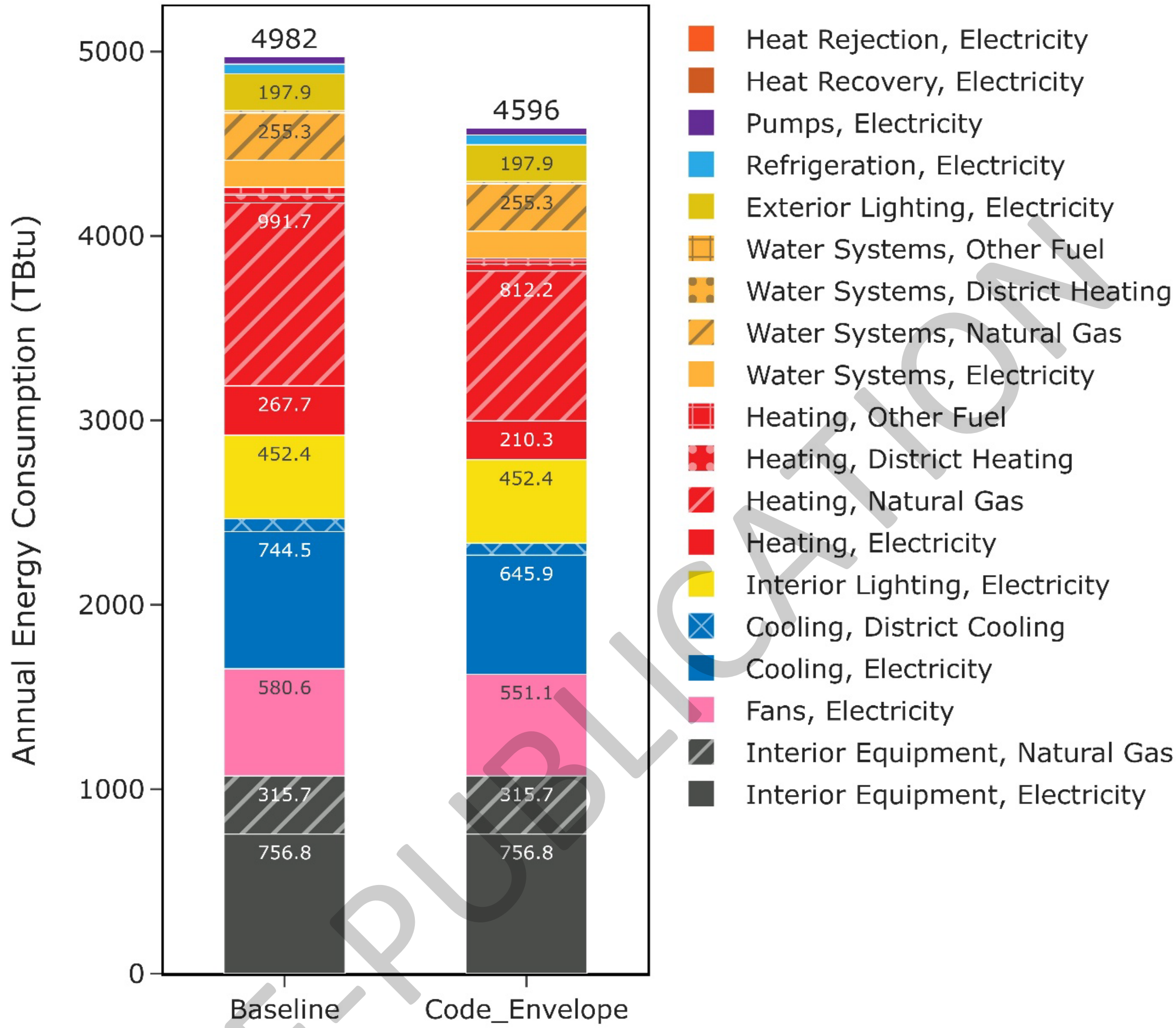

Figure 8. Comparison of annual site energy consumption between the ComStock baseline and the Upgrade Envelope to Current State Code measure scenario

5.3 Stock Utility Bill Impacts

This section includes a comparison of national-level annual utility bills of the stock across different fuel sources (i.e., electricity, natural gas, propane, and fuel oil). ComStock uses utility region mapping to determine all associated electricity rates that can be used by a building in that region; therefore, the results can include many annual utility rates per building. The comparison in this section highlights three statistics (maximum, mean, and minimum) across all possible electric utility rates in each location. For more information about the utility bill methodology in ComStock, see the *ComStock Reference Documentation* [11].

