



→ Energy Efficiency Modeling of Gas-Fired Heat Pump Water Heater

Project Number ET22SWG0009

GAS EMERGING TECHNOLOGIES (GET) PROGRAM
August 2025

Prepared by ICF for submission to Southern California Gas Company



CONTENTS

Acknowledgements	9
Disclaimer	9
Executive Summary	10
Overview	11
Background	11
OpenStudio/EnergyPlus.....	12
OpenStudio-HPXML/ResStock	13
BuildStock Batch.....	14
Assessment Objectives	14
Scenarios	15
Stock Projections	18
Scenario Details.....	20
Scenario Comparisons	24
Shared Water Heater Modeling	31
ResStock Modeling Enhancements	32
Central System Layouts	35
Simulation Outputs and Results.....	48
Building Segment Results	48
GAHP Upgrade Results	62
Conclusions and Future Work.....	66
Appendix A. Title 24/20 Mapping	68
A.1 Code Adoption	68
A.2 2022 Prescriptive Path Code-Compliant Equipment Options.....	69
A.3 2022 Prescriptive Path Code-Compliant Envelope Options.....	75
A.4 Future Code Years.....	76
Appendix B. Electrification.....	80
B.1 Options for Fuel-Switching	80
B.2 New Construction Local Electrification Locations.....	82

Appendix C. Dwelling Unit Counts.....	84
C.1 Multifamily Buildings.....	84
C.2 Natural Gas	86
C.3 All-Electric.....	87
Appendix D. Additional Building Segment Results	88
D.1 Energy Consumption.....	88
D.2 Emissions	100
D.3 Utility Bills.....	112
Glossary	118
References	119

LIST OF TABLES

Table 1: Example BuildStock CSV File.....	16
Table 2: High-Level Summary Table of the Six ResStock Projection Scenarios	17
Table 3: Summary Table for How the Six ResStock Projection Scenarios Are Parameterized.....	21
Table 4: Mapping of ResStock Scenarios to Distribution Plots Projection Year Keys.....	26
Table 5: Plant Loop Component Summary for Boiler With Storage Tanks	39
Table 6: Plant Loop Component Summary for Heat Pump Water Heater With Storage Tanks.....	43
Table 7: California Code HVAC Options	70
Table 8: California Code Water Heating Options.....	71
Table 9: Lighting and Appliance Options.....	72
Table 11: 2022 and 2025 Title 24 PV Capacity Factors for Buildings With Four or More Stories.	74
Table 10: 2022 Title 24 Parameters for Minimum PV Size for Buildings With Three or Fewer Stories.....	74
Table 12: 2022 Title 24 Envelope Options.....	75
Table 13: 2025 Title 24 Code Updates.	76
Table 14: 2025 Title 24 Parameters for Minimum PV Size for Buildings With Three or Fewer Stories.....	78
Table 15: 2025 Title 24 Battery Energy Capacity Factors for Buildings With Four or More Stories.	79
Table 16: Estimated 2028 Title 24 Code Charges	79
Table 17: List of All Sampled Parameter/Options That Are Updated to Corresponding Electric Options.	80
Table 18: List of ResStock-Sampled Cities for Which Local Electrification Policies Are Applied in Years 2026 and 2029 for New Construction.	82
Table 19: List of ResStock-Sampled Counties for Which Local Electrification Policies Are Applied in Years 2026 and 2029 for New Construction.	82

Table 20: List of Places (County and PUMA) for Which Local Electrification Policies Are Applied in Years 2026 and 2029 for New Construction.....	83
Table 22: Counts of Total Dwelling Units and Buildings, Across the CEC Climate Zones, for the Multifamily Segment in Year 2020.....	85
Table 21: Counts of Total Dwelling Units and Buildings, Across Building Stories, for the Multifamily Segment in 2020.	85

LIST OF FIGURES

Figure 1: Flowchart depicting the process of converting ResStock housing characteristics data into complete building energy models.....	12
Figure 2: A high-level overview of the ResStock workflow steps and what occurs during those steps.	14
Figure 3: Flowchart depicting the process of using a sampled buildstock CSV file and the BuildStock Projections tool to output updated buildstock CSV files.	18
Figure 4: Count of total dwelling units across projection years.	25
Figure 5: Counts of total dwelling units across projection years, broken out by CEC climate zone.	26
Figure 6: Distributions of heating fuel options, across projection scenarios, for the entire stock.	27
Figure 7: Distributions of water heater fuel options, across projection scenarios, for the entire stock.	28
Figure 8: Fraction of dwelling units, across projection scenarios, having at least one gas-consuming end use.	29
Figure 9: Fraction of dwelling units, across projection scenarios, for which all end uses consume only electricity.	30
Figure 10: Fraction of dwelling units, across projection scenarios, having PV installed.	31
Figure 11: Plumbing diagram of an existing boiler that provides water heating.	36
Figure 12: Plumbing diagram of GAHP retrofits that provide water heating.	37
Figure 13: Supply loop of a storage tank with a boiler.....	40
Figure 14: Storage loop for a boiler serving domestic hot water.....	42

Figure 15: Recirculation loop serving domestic hot water in units.....	42
Figure 16: Supply loop of a storage tank with a GAHP.....	43
Figure 17: GAHP heating capacity correction factor as a function of ambient and return temperature.....	44
Figure 18: GAHP coefficient of performance (COP) as a function of ambient and return temperature.....	44
Figure 19: Example of the EMS program impacting COP during startup. Without this EMS program, the COP during the first timestep when the GAHP turns on (at 15 minutes) would be near 1.2.	45
Figure 20: Storage loop for cases with a GAHP. The GAHP is coupled with the first storage tank as a preheater, while the existing boiler coupled with a storage tank serves the loads.....	46
Figure 21: Storage loop for cases with three GAHPs. Multiple GAHPs are configured in series as preheaters, with one GAHP and an associated storage tank serving as preheaters. The existing boiler remains after the last GAHP storage tank to meet any remaining loads.....	47
Figure 22: Per-unit average net energy use across projection scenarios, for California.....	50
Figure 23: Per-unit average hot water energy use across projection scenarios, for California.	51
Figure 24: Per-unit average net electricity use across projection scenarios, for California...	52
Figure 25: Per-unit average hot water electricity use across projection scenarios, for California.	52
Figure 26: Per-unit average natural gas use across projection scenarios, for California.....	53
Figure 27: Per-unit average hot water natural gas use across projection scenarios, for California.	54
Figure 28: Cambium’s generation and emission assessment (GEA) regions.....	55
Figure 29: Per-unit average net emissions across projection scenarios, for California.....	56
Figure 30: Per-unit average hot water emissions across projection scenarios, for California.	56
Figure 31: Per-unit average net electricity emissions across projection scenarios, across California.....	57

Figure 32: Per-unit average hot water electricity emissions across projection scenarios, across California.....	58
Figure 33: Per-unit average natural gas emissions across projection scenarios, across California.....	59
Figure 34: Per-unit average hot water natural gas emissions across projection scenarios, across California.....	59
Figure 35: Per-unit average bills across projection scenarios, for California.....	61
Figure 36: Per-unit average electricity bills across projection scenarios, across California.....	61
Figure 37: Per-unit average natural gas bills across projection scenarios, across California.....	62
Figure 38: Bar plot of total (top) and per-unit average (bottom) hot water (electricity + natural gas) energy consumption across baseline/upgrade scenarios, broken out by CEC climate zone.....	63
Figure 39: Bar plot of total (top) and per-unit average (bottom) hot water (electricity + natural gas) energy consumption across baseline/upgrade scenarios, broken out by number of dwelling units per building.....	64
Figure 40: Scatterplot of per-unit hot water (electricity + natural gas) energy consumption across baseline/upgrade scenarios, in year 2029.....	65
Figure 41: California Energy Commission climate zones.....	69
Figure 42: Counts of total dwelling units across projection years, broken out by building type.....	84
Figure 43: Counts of total dwelling units across projection years for multifamily buildings, broken out by building stories.....	84
Figure 44: Counts of total dwelling units, across projection scenarios, having at least one gas consuming end use.....	86
Figure 45: Counts of total dwelling units, across projection scenarios, for which all end uses consume only electricity.....	87
Figure 46: Total net energy use across projection scenarios, for California.....	88
Figure 47: Total (top) and per-unit average (bottom) net energy use across projection scenarios, broken out by CEC climate zone.....	89
Figure 48: Total hot water energy use across projection scenarios, for California.....	90

Figure 49: Total (top) and per-unit average (bottom) hot water energy use across projection scenarios, broken out by CEC climate zone.....	91
Figure 50: Total net electricity use across projection scenarios, for California.....	92
Figure 51: Total (top) and per-unit average (bottom) net electricity use across projection scenarios, broken out by CEC climate zone.....	93
Figure 52: Total hot water electricity use across projection scenarios, for California.....	94
Figure 53: Total (top) and per-unit average (bottom) hot water electricity use across projection scenarios, broken out by CEC climate zone.....	95
Figure 54: Total natural gas use across projection scenarios, for California.	96
Figure 55: Total (top) and per-unit average (bottom) natural gas use across projection scenarios, broken out by CEC climate zone.	97
Figure 56: Total hot water natural gas use across projection scenarios, for California.	98
Figure 57: Total (top) and per-unit average (bottom) hot water natural gas use across projection scenarios, broken out by CEC climate zone.....	99
Figure 58: Total net emissions across projection scenarios, for California.	100
Figure 59: Total (top) and per-unit average (bottom) net emissions across projection scenarios, broken out by CEC climate zone.	101
Figure 60: Total hot water emissions across projection scenarios, for California.....	102
Figure 61: Total (top) and per-unit average (bottom) hot water emissions across projection scenarios, broken out by CEC climate zone.....	103
Figure 62: Total net electricity emissions across projection scenarios, across California...	104
Figure 63: Total (top) and per-unit average (bottom) net electricity emissions across projection scenarios, broken out by CEC climate zone.....	105
Figure 64: Total hot water electricity emissions across projection scenarios, across California.....	106
Figure 65: Total (top) and per-unit average (bottom) hot water electricity emissions across projection scenarios, broken out by CEC climate zone.....	107
Figure 66: Total natural gas emissions across projection scenarios, across California.....	108
Figure 67: Total (top) and per-unit average (bottom) natural gas emissions across projection scenarios, broken out by CEC climate zone.....	109