As shown in Table 19, when combining all fuels, the Upgrade Envelope to Current State Code measure scenario resulted in $8.9 billion (7%) total utility bill savings across the building stock when using the mean electricity rate. Most of the absolute bill savings are attributed to electricity bills ($6.7 billion), followed by natural gas bills ($1.9 billion). Fuel oil and propane, despite showing high percentage bill savings, do not contribute much to the absolute bill savings because these fuels are not very common in the building stock. Because this measure is applicable to 100% of the stock, the savings for the full stock and applicable buildings are the same.

Table 19. Summary of Key Results for Annual Utility Bill Savings

Electricity bill savings in this table are calculated using the mean available electricity rate available for each building. Other electricity rate structures are available in this report and in the public dataset. "Applicable" buildings are those that receive the upgrade based on the criteria defined for this study.

End Use/Fuel Type	Percentage Savings (All Buildings)	Percentage Savings (Applicable Buildings Only)	Absolute Savings (Billion USD, 2022)
Natural gas	10.6%	10.6%	1.9
Electricity	6.1%	6.1%	6.7
Fuel oil	26.0%	26.0%	0.2
Propane	15.0%	15.0%	0.2
Total	6.9%	6.9%	8.9

Figure 9 shows the utility bill savings for a range of electricity rates. Note that this figure rounds to the nearest billion. The total bill savings across all fuels are $8–$10 billion, depending on the electricity rate used. Electricity bills are reduced by $6 billion when using the minimum rate and $7 billion when using the maximum rate. Natural gas bills are reduced by $2 billion across all three scenarios. Propane and fuel oil bills show small savings but are not reflected in this figure, which rounds to the nearest $1 billion.

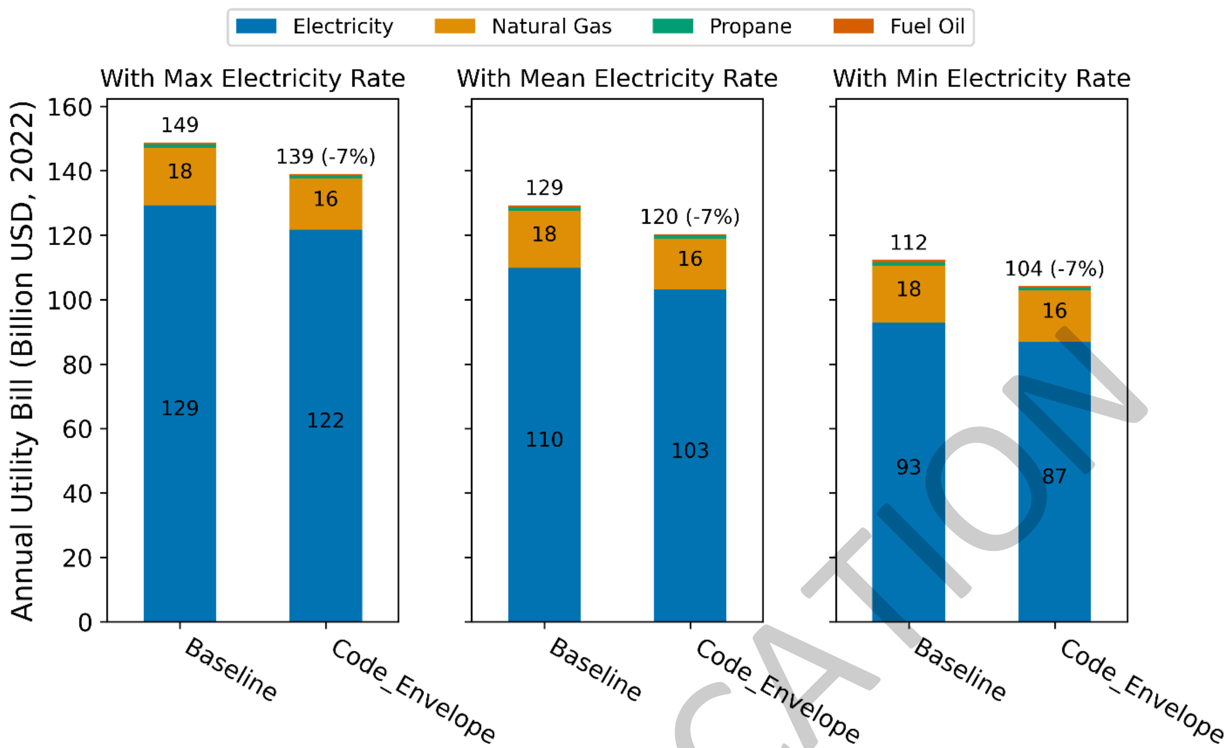

Figure 9. Annual utility bill impacts using the max, mean, and minimum bills across available rate structures for buildings for the Upgrade Envelope to Current State Code measure scenario

5.4 Peak Demand Impacts

Figure 11 shows the impact of the Upgrade Envelope to Current State Code measure on the median seasonal peak intensity. The peak intensity is the seasonal peak normalized by square footage in units of watts per square foot. Note that this plot shows only the median peak values, meaning there could be individual buildings with lower or higher peak reductions than what are shown in Figure 10.