Figure 68: Total hot water natural gas emissions across projection scenarios, across California.....	110
Figure 69: Total (top) and per-unit average (bottom) hot water natural gas emissions across projection scenarios, broken out by CEC climate zone.....	111
Figure 70: Total bills across projection scenarios, for California.....	112
Figure 71: Total (top) and per-unit average (bottom) bills across projection scenarios, broken out by CEC climate zone.	113
Figure 72: Total electricity bills across projection scenarios, across California.....	114
Figure 73: Total (top) and per-unit average (bottom) electricity bills across projection scenarios, broken out by CEC climate zone.	115
Figure 74: Total natural gas bills across projection scenarios, across California.....	116
Figure 75: Total (top) and per-unit average (bottom) natural gas bills across projection scenarios, broken out by CEC climate zone.	117

TABLE OF EQUATIONS

Equation 1: Minimum PV sizing for buildings with four or more stories under Title 24.....	73
Equation 2: PV sizing for buildings with four or more stories	73
Equation 3: Battery sizing based on PV capacity	74
Equation 4: Minimum PV sizing for buildings with four or more stories under Title 24 which factors in EER2.....	77
Equation 5: Battery sizing based on floor conditions	78

Acknowledgements

ICF is responsible for this project. This project, ET22SWG0009, was developed as part of the Statewide Gas Emerging Technologies (GET) Program under the auspices of SoCalGas as the Statewide Lead Program Administrator. The National Renewable Energy Laboratory (NREL) conducted a simulation analysis study using EnergyPlus where efforts were led by Jeff Maguire and Joseph Robertson. Madeline Talebi provided project oversight with overall guidance and management from the ICF Technical Lead, Steven Long. For more information on this project, contact steven.long@icf.com.

Disclaimer

This report was prepared by ICF and funded by California utility customers under the auspices of the California Public Utilities Commission. Reproduction or distribution of the whole or any part of the contents of this document without the express written permission of ICF is prohibited. This work was performed with reasonable care and in accordance with professional standards. However, neither ICF nor any entity performing the work pursuant to ICF's authority make any warranty or representation, expressed or implied, with regard to this report, the merchantability or fitness for a particular purpose of the results of the work, or any analyses, or conclusions contained in this report. The results reflected in the work are generally representative of operating conditions; however, the results in any other situation may vary depending upon particular operating conditions.

Executive Summary

This report details an effort to model gas absorption heat pumps (GAHP) as a potential water heating efficiency upgrade for larger multifamily buildings in the California housing stock. GAHPs, also referred to as gas heat pumps or gas-fired heat pumps, are an emerging technology that use heat from natural gas combustion instead of electricity to transfer heat from outdoor air to indoor water. The technology is more efficient than other fuel-fired water heating equipment used in multifamily buildings today.

As part of this effort, researchers from NREL used ResStock™ to model the impact of installing GAHPs as a retrofit in a portion of the California housing stock that is currently using large central boilers to meet domestic hot water loads in multifamily buildings. ResStock modeling helped us understand the statewide and per-dwelling-unit impact this upgrade would have on:

- Annual energy use
- Operational costs
- Greenhouse gas emissions

The analysis relies on ResStock modeling in 16 California Energy Commission (CEC) climate zones for the residential multifamily building segment. The scenarios outlined below were used for the ResStock analysis. Note that additional details are discussed in the Scenario and Scenario Details Sections.

- Scenario 1: The baseline/existing California residential multifamily housing stock.
- Scenario 2: The 2023 multifamily housing stock reflecting 2022 Title 24/Title 20 code compliance (see Appendix A for more details) in new construction, adoption of more efficient gas waters in 20% of the stock, adoption of PV in 1% of the stock, and local electrification measures as of February 2023.
- Scenario 3a: The 2026 projected multifamily housing stock reflecting projected 2025 code compliance, gas water heater adoption at 20% turnover every 3 years, PV adoption in 1% of the stock, and baseline electrification of 1% of the stock.
- Scenario 3b: Scenario 3a with gas heat pump water heaters targeting 0.7% market penetration and 0.1% baseline electrification.
- Scenario 4a: The 2029 projected multifamily housing stock reflecting estimated 2028 code compliance, gas water heater adoption at the same rate of 20% turnover every 3 years, adoption of PV in 1% of the stock, and baseline electrification of 1% of the stock.
- Scenario 4b: Scenario 4a with gas heat pump water heaters targeting 6.5% market penetration and 0.1% baseline electrification.

Whole-building models were created from ResStock samples for individual dwelling units that were identified as being served by gas-fired shared water heating systems. A new OpenStudio® measure was developed for integrating these shared water heating systems into whole-building models. The types of water heating system configurations applied were a central boiler with storage tanks as well as a central gas heat pump (with boiler backup) and storage tanks. For both configurations, a series of plant loops were plumbed and connected, including supply loops, storage loops, and domestic hot water (DHW) recirculation loops.

Results generally show some decreases in net energy consumption, utility bills, and emissions across all scenarios compared to the baseline. Additionally, the more efficient gas heat pump water heater can offer substantial energy and emissions savings over the baseline boiler across the entire housing stock, with more modest total utility bill savings due to most of the bills being related to electricity use. Savings are larger in smaller multifamily buildings. In larger buildings, multiple GAHPs would be used to offset more of the load, and installing GAHPs in series can lead to lower efficiencies in subsequent units.

Overview

This work involves NREL generating a set of six ResStock scenarios, simulating them using the analysis tools described in the Background section, processing results, and reporting aggregated outputs and other research findings related to energy consumption, operational costs (i.e., utility bills), and greenhouse gas emissions for the multifamily residential building stock segment in California. The overall goal and purpose of this work is to assess the impact of adopting gas heat pumps for water heating for multifamily housing, as well as the impact of certain changes on both the gas and electric side due to policy and market changes, on the residential multifamily housing segment.

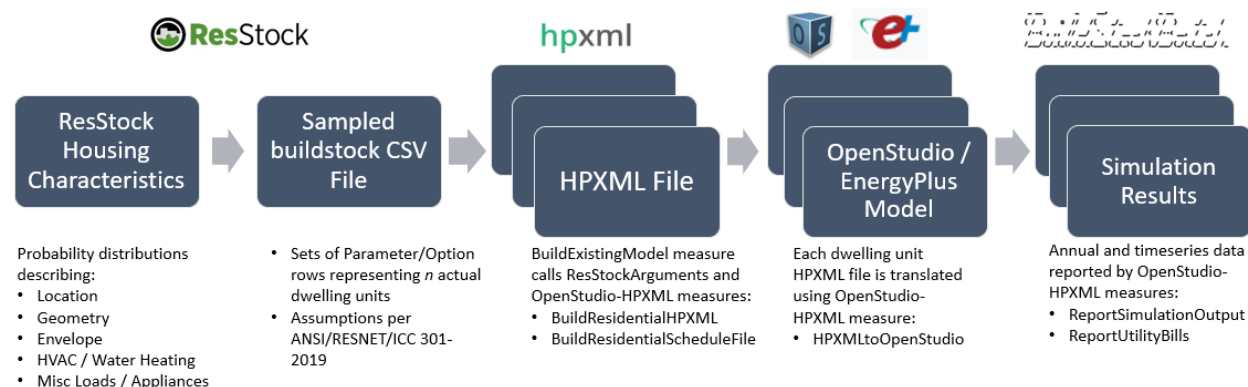
Background

NREL uses a collection of software tools for residential building modeling, including:

- EnergyPlus®
- OpenStudio
- OpenStudio-HPXML
- ResStock

The general workflow of these tools is depicted in the flow chart in Figure 1. This flow chart depicts the process of assembling ResStock characteristics data combined with other assumptions to generate descriptions of individual dwelling units that form building energy models.

Figure 1: Flowchart depicting the process of converting ResStock housing characteristics data into complete building energy models.



For this project, ResStock was used to estimate the energy, operational cost, and emissions impacts of various projected scenarios involving CEC code compliance, electrification, and gas efficiency upgrades. A subset of the existing residential housing stock was considered.

The following sections provide more detail for each piece of the overall workflow. This Background section describes the down-selected building stock and the approach taken for assessing the impact of adopting gas efficiency technologies in California.

OpenStudio/EnergyPlus

[OpenStudio](https://openstudio.net/)¹ (and various other OpenStudio related resources and tools) allow building modelers to access and use [EnergyPlus](https://energyplus.net/).² For example, the [OpenStudio SDK](https://github.com/NREL/OpenStudio)³ (software development kit) provides an interface (i.e., an application programming interface, or API) to access the EnergyPlus modeling engine. The interface is, among other things, version controlled; it connects to specific versions of EnergyPlus. OpenStudio is updated and improved on a regular schedule (twice annually) and follows the release schedules of EnergyPlus. Any change or update (inputs, new models, etc.) made to EnergyPlus generally necessitates a subsequent change or update in the OpenStudio SDK.

Additionally, OpenStudio measures are used to encapsulate Ruby (or Python) scripts that create/modify an OpenStudio model. Residential building energy modeling workflows rely on and use measures for both the generation and reporting of building energy models and outputs, respectively, and are described further in the OpenStudio-HPXML/ResStock Section.