This measure shows moderate impact on summer peaks. In warmer, cooling-dominated climates (1–3), we see the highest summer peak reductions, with a median reduction of 9% in climate zone 2. In moderate and colder climates (4+), the median summer peak reductions are near 3%; however, these climate zones have lower cooling demand, so we would expect less impact on summer peaks in these locations.

Winter peaks show nontrivial reductions in most climate zones. Winter electric peak reductions are going to be the most pronounced in buildings with electric heating. The insulation improvements applied through this measure will reduce the electric heating demands in those buildings. The winter peak reductions range from 5.2% in climate zone 1 to 15.4% in climate zone 8. The percentage peak reduction increases when going from the warmest to the coldest climate zones, which is expected based on relative heating demands.

In shoulder seasons, the peak intensity reduction ranged from 4.1% to 6.5% for all climate zones except climate zone 8, which was a 2.1% reduction. Climate zone 1 showed the highest peak reduction, 6.5%, as cooling still dominates electricity peak loads in shoulder seasons in the hottest climates. In general, the Upgrade Envelope to Current State Code measure shows some peak reductions across nearly all seasons and climate zones. The upgraded insulation reduces heating and cooling loads in buildings, which, in turn, reduce peak loads during crucial times of year when the electric grid is most stressed.

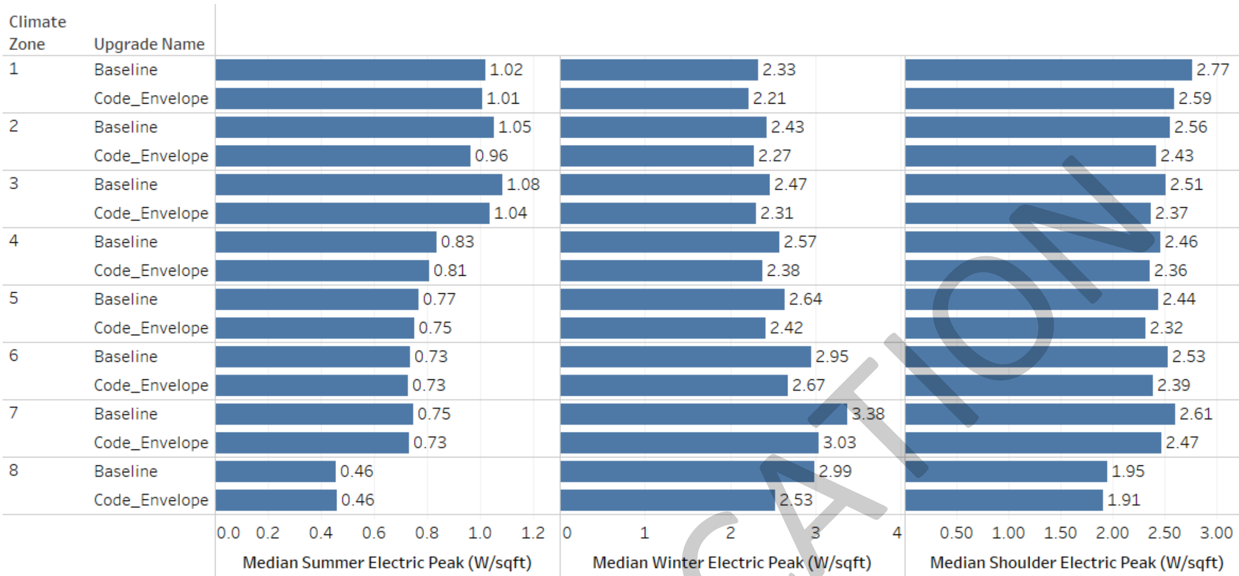

Figure 10. Seasonal peak intensity when applying the Upgrade Envelope to Current State Code measure scenario

5.5 Site Energy Savings Distributions

This section discusses the site energy consumption for quality assurance/quality control. Note that site energy savings can be useful for these purposes, but other factors should be considered when drawing conclusions because they do not necessarily proportionally translate to source energy savings or energy cost.

Figure 11 shows the percentage savings distributions of the baseline ComStock models versus the Upgrade Envelope to Current State Code measure by end use and fuel type for applicable models. In other words, each data point in the distribution represents the percentage energy savings between a baseline ComStock model and the corresponding model with measures applied.

The highest percentage savings are seen in natural gas heating, other fuel heating, and electricity heating, with median savings of 20% or more. The cooling and fan electricity end uses show median savings of 10% and 5%, respectively. Several other end uses—such as pumps, district heating and cooling, and heat rejection—show median savings of 5% to 10%; however, these end uses comprise only a small portion of the total site energy consumption of the building stock. As previously stated, the insulation and window improvements implemented by this measure help reduce HVAC loads by keeping the building conditioned for longer.