EnergyPlus is NREL's whole-building energy modeling program that is used to model energy consumption in buildings, and is the U.S. Department of Energy-funded flagship building

¹ <https://openstudio.net/>

² <https://energyplus.net/>

³ <https://github.com/NREL/OpenStudio>

energy modeling engine used by engineers, architects, and researchers. EnergyPlus uses sophisticated hourly heat transfer algorithms and sub-hourly system algorithms for calculating the energy required for heating and cooling a building using a variety of systems and energy sources.⁴

OpenStudio-HPXML/ResStock

[OpenStudio-HPXML](#)⁵ is a workflow based on using OpenStudio/EnergyPlus. Specifically, it uses OpenStudio measures and [HPXML](#)⁶ building description files for building, translating, and reporting individual models corresponding to residential dwelling units. Each HPXML file contains all properties of a building that affect energy consumption, including information about the site, enclosure, systems, appliances, lighting, ceiling fans, pools, hot tubs, and miscellaneous loads. In terms of workflow outputs, OpenStudio-HPXML can calculate and report outputs related to energy, emissions, building loads, hot water uses, resilience metrics, etc. Other outputs include utility bills, based on either simple utility rate structures or detailed utility rate structures using a tariff JSON file. OpenStudio-HPXML reports both annual and timeseries outputs.

NREL's building stock model, [ResStock](#),⁷ uses detailed U.S. residential housing stock characterization data for creating and simulating individual building models using OpenStudio/EnergyPlus and OpenStudio-HPXML. For the entire national housing stock, a set of 550,000 sampled archetypes are derived from statistical distributions, representing dwelling units contained in single-family detached, single-family attached, and multifamily buildings. Sampled archetypes represent approximately 140 million dwelling units in the existing building stock based on the American Community Survey 5-year 2021 data.⁸ ResStock periodically does Standard Data Releases corresponding to national-scale runs of the stock with different upgrades; this report uses ResStock outside of a Standard Data Release.

A very high-level depiction of ResStock's workflow is shown in Figure 2. Beginning with samples from housing stock characterization data, ResStock uses OpenStudio-HPXML to assemble building energy model input files in OpenStudio, and subsequently batch simulates them using high-performance computing or cloud computing resources.

⁴ See <https://bigladdersoftware.com/epx/docs/24-1/engineering-reference/> for the Engineering Reference of EnergyPlus.

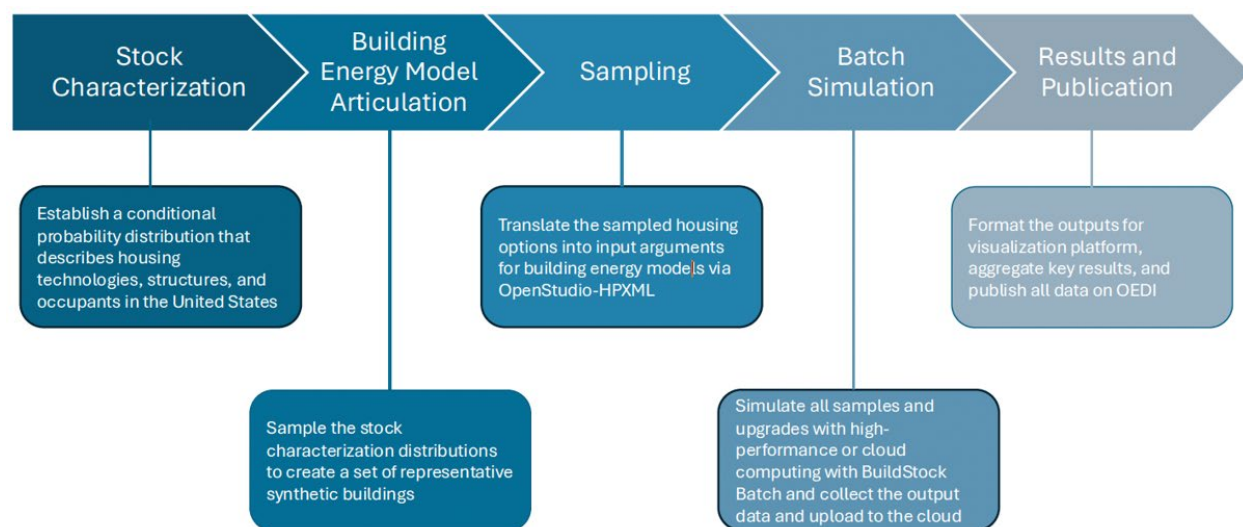
⁵ <https://github.com/NREL/OpenStudio-HPXML>

⁶ <https://hpxml.nrel.gov/>

⁷ <https://github.com/NREL/resstock>; see <https://resstock.nrel.gov/> for various links to ResStock-related pages such as data visualization, state fact sheets, and publications.

⁸ ResStock v3.3.0 represents ~140 million dwelling units (not including Hawaii), whereas future versions of ResStock, e.g., v3.5.0, will include Hawaii.

Figure 2: A high-level overview of the ResStock workflow steps and what occurs during those steps.



BuildStock Batch

NREL's [BuildStock Batch](#)⁹ is a set of software tools allowing for running and managing batch simulations of ResStock and ComStock¹⁰ building stock energy models. NREL's high-performance computing resources, used in conjunction with BuildStock Batch, allows fast and efficient building stock modeling and processing.

BuildStock Batch is also able to upload annual and timeseries simulation output to the cloud using various Amazon Web Services resources. This allows not only access of simulation results, but also the ability to query and report information and findings in a meaningful way.

Assessment Objectives

The approach was to define various ResStock scenarios reflecting different types of changes that may occur in the building stock over time. Each scenario is down-selected (or filtered, in terms of their samples) so that the only samples that are left represent:

- California (16 climate zones)
- Multifamily segment (multiple dwelling units per building; units must be stacked vertically)

⁹ <https://github.com/NREL/buildstockbatch>

¹⁰ ComStock models the commercial U.S. building stock.

Six ResStock scenarios, in total, were defined. The first scenario is the baseline; it represents the state of the existing stock as described by ResStock v3.3.0 (i.e., year 2020¹¹). The remaining five scenarios are based on “what-if” projections representing the residential stock in years 2023, 2026, and 2029. The Scenarios Section describes the six ResStock scenarios in greater detail.

For projection years 2026 and 2029, alternative sets of gas-efficiency scenarios were defined to explore how the building stock might be impacted by the adoption of high-efficiency gas technologies, including gas-fired absorption heat pumps. To this end, updates to both the EnergyPlus and OpenStudio software tools were required. Whereas EnergyPlus updates¹² were supported by GARD Analytics, under this project, NREL was tasked with supporting subsequent developmental efforts on the OpenStudio side. As a result, OpenStudio v3.6.0 includes newly wrapped objects and capabilities for fuel fired heat pump modeling.

The excerpt from the [OpenStudio v3.6.0 release notes](#)¹³ for item “#4806¹⁴ Wrap Gas-Fired Absorption Heat Pump (GAHP)” pertaining to the newly wrapped model objects is summarized below. See the Shared Water Heater Modeling Section for more information about how OpenStudio/EnergyPlus objects were used for modeling gas-fired heat pumps.

- Wrap HeatPump:AirToWater:FuelFired:Heating and HeatPump:AirToWater:FuelFired:Cooling objects
- The objects define an “equation-fit fuel fired absorption heat pump,” which can use data taken from manufacturer specification sheets or detailed laboratory testing to represent the performance of the heat pump under a range of operating conditions.

The GAHP is a combined space heating and domestic hot water solution, especially for cold climates. It can serve as a heat source for central water heaters and other systems. Driven by gas heat or other types of fuel heat, the equipment can have a higher coefficient of performance (COP) than conventional fuel-combustion type boilers or water heaters.

Scenarios

Six ResStock scenarios were created to help identify and understand the overall impact of adopting gas-fired heat pump water heaters in California multifamily buildings. For this

¹¹ “Year 2020” is used as part of the buildstock projections tool as the baseline year for determining the housing stock in future years. Note this version reflects the ResStock baseline in version 3.3, which includes data from sources more recent than 2020 when available.

¹² See <https://github.com/NREL/EnergyPlus/pull/9405> for more information about the updates that were made to EnergyPlus.

¹³ <https://github.com/NREL/OpenStudio/releases/tag/v3.6.0>

¹⁴ <https://github.com/NREL/OpenStudio/pull/4806>

project, a ResStock scenario begins with statistically sampling the California multifamily building stock. The sample is a table of statistically representative buildings and their characteristics. See Table 1 for an example of this type of table. Columns are ResStock parameters, and fields are filled in with sampled (or updated) options. Each row corresponds to a single statistically sampled dwelling unit. The dwelling unit has a set of options that, when mapped to model input values, are used to create a model representing a single representative dwelling unit within the actual housing stock.

Table 1: Example BuildStock CSV File.

Building	Geometry Building Type RECS	Clothes Washer	Cooking Range	Geometry Floor Area	Geometry Building Number Units Multifamily	Insulation Wall
1	Multifamily with 5+ Units	ENERGY STAR®	Electric Induction	1500–1999	43	Brick, 12-in, 3-wythe, R-15
2	Multifamily with 5+ Units	None	None	2500–2999	9	CMU, 6-in Hollow, R-15
3	Multifamily with 5+ Units	ENERGY STAR	Gas	2500–2999	19	Brick, 12-in, 3-wythe, R-7

To understand what constitutes a ResStock scenario, it's important to describe in more detail the following key terms/components in the context of ResStock:

- **Parameter and option:** ResStock has over 100 housing characteristic files containing statistical distributions derived from various data sources. Each file, or category, is a "parameter". Each parameter has a set of options defined and assigned. Each "option" designates a set of arguments and corresponding input values that ultimately define the building model. An example of a parameter and option pair is "Insulation Wall/Wood Stud, Uninsulated".
- **Sampled option:** ResStock uses a quota-based sampling with random assignment algorithm for probabilistically choosing a set of options for each representative building. The existing housing stock resulting from ResStock's sampling routine is a collection of sampled options. It is the direct result of sampling from the statistical distributions contained in the housing characteristic files.