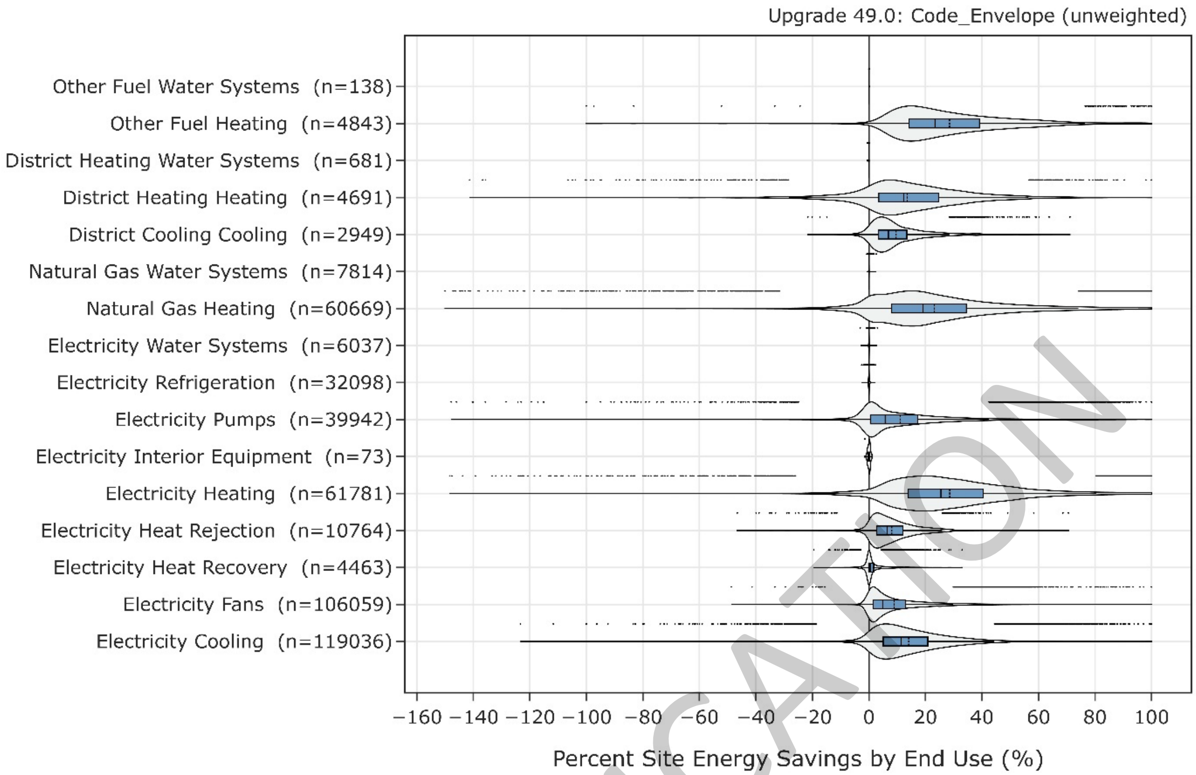

Figure 11. Percentage site energy savings distribution for ComStock models with applied measure scenario by end use and fuel type.

The data points that appear above some of the distributions indicate outliers in the distribution, meaning they fall outside 1.5 times the interquartile range. The value for n indicates the number of ComStock models that were applicable for energy savings for the fuel type category.

Figure 12 shows the percentage savings distributions of the baseline ComStock models versus the Upgrade Envelope to Current State Code measure by fuel for applicable models. "Other Fuel" shows the highest percentage savings (median 20%); however, this fuel comprises a relatively small portion of the total site energy of the stock. Natural gas and district heating show median savings of approximately 10%, and electricity and district cooling show median savings closer to 5%. When combining all fuels, the total site energy savings are range from 5% to 13% for the middle 50% of the buildings, with some outliers nearing 40% savings. A very small number of buildings show negative savings. These are buildings with very minimal HVAC loads (such as warehouses, some of which are effectively unconditioned) or buildings without cooling; therefore, this measure is not very effective, and small-magnitude changes to HVAC loads can result in a high percentage change. On average, this measure results in approximately 8% site energy savings when upgrading the wall and roof insulation and replacing the windows to meet the criteria of the current state code.