- **Updated option:** This refers to changing an option from its sampled value. Updated options are used to represent “upgrading” a dwelling unit’s existing property. For example, an updated option may substitute the previously sampled “Wood Stud, Uninsulated” option with the upgraded “Wood Stud, R-19” option.
- **Buildstock CSV file:** This is the collection of parameter/option pairs for all dwelling units that represent actual buildings. It is basically the input file for which ResStock maps into sets of building models. See Figure 41 for an example.

Each individual buildstock CSV file is a text-based input file containing all the options that describe a given ResStock scenario. At a high level, each ResStock scenario is defined, and then other tools and processing techniques are used to translate that information into sets of projected buildstock CSV files. Table 2 describes the high-level parameters of each ResStock scenario of interest for this project.

Table 2: High-Level Summary Table of the Six ResStock Projection Scenarios

Scenario	Year	Code Basis	Electric Efficiency	Gas Efficiency	Electrification	Includes GAHP
1	2020	Existing conditions	–	–	–	–
2	2023	Title 24/ Title 20	Electric heat pumps	Tankless water heaters	–	–
3a	2026	Title 24/ Title 20 (projected)	Electric heat pumps	Condensing tankless water heaters	Baseline 1.0% by end use; Local policy for new construction (NC)	–
3b	2026	Title 24/ Title 20 (projected)	Electric heat pumps	Condensing tankless water heaters; Condensing furnaces/ boilers	Baseline 0.1% by end use; Local policy for NC	0.7%
4a	2029	Title 24/ Title 20 (estimated)	Electric heat pumps	Condensing tankless water heaters	Baseline 1.0% by end use; Local policy for NC	–

Scenario	Year	Code Basis	Electric Efficiency	Gas Efficiency	Electrification	Includes GAHP
4b	2029	Title 24/ Title 20 (estimated)	Electric heat pumps	Condensing tankless water heaters; Condensing furnaces/ boilers	Baseline 0.1% by end use; Local policy for NC	6.5%

The following four subsections describe in detail the components used to define, generate, and distinguish the six ResStock scenarios.

Stock Projections

This section provides an overview of NREL's [BuildStock Projections](#)¹⁵ tool and the approach taken to utilize this approach.

Overview

NREL's BuildStock Projections tool uses baseline housing characteristics, future population projections, expected demolition and vacancy rates,¹⁶ and user-defined technology adoption rates to produce future ResStock scenario input files.

Figure 3 depicts at a high level how the BuildStock Projections tool converts a sampled baseline ResStock input file into one or more projected ResStock scenario input files.

Figure 3: Flowchart depicting the process of using a sampled buildstock CSV file and the BuildStock Projections tool to output updated buildstock CSV files.



¹⁵ <https://nrel.github.io/buildstock-projections-docs/readme.html>

¹⁶ Population projections by Public Use Microdata Area (PUMA) for 2030 and 2050 are generated by Oak Ridge National Laboratory. Demolition and vacancy rates are calculated based on these population projections as well as the initial baseline buildstock CSV file. See the [Overview and Methodology](#) section of the BuildStock Projections documentation for more information (<https://nrel.github.io/buildstock-projections-docs/overview.html>).

Each updated buildstock CSV (comma-separated value) file corresponds with preconfigured timestep intervals (e.g., ResStock input files for 2025, 2030, 2035). At each timestep, the following operations are applied sequentially in the generation of an updated buildstock CSV file:

1. Demolition
2. Vacancy
3. New Construction
4. Building Options

Thus, at each future timestep, existing rows in the buildstock CSV file (representing the existing stock) are adjusted in terms of their sample weights (Steps 1 and 2). Additional rows representing new construction are appended to the existing stock rows of buildstock CSV file (Step 3). It is important to note the distinction between existing and new construction stock portions of the buildstock CSV file, as each segment can have separate sets of technology adoption rates defined (Step 4). The previous four steps have the effect of not only iteratively changing the number of rows/size of the buildstock CSV file (representing an expanding housing stock) but also allowing for a systematic approach of updating ResStock options. The ability to specify the segment, rate, and future year for which ResStock options are updated allows us, for example, to mimic existing stock turnover and code compliance requirements for new construction installs following building code revisions.

The BuildStock Projections tool also includes a visualization module for making high-level comparisons between future projection scenarios. This is described in Scenario Comparisons Section.

Approach

ResStock option mappings were used to populate input files of the BuildStock Projections tool. A timestep interval of 3 years was fixed (representing running ResStock scenarios having adopted California code cycles for years 2022, 2025, and 2028). For the new construction stock, the assumption was made that all dwelling units are built exactly to code (i.e., an adoption rate of 100%). For the existing stock, it was assumed that 20% of the existing stock upgraded their water heater every 3 years and engineer judgement.¹⁷ For PV install, 1% of the stock was used an assumption where the sizing was consistent to the requirements of the current code year for every 3 years.¹⁸ No other efficiency upgrades were assumed to be installed as they would have a minimal impact on the results of

¹⁷ [A Comprehensive, High Efficiency Solution for Water Heating in Multifamily Buildings Final Project Report](#)

¹⁸ [Tracking the Sun: Pricing and Design Trends for Distributed Photovoltaic Systems in the United States, 2024 Edition | Energy Markets & Policy](#)

interest for this study. Features of the tool were leveraged to update options corresponding to electrification. The Scenario Details Section outlines the various parameter definitions contributing to the six ResStock scenarios.

The BuildStock Projections tool was employed with supporting infrastructure that was developed for the specific use case. The tool has a command line interface (`run_abm`) to run different future scenarios for multifamily housing in California. It will create a zipped `buildstock.csv` (full housing characteristic) of each future year. To ensure compatibility between future buildstock inputs and our updated version of ResStock that includes Title 24/Title 20 options mappings, a Python script named `run_and_check.py` was used to programmatically validate the content of newly created `buildstock.csv` files. The Python code will uncompress the zip files (future `buildstock.csv` files) and then filter and validate against `options_lookup.tsv` (the dictionary containing model arguments, located in our specific ResStock project folder, and specified by BuildStock Projections input file). The Python script requires two arguments: the path of BuildStock Projections input and the path of OpenStudio CLI (command line interface) executable. The `check_buildstock.rb` script runs at the end of the validation process. Any reported error from the script output should be addressed manually by updating or fixing the `options_lookup.csv` file. A customized filter task with ongoing scalabilities in a Python script for the multifamily building type is available (i.e., single-family detached or attached homes is not an error concern).

Scenario Details

The findings from the Title 24/Title 20 mapping (see Appendix A for more details), the BuildStock Projections tool, and other assumptions/strategies within the following set of parameters were used to produce modified versions of the original sampled baseline buildstock CSV file:

- Code year
- Stock type
- Baseline electrification
- Local electrification
- Gas efficiency.

Table 3 summarizes how these six scenarios are parameterized.

Table 3: Summary Table for How the Six ResStock Projection Scenarios Are Parameterized.

Scenario	Code year	Stock type	Baseline electrification	Local electrification	Gas efficiency
1	-	Existing	-	-	-
2	2022	Existing, new construction (NC)	-	-	-
3a	2025	Existing, NC	1.0%	NC	-
3b	2025	Existing, NC	0.1%	NC	50/50 condensing/ conventional 0.7% GAHP
4a	2028	Existing, NC	1.0%	NC	-
4b	2028	Existing, NC	0.1%	NC	100/0 condensing/ conventional 6.5% GAHP

Below are additional notes and descriptions for the six ResStock scenarios:

- **Scenario 1:** This is a direct sampling from ResStock; it represents the existing California residential multifamily housing stock in 2020 (the basis for the BuildStock Projections tool).
- **Scenario 2:** This scenario represents the housing stock in 2023. It includes 2022 code compliance update options assembled and described in Appendix A: Title 24/Title 20 Mapping.
- **Scenario 3a:** This scenario represents the housing stock in 2026. It includes 2025 code compliance update options and introduces electrification at a rate of 1% for both the existing and new construction stocks. It also introduces local electrification policies for the new construction stock only.
- **Scenario 3b:** This is the same as Scenario 3a but with a decreased electrification rate of 0.1%; additionally, gas HVAC/water heater equipment efficiency is increased to include condensing systems targeting a 50% market penetration level for homes that consume natural gas. It also introduces the GAHP into the same market for

buildings with 10+ dwelling units at the defined target penetration level of 0.1%; this represents ~0.7% of the entire multifamily building segment.¹⁹

- **Scenario 4a:** This scenario represents the housing stock in 2029. It includes *estimated* 2028 code compliance update options and introduces electrification at a rate of 1% for both the existing and new construction stocks. It also reflects local electrification policies for the new construction stock only. See the Baseline Electrification Section for details on how electrification was modeled.
- **Scenario 4b:** This is the same as Scenario 4a but with a decreased electrification rate of 0.1%; additionally, gas HVAC/water heater equipment efficiency is increased to include condensing systems targeting a 100% market penetration level for homes that consume natural gas. It also introduces the GAHP into the same market for buildings with 10+ dwelling units at the defined target penetration level of 100%; this represents ~6.5% of the entire multifamily building segment.²⁰

The following subsections describe in more detail what each scenario parameter represents.

Stock Type

As previously described, ResStock samples may be categorized as existing or new construction. New construction stock is always built to code (i.e., an adoption rate of 100% is assumed for all options defined for each code year).

Existing stock, on the other hand, only receives an updated option when the new option exceeds or is better than the sampled option, and this only applies for a few specific categories. In this case, 20% of the stock upgrade their central water heaters every 3 years, 1% of the stock installs PV sized according to the requirements of the current year's code, and no other upgrades are assumed to be installed. While other upgrades may be installed in some fraction of buildings, it is assumed that the fraction is low and due to the minimal impact, many other upgrades would have the results on the overall building consumption (and water heating energy consumption in particular) that these upgrades do not need to be modeled here.

Code Year

The building energy code for year 2022 as well as projected code for year 2025 and estimated code for 2028 were reflected in the ResStock scenarios according to Table 16.

¹⁹ 0.7% of the entire multifamily building segment is representative of buildings with 10+ dwelling units for GAHP market penetration per the 2026 housing stock. This was determined based on a systemic breakdown of the multifamily sector in California based on NREL's BuildStock Projections analysis outlined in Stock Projections Section.

²⁰ 6.5% of the entire multifamily building segment is representative of buildings with 10+ dwelling units for GAHP market penetration per the 2029 housing stock. This was determined based on a systemic breakdown of the multifamily sector in California based on NREL's BuildStock Projections analysis outlined in Stock Projections Section.

Year 2022 is known, meaning the current versions of Title 24 and Title 20 were analyzed, and subsequently created/modified a mapping from ResStock options to model input values. For future code years 2025 and 2028, future versions of Title 24 and Title 20 were projected based on draft proposals and other assumptions/judgment. See the Appendix A.4 Future Code Years Section for more information.

For the existing stock, the buildings that receive upgrades to their central water heating system do compound over time. In 2023, 20% of the stock received this upgrade. By 2026, an additional 20% of the remaining stock was upgraded, resulting in 36% of the total stock having been upgraded at least once by 2026. By 2029, it is projected that 49% of the stock will have been upgraded at least once. Since only 1% of the stock receives PV every 3 years, this compounding rate has minimal impact on PV adoption, with only slightly less than 2% and 3% of the stock installing PV by 2026 and 2029, respectively.

Baseline Electrification

For this project, ResStock buildstock CSV file option changes were used at specified rates to account for “baseline electrification.” The specific rate values generally follow guidelines from ICF; they are intended to effectively reduce gas-consuming systems and appliances, and overall customer counts. See Table 17 for a list of all possible ResStock “fuel-consuming” options that can be switched to their electric counterparts. For example, a ResStock option for a gas clothes dryer is switched to an electric clothes dryer with equivalent space type location and usage level.

Baseline electrification is reflected in years 2026 and 2029 for Scenarios 3a–4b. Scenarios 3a and 4a use a specified baseline electrification rate of 1%. The BuildStock Projections tool targets a random 1% of all fuel-consuming samples, for any given parameter, for which the electric option change is made. Therefore, baseline electrification, in the context of this project, happens at the end-use level; a dwelling unit may electrify, for example, its clothes dryer but leave its gas cooking range in place. From the standpoint of the buildstock CSV file this means that for a given column, 1% of its fuel options are converted to electric options. A dwelling unit no longer consumes gas once all of its gas options have been changed to electric.

Scenarios 3b and 4b reduce the baseline electrification rate from 1% to 0.1%. This allows us to show the effects of targeting more aggressive gas efficiency scenarios while simultaneously assuming a slower rate of baseline electrification. For example, comparing buildstock CSV files, there are more electric clothes dryers for Scenario 3a than for Scenario 3b.

Local Electrification

To project the effects of imposing future local electrification policies, ResStock was used to essentially take the same approach as baseline electrification. Any local electrification policies in the state as of February 2023 were included in the analysis.²¹ The BuildStock Projections tool was still used to change existing options to their electric counterparts, but the approach differs in terms of geographic locations, assumed rates, and housing stock types for which the local electrification policies are applicable. See Table 18, Table 19, and Table 20 for information about which ResStock locations have applicable local electrification policies imposed. Compared to baseline electrification, local electrification policies are only applied to the new construction portion of the housing stock. Furthermore, the local electrification policies are assumed to be fully adopted; that is, 100% of new construction installations (in applicable city/county) receive the new electric options. Like baseline electrification, local electrification policies are reflected in years 2026 and 2029 for Scenarios 3a–4b.

Gas Efficiency

Scenarios 3b and 4b are intended to reflect what happens if Scenarios 3a and 4a assumed slower electrification rates while simultaneously increasing efficiency levels of gas equipment. Scenario 3b, reflecting the stock in year 2026, targets a 50/50 split between penetrations of (1) condensing gas heating systems and water heaters, and (2) conventional gas heating systems and water heaters. In Scenario 4b (reflecting the stock in 2029), all installed gas heating systems and water heaters move to condensing.²²

In addition to increasing the efficiency of existing gas technologies, Scenarios 3b and 4b also target the introduction of a gas-fired heat pump water heater at rates of 0.7% and 6.5%, respectively, in the multifamily building segment.

Scenario Comparisons

The BuildStock Projections tool includes a module for visualizing output files. Because buildstock CSV files are simply text input files used by ResStock, the visualization module provides a valuable and convenient method for understanding key differences across

²¹ Note that many local electrification policies have changed since this date and continue to rapidly evolve. See Appendix B for a list of locations affected by local policies in this report at the time the evaluation was done.

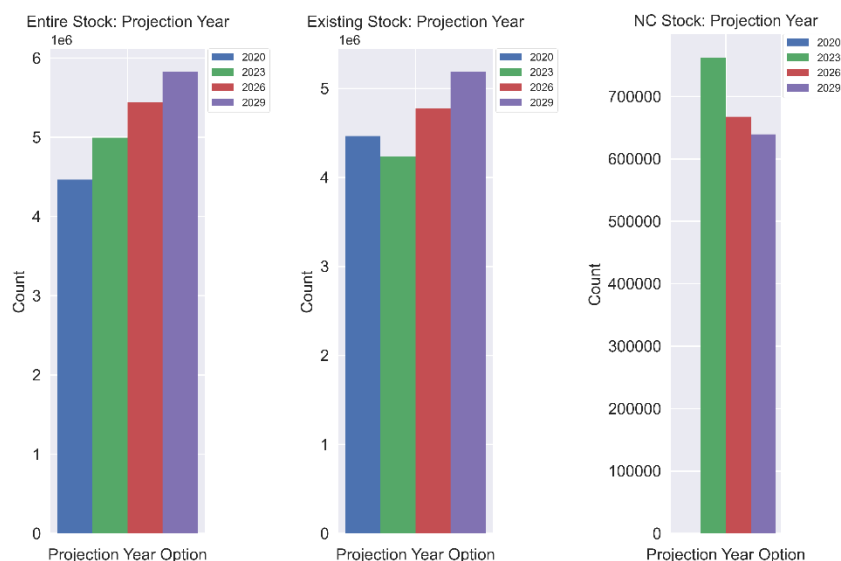
²² On December 26, 2024, DOE published a Final Rule establishing new efficiency standards for gas-fired instantaneous water heaters manufactured on or after December 26, 2029. This rule requires all new models to meet a UEF of 0.91 for medium draw patterns and 0.93 for high draw patterns—thresholds that only condensing units can achieve. Since non-condensing models max out at a UEF of 0.81, they will be effectively banned from the market. However, following this report creation, on Feb 14, 2025, the DOE postponed the Dec 26, 2024 efficiency standards for Gas Instantaneous Water Heaters.

It is expected that the new gas instantaneous water heater efficiency standards will be revised and issued in 2025 to allow the continued use of non-condensing gas instantaneous water heaters.

scenarios. By displaying summaries of counts/distributions side-by-side, it is much easier to recognize how parameters are changing from one scenario to the next. For example, the module can summarize changes in total dwelling unit counts (e.g., based on existing homes being demolished, or new homes being constructed) across projection years, including breakouts by CEC climate zone. The module can also describe the penetration of options across all ResStock parameters (i.e., distributions of options across all ResStock parameters).

Furthermore, plots can be summarized over (a) the entire stock (i.e., the existing plus new construction stocks), (b) just the existing stock,²³ and (c) just the new construction stock. By isolating count/distribution plots to either (b) or (c), it's possible to see the effect that a variable adoption rate may have on the different stock types. Figure 4 shows the estimated total dwelling unit counts across the projection years considered for this analysis. Note the change in y-axis scales between (a), (b), and (c).

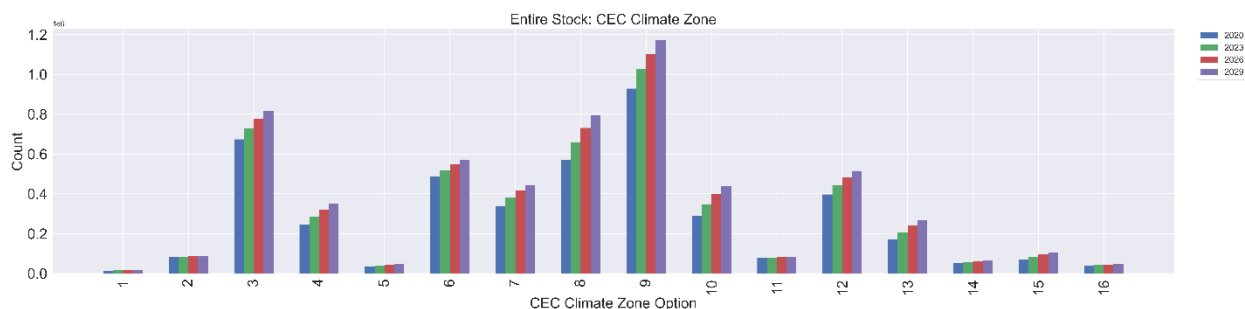
Figure 4: Count of total dwelling units across projection years.