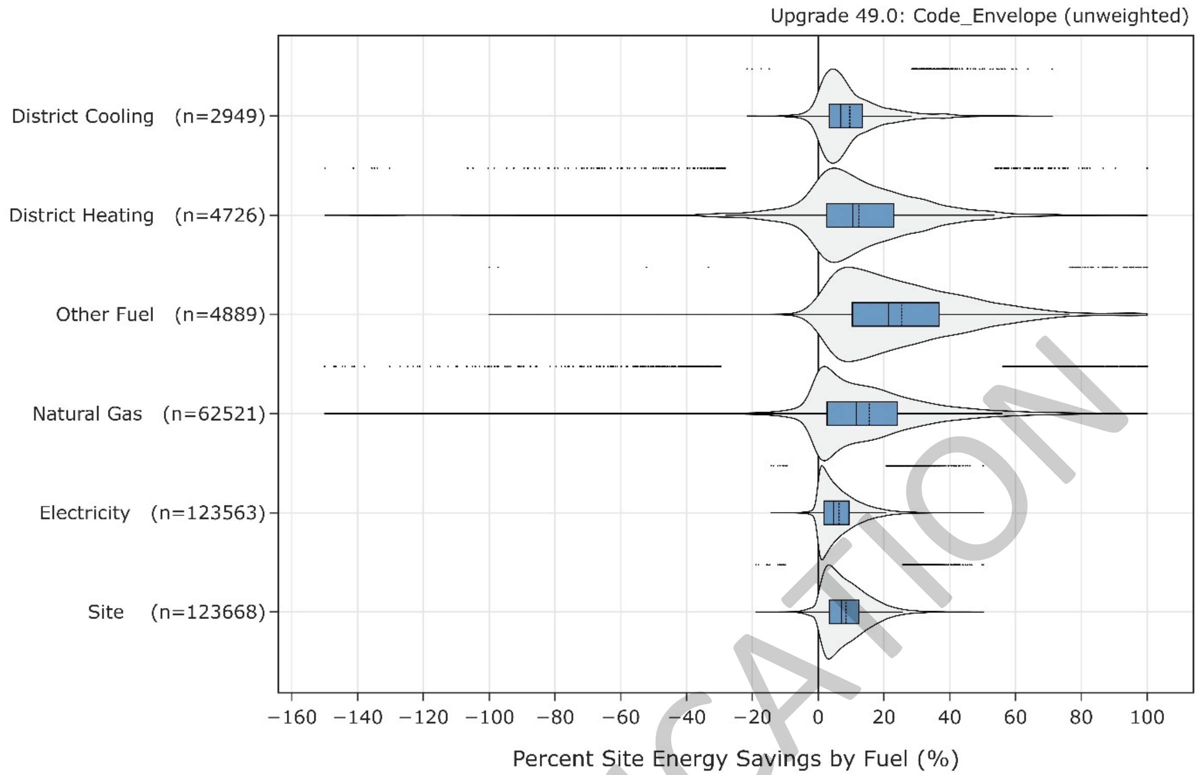

Figure 12. Percentage site energy savings distribution for ComStock models with the applied measure scenario by fuel type.

The data points that appear above some of the distributions indicate outliers in the distribution, meaning they fall outside 1.5 times the interquartile range. The value for n indicates the number of ComStock models that were applicable for energy savings for the fuel type category.

5.6 Utility Bill Savings Distributions

Figure 13 shows the percentage utility bill savings distributions of the baseline ComStock models versus the Upgrade Envelope to Current State Code measure by fuel type for applicable models. In other words, each data point in the distribution represents the percentage utility bill savings between a baseline ComStock model and the corresponding model with the measure applied.

Like the site energy results, propane and fuel oil bills show the largest percentage reduction in bills, but these fuels are only present in a small fraction of the stock. This measure shows median natural gas bill savings of approximately 11%, with the upper quartile reaching 20% savings. The median electricity bill savings are approximately 6% when using the mean electricity rate. The total utility bills for the median building are reduced by approximately 7% when combining all fuels. Some buildings at the upper end of the distribution can reach 20% or more in total bill savings from upgrading their building envelope to the current code.