²³ Note that the BuildStock Projections tool counts the entire stock as existing stock in the baseline 2020 year; the existing stock does not reflect the prior projection year's new construction stock until subsequent years.

Figure 5 once again shows total dwelling unit counts across projection years but across the entire stock broken out by CEC climate zone.

Figure 5: Counts of total dwelling units across projection years, broken out by CEC climate zone.



See Appendix B.1 for more information describing the process for down-selecting the entire national ResStock space to the particular segment of interest.

The following plots show distributions of various options across the six ResStock scenarios. The projection years in the legend maps to ResStock scenarios according to Table 4.

Figure 6 shows the distributions of heating fuel (i.e., space heating) options across all the projection scenarios. In 2023, there is a switch between predominantly gas space heating to electric space heating. This can be explained mostly by the adoption of air-source heat pumps per the Title 24 building energy code. The trend continues for years 2026 and 2029 as electrification is now playing a role. The gas efficiency scenarios (i.e., those in the legend with “_gasEff” suffix) show a slightly reduced rate of switching from gas to electric space heating, which is expected.

Table 4: Mapping of ResStock Scenarios to Distribution Plots Projection Year Keys.

Scenario	Legend Key
1	2020
2	2023
3a	2026
3b	2026_gasEff
4a	2029
4b	2029_gasEff

Figure 6: Distributions of heating fuel options, across projection scenarios, for the entire stock.

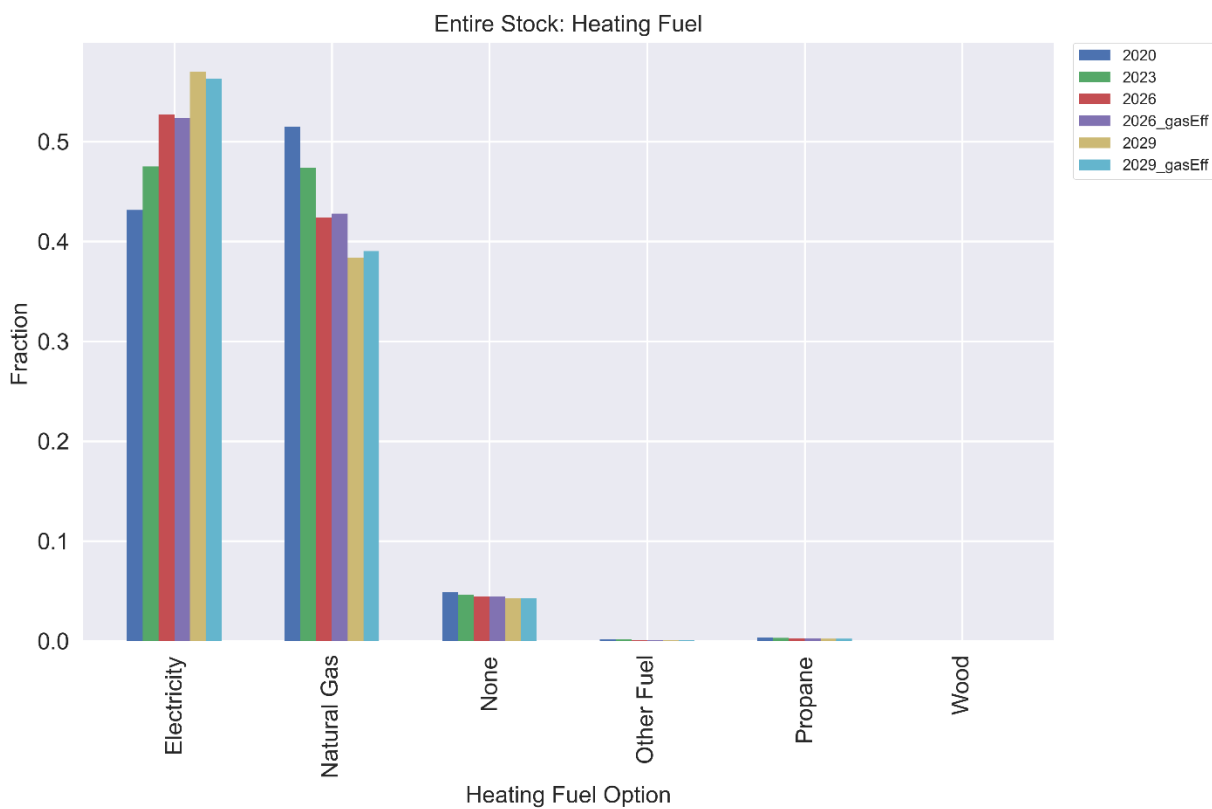


Figure 7 is similar to Figure 6, but for water heater fuel. Gas water heating increases slightly in year 2023 and subsequently falls in years 2026 and 2029. Again, the gas efficiency scenarios show a slightly reduced rate of switching from gas to electric water heating.

Figure 7: Distributions of water heater fuel options, across projection scenarios, for the entire stock.

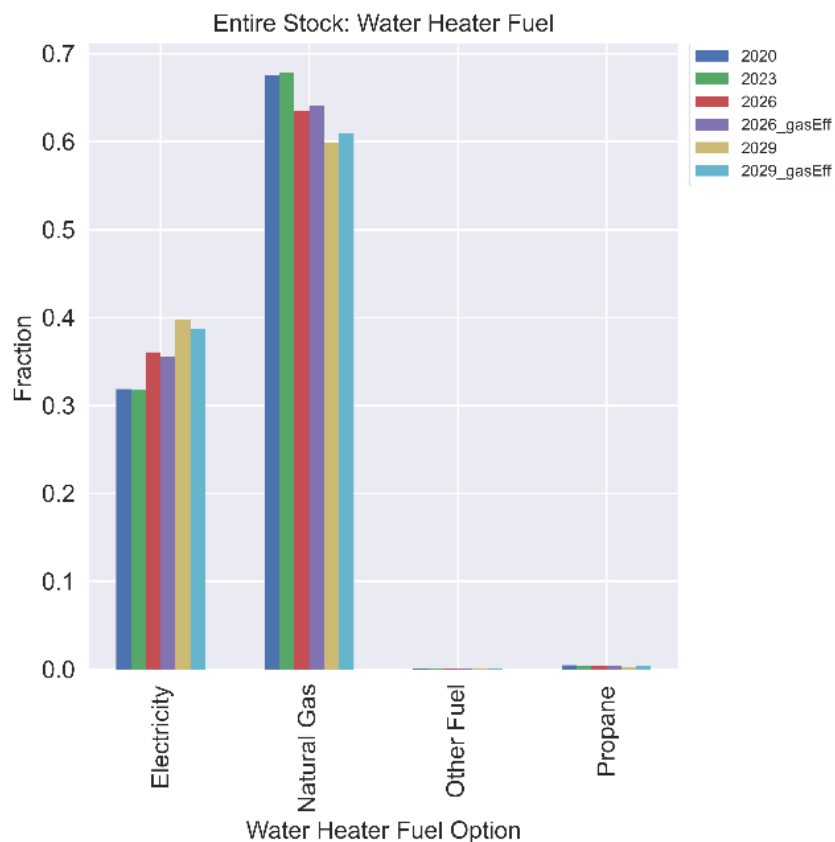
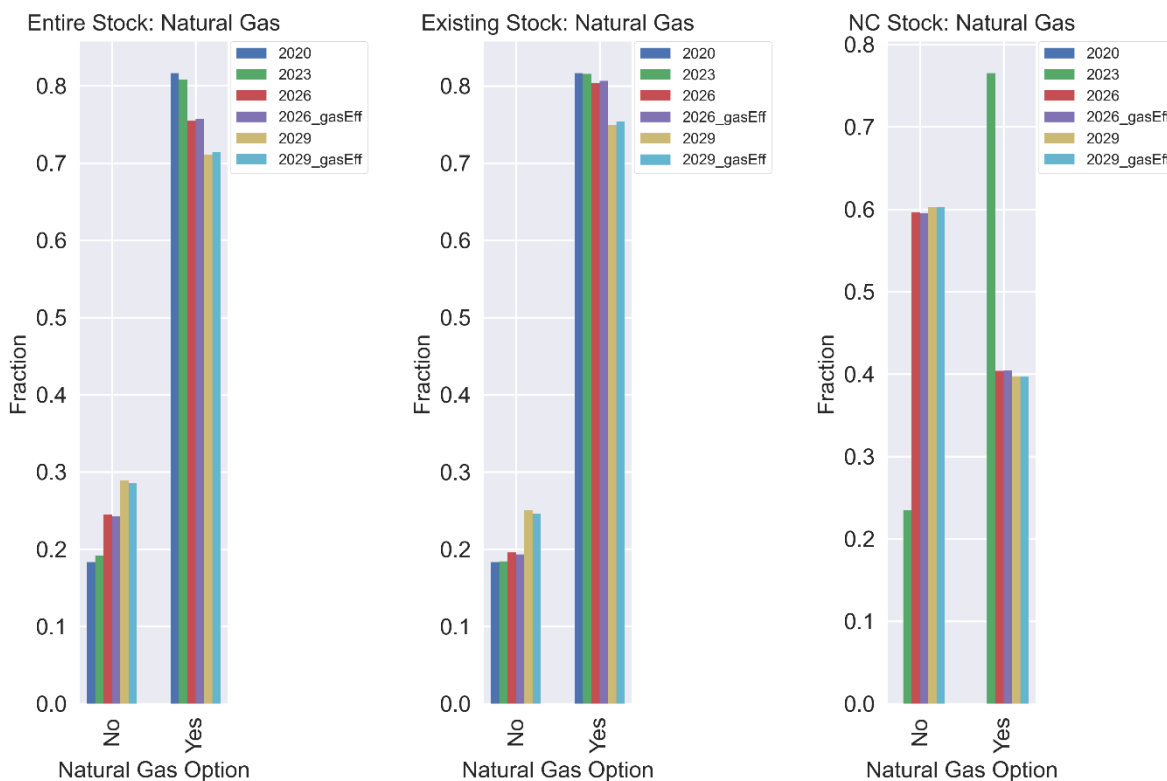


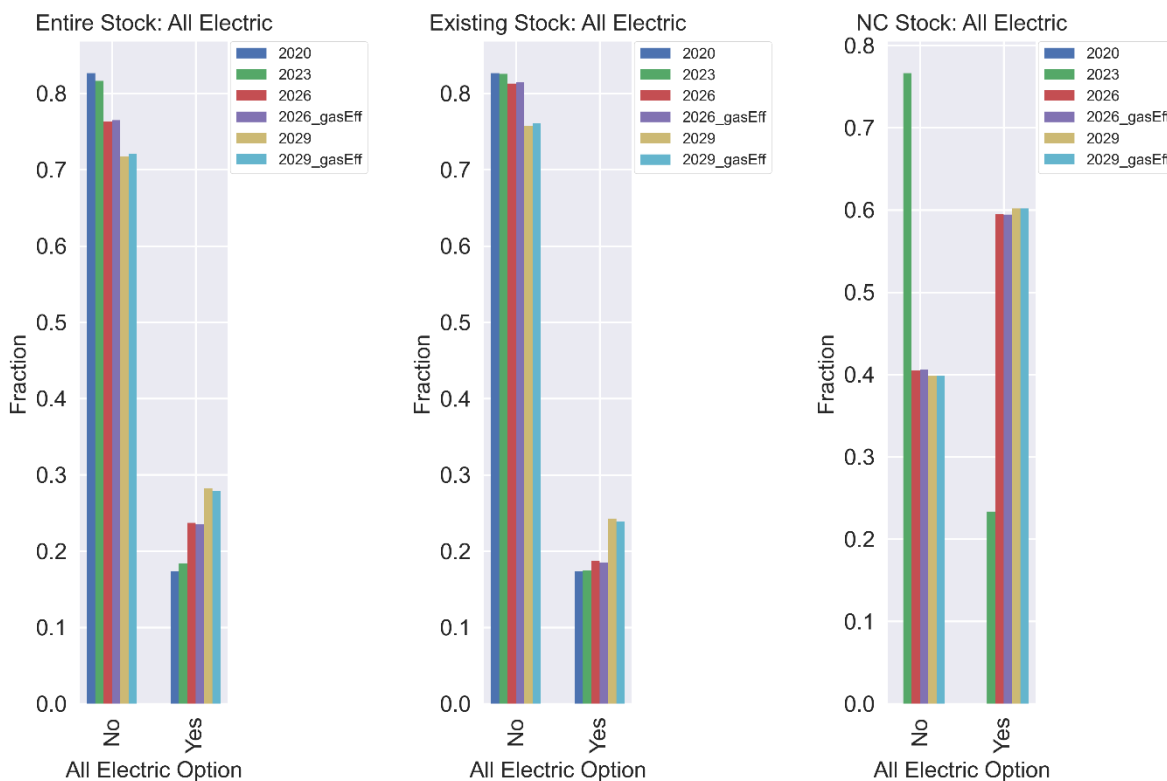
Figure 8 and Figure 9 show distributions, across each of (a) the entire stock, (b) the existing stock, and (c) the new construction stock, for dwelling units (1) having at least one gas-consuming end use (e.g., gas clothes dryer) and (2) having no end uses consuming gas (all-electric). As expected, the general trend is that over time the proportion of gas-consuming dwelling units decreases while the proportion of all-electric dwelling units increases.

Figure 8: Fraction of dwelling units, across projection scenarios, having at least one gas-consuming end use.



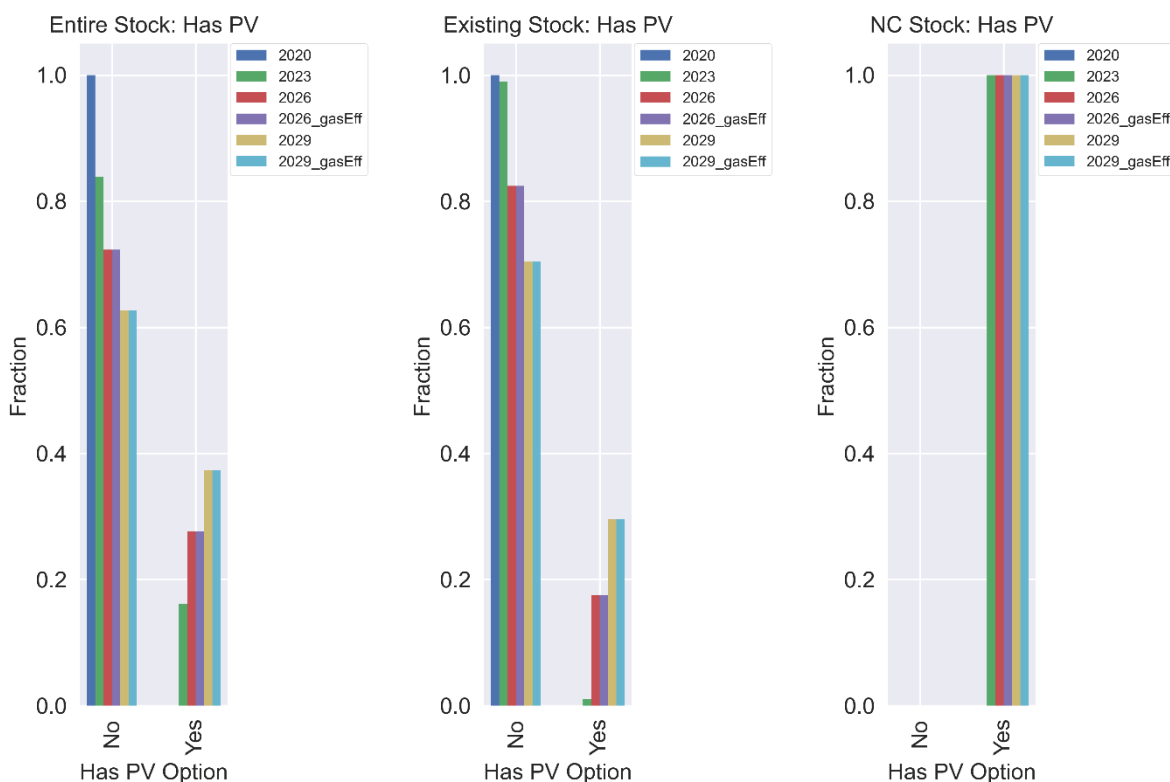
In the “NC Stock: Natural Gas” (c) subplot in Figure 8, the sharp decreases in years 2026 and 2029 are attributed mostly to encouragement of all electric installations per local electrification policies, whereas the slight changes relative to “2026_gasEff” and “2029_gasEff,” respectively, are attributed to decreases in baseline electrification rates.

Figure 9: Fraction of dwelling units, across projection scenarios, for which all end uses consume only electricity.



See Figure 44 and Figure 45 for similar versions of the previous plots but displaying total counts instead.

In Figure 10, because no existing multifamily dwelling units have PV in 2020, the assumed PV adoption rate of 1% for the 2023 existing stock is reflected, whereas the new construction stock adopts PV at 100%.

Figure 10: Fraction of dwelling units, across projection scenarios, having PV installed.

Shared Water Heater Modeling

The ability to model central water heating systems was not part of ResStock prior to this project. ResStock generally models multifamily buildings with a unit-by-unit approach, rather than modeling entire multifamily buildings at the same time. This approach assumes that any shared surfaces, such as walls, floor, or ceilings, are adiabatic. However, this approach also makes it difficult to explicitly model shared systems, which are common in many multifamily facilities. Rather than explicitly modeling the distribution system, simpler correction factors were applied to account for the impact of the distribution system on the efficiency of the shared system. As part of this project, new capabilities were added to combine multiple similar units into a multifamily building model. The multifamily building model explicitly models the central system, including any storage and distribution, and can be layered on top of a typical ResStock run. Details of this new approach — including how units are combined, the applicability of this new approach, and the details of the modeling of these different distribution systems — are provided below.

ResStock Modeling Enhancements

Enhancements to the ResStock tool were made for supporting simulations of whole-building models. Additionally, a new [OpenStudio measure](#)²⁴ was developed for adding shared water heater configurations to multifamily buildings. The following sections describe the new enhancements and developments.

Whole-Building Models

The publicly available ResStock v3.3.0 only supports modeling individual dwelling units within a whole building. And although it uses U.S. Energy Information Administration (EIA) 2020 RECS data to determine whether water heaters are shared across dwelling units or not, in-unit water heaters are always explicitly modeled. Because the goal is to model shared systems serving all dwelling units of a building, significant updates needed to be made to the ResStock tool for combining individual dwelling unit models into a single building model. From there, central plant loop(s) can be constructed to serve all the individual dwelling unit hot water use connections.

For this analysis, the general approach for modeling whole multifamily buildings consists of:

- Determining whether the sampled dwelling unit is served by a gas-fired shared water heating system
- Using OpenStudio-HPXML to combine individual dwelling unit models into a single whole-building model
- Replacing in-unit gas-fired storage tank water heating systems with shared gas-fired systems serving multiple dwelling units
- Simulating the model and then dividing building-level results by number of dwelling units.