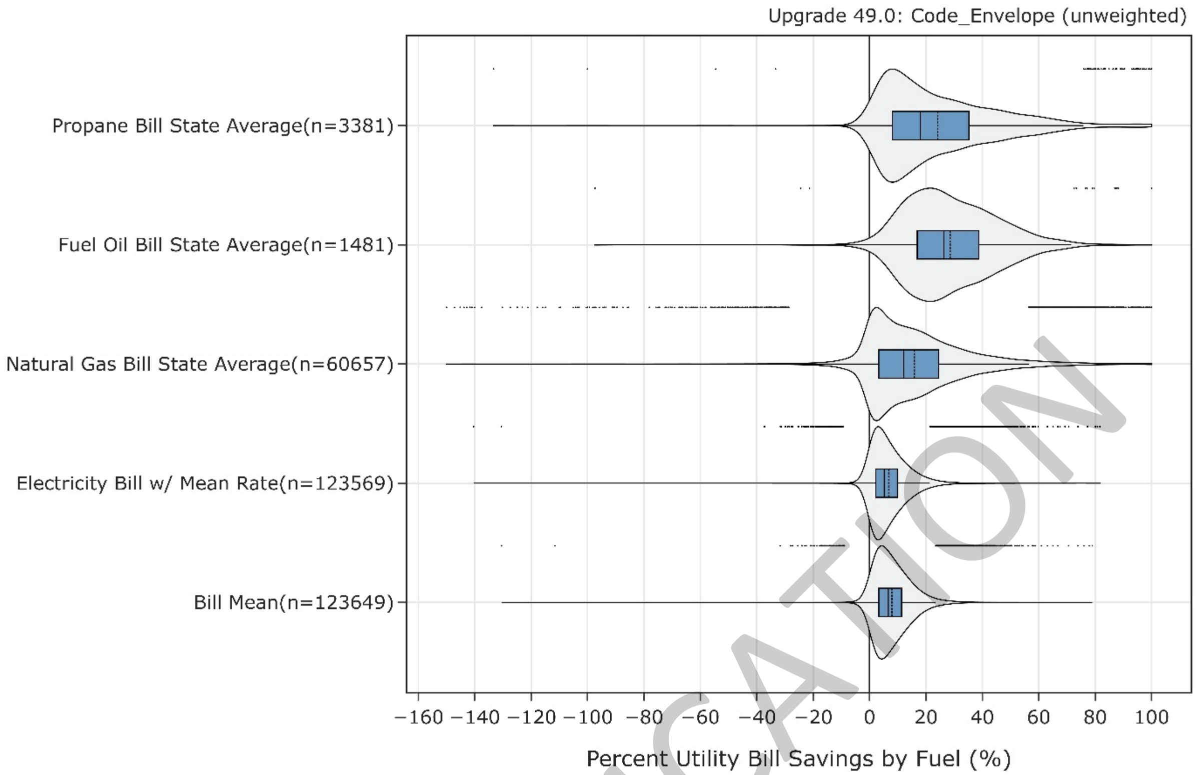

Figure 13. Percentage annual utility bill savings distribution for ComStock models with the Upgrade Envelope to Current State Code measure scenario by fuel type.

Results shown in this plot are the savings for the average available utility rate per building. The data points that appear above some of the distributions indicate outliers in the distribution, meaning they fall outside 1.5 times the interquartile range. The value for n indicates the number of unweighted ComStock models that were applicable for energy savings for the fuel type category.

When evaluating utility bill savings by climate zone (Figure 14), we see a very subtle trend of higher savings when going from warmer to colder climates. Most climate zones show median bill savings that range from 5% to 10%. The savings potential for a building is largely driven by the difference in the code followed in the orginal building versus the current state code in force that the building gets upgraded to, so climate zone is not necessarily linked to energy savings; however, because colder climates will benefit more from better insulation and better windows, it makes sense to see colder climates with slightly higher savings.

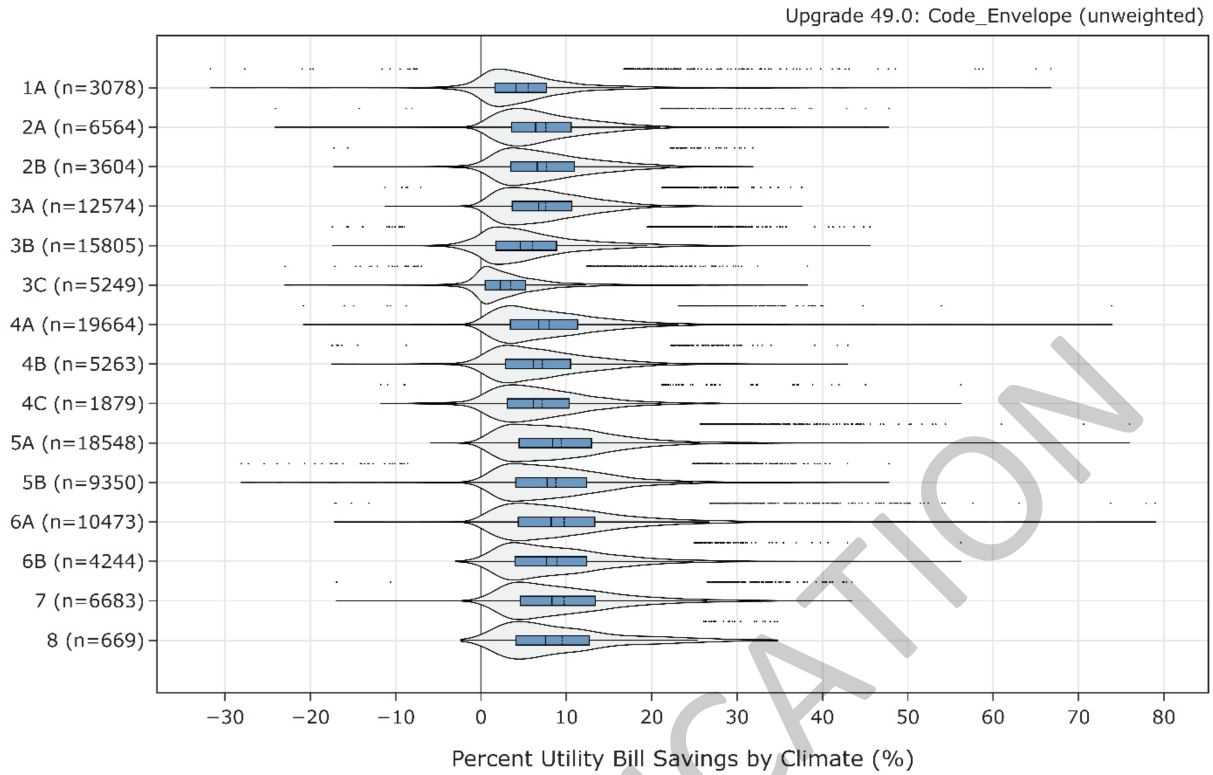

Figure 14. Percentage annual utility bill savings distribution for ComStock models with the Upgrade Envelope to Current State Code measure scenario by climate zone.

Results shown in this plot are the savings for the average available utility rate per building. The data points that appear above some of the distributions indicate outliers in the distribution, meaning they fall outside 1.5 times the interquartile range. The value for n indicates the number of unweighted ComStock models that were applicable for energy savings for the fuel type category.

5.7 Other Findings

Because this measure determines the target code in force at the state level, Figure 15 shows the median site energy savings by state for the full building stock. The median values shown are not area weighted, meaning every building model is equally weighted when calculating the median savings by state. The trends we see are driven by (1) the starting code followed by the baseline building, (2) the target code currently followed by the state, and (3) the climatic conditions of the state that drive the HVAC energy performance. Higher savings of 9% to 12% are seen mainly in the cold northern states of the West, Midwest, and New England regions. Vermont has the highest median savings of any state, 12.0% (value not shown on map). Warm southern states show median savings closer to 5% to 7%. California shows the lowest savings potential, only 2.9%, but this is likely driven by the fact that the baseline stock in California already adheres to more stringent energy codes than the rest of the country, and therefore there is less opportunity for energy savings. In addition, much of California's building stock resides in more mild, coastal climates, so we might expect lower savings for a measure that primarily impacts HVAC loads.

When comparing the savings map to the map of current code in force by state (Figure 16), the results show that the highest savings are typically found in states that have adopted more ambitious energy codes (90.0-2016 or 90.1-2019). These newer codes require higher insulation R-values and higher performance windows and are therefore going to have higher savings potential. This is particularly true in states with cold climates, where additional insulation and high-performance windows are going to have the most impact on HVAC energy performance. The savings potential for this measure can vary greatly from one building to another because it is a complex interaction of many factors, including the starting insulation levels and window properties in the building (determined by the energy code of the existing building), the target insulation levels and window properties (determined by the current energy code in force by the state), and the HVAC loads of the building (determined by, among other factors, the type of building, HVAC system, and climatic conditions of the building location). Despite this complexity and some of the limitations discussed earlier, this measure is meant to give an idea of the aggregated state-, regional-, or stock-level savings expected if all commercial buildings improved their envelope to meet the current code enforced in their state. The total site energy savings for the stock are 7.7%, with state median savings ranging from 2.9% to 12.0%.

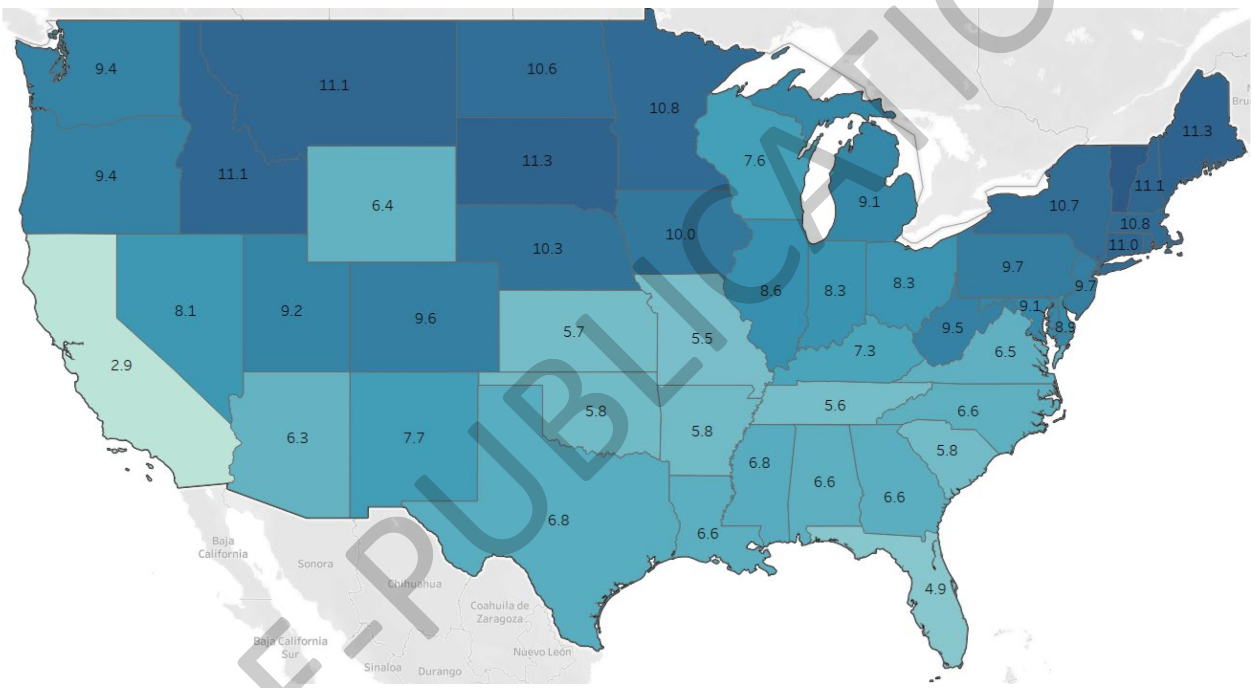

Figure 15. Annual median percentage site energy savings by state.

Alaska: 11.7%, Hawaii: 3.6%

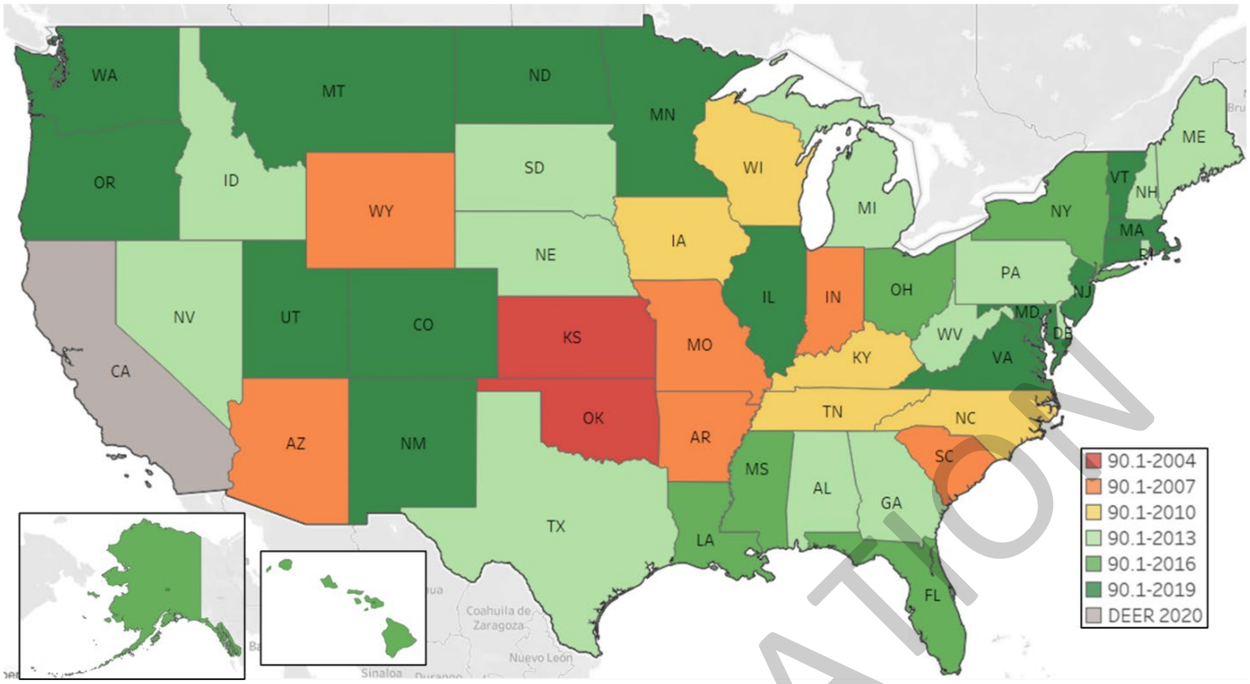

Figure 16. Final assumptions for current code in force by state

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