Whole-building models are created for ResStock samples that are determined to be served by a gas-fired shared water heating system. This determination is made based on sampled combinations of the following ResStock parameters that describe water heaters:

- **Water Heater In-Unit:** this parameter has options of Yes and No, describing whether the individual water heater is present or not present in the dwelling unit that solely serves the specific dwelling unit.
- **Water Heater Fuel:** this parameter has options of Electricity, Natural Gas, Fuel Oil, Propane, and Other Fuel, describing the water heater fuel type.

²⁴ https://nrel.github.io/OpenStudio-user-documentation/reference/measure_writing_guide/

- **Water Heater Efficiency:** this parameter has various options for storage tank, tankless, and heat pump, describing the water heater efficiency, type, and heating fuel.

The following Parameter|Options describe the specific combinations indicating a whole building is served by a gas-fired shared water heating system:

- A shared water heating system serves multiple dwelling units of a building:
 - Water Heater In-Unit|**No**
- Natural gas is the domestic hot water heating fuel:
 - Water Heater Fuel|**Natural Gas**
- Storage tank is the domestic hot water system type:
 - Water Heater Efficiency|**Natural Gas Standard**
 - Water Heater Efficiency|**Natural Gas Premium**
 - Water Heater Efficiency|Natural Gas Premium, Condensing
 - Water Heater Efficiency|**Natural Gas Tankless**
 - Water Heater Efficiency|Natural Gas Tankless, Condensing
 - Water Heater Efficiency|Natural Gas Heat Pump, Standard
 - Water Heater Efficiency|Natural Gas Heat Pump, Premium
 - Water Heater Efficiency|Natural Gas Heat Pump, Premium, Condensing.

In other words, for this analysis a whole building is modeled rather than applying the simpler correction factors whenever a ResStock sample indicates presence of a shared water heating system providing domestic hot water (DHW). The in-unit storage tank systems are modeled as shared boilers with the following efficiencies: “Standard” maps to 80% AFUE (annual fuel utilization efficiency), “Premium” and “Tankless” to 85% AFUE, and “Premium, Condensing” and “Tankless, Condensing” to 90% AFUE. The following sections provide more information.

Ten **unique** dwelling units of a multifamily building were modeled; if the actual represented building consists of more than 10 dwelling units, unit multipliers are apportioned to each of the modeled units. Unit multipliers, in the context of EnergyPlus, send multiplied loads to attached systems. Applying a unit multiplier makes it so EnergyPlus considers there to be multiple identical units. Unique dwellings are modeled first to account for variability in occupant behavior, such as the timing of hot water usage, but unit multipliers are utilized for larger buildings after accounting for enough units that there is substantial diversity in occupant. ResStock includes a [stochastic occupant model](https://www.sciencedirect.com/science/article/abs/pii/S0306261922011540),²⁵ based on American Time Use Survey data, to represent what each individual occupant in a unit is doing every 15 minutes.

²⁵ <https://www.sciencedirect.com/science/article/abs/pii/S0306261922011540>

This includes activities that use hot water, such as bathing, dishwashing, and doing laundry. The resulting water use of all occupants is then combined into the hot water usage profile of each dwelling. Large, multizone EnergyPlus models can be quite computationally expensive, and so limiting the number of modeled units by using unit multipliers helps to maintain a reasonable and manageable overall simulation runtime. Modeled units within a whole building are identical except for their unique stochastically generated occupancy schedules, including hot water fixtures, clothes washers, and dishwashers. Including up to 10 unique sets of hot water occupancy schedules helps to provide water use variability across end uses of the shared water heating system. This variability ensures that peak water usage stays realistic so that water heating systems can be appropriately sized.

A newly created OpenStudio measure, developed by NREL and called `AddSharedWaterHeater`, is then applied to the whole-building model. Its general purpose is to replace **in-unit** water heating systems with **shared** systems. Further detail and description for the various plumbing configurations that the `AddSharedWaterHeater` measure supports is given in the following section.

Once the shared water heating systems are applied and the whole-building model is simulated, reported simulation outputs are collected and processed. Simulation outputs reflect energy consumption, the loads met (and any unmet loads), utility bills, and emissions for the entire building (i.e., the sum across all units in the building). Each reported building-level output is divided by the total number of dwelling units in the building so that results correspond to an average dwelling unit; therefore, ResStock reported outputs at the dwelling unit level is preserved while still capturing the whole building energy consumption.

AddSharedWaterHeater Measure

To explicitly support modeling shared water heating systems²⁶ for ResStock samples, NREL created a new OpenStudio measure called `AddSharedWaterHeater`. It operates on an already-constructed whole-building model that contains individual in-unit water heating systems (i.e., the current technical limitation of water heating systems in ResStock/OpenStudio-HPXML). The measure enables individual units of the whole-building model to instead be served by a shared water heating system. Generally, the measure:

- Removes any existing **in-unit** water heating supply components (i.e., plant loops, pumps, water heaters)
- Creates central plant loop(s) with **shared** DHW supply components (i.e., boiler and GAHP) and storage tanks

²⁶ OpenStudio-HPXML supports modeling of shared systems (HVAC, water heating, etc.) serving multiple dwelling units, but these systems are approximated/modeled as individual systems with efficiency adjustments to estimate the energy use attributed to the dwelling unit.

- Creates central recirculation loop and reconnects existing domestic water use connections to its demand side.

The measure was used for modeling two configuration choices for water heating system type:

1. Boiler with storage tanks
2. Gas heat pump with boiler and storage tanks.

For ResStock analysis, the first option serves as the **baseline** configuration against which the second gas absorption heat pump (GAHP) **upgrade** configuration is compared. The heat pump upgrade configuration choice *is* the baseline boiler configuration (i.e., retains the existing building's boiler configuration and efficiency) *plus* the new GAHP retrofit. In this way, the existing boiler serves as available backup to the retrofitted heat pump.

The following sections describe the general plant loop plumbing layouts for each of the supported configurations.

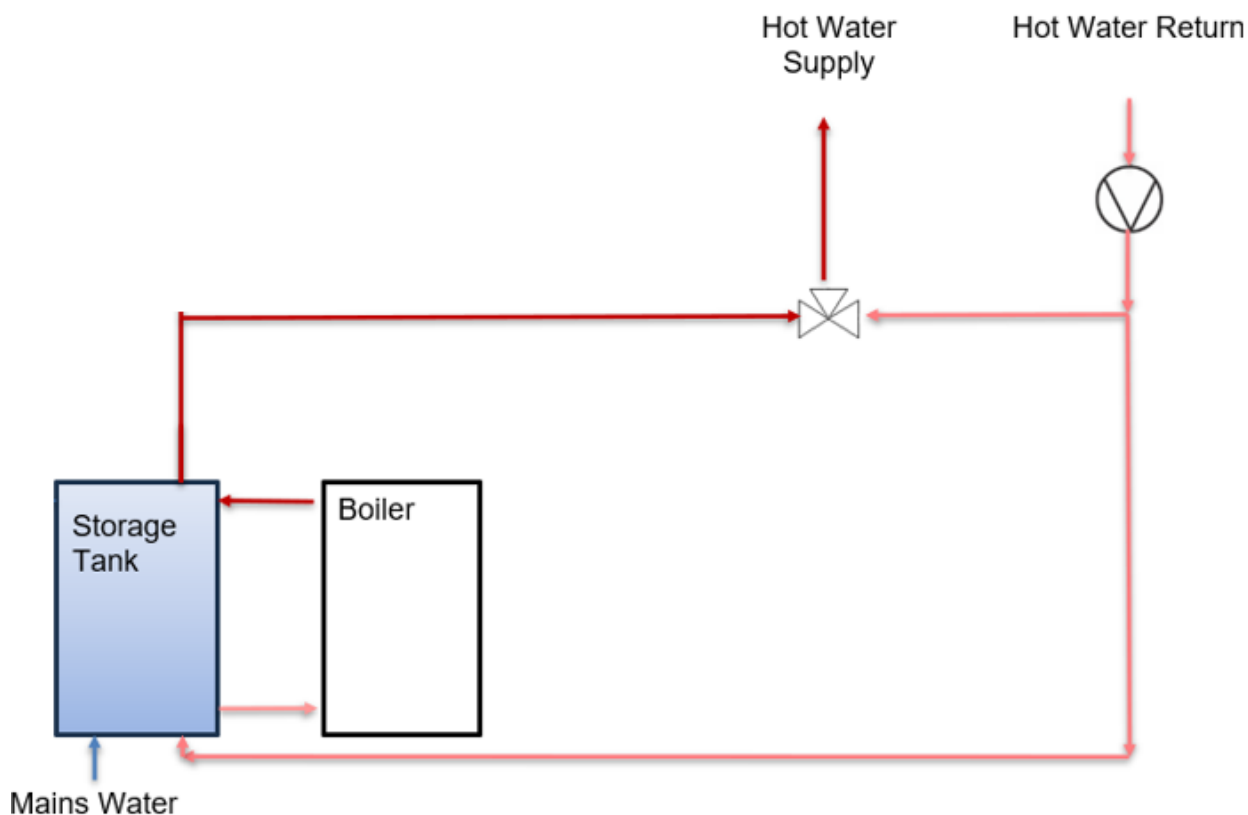
Central System Layouts

Two different central configurations layouts were developed as part of this project for the AddSharedWaterHeater measure.

High-level diagrams and descriptions of each layout are provided in the following sections. Additional system details, such as setpoints, flow rates, system sizes, and more are provided in the more detailed diagrams of each loop used in the model.

Gas-Fired Boiler

Figure 11 shows the plumbing diagram for existing buildings with a boiler used for water heating. In this case, an appropriately sized storage tank is paired with a boiler, where the boiler is the only source of heating to meet the water heating load. Hot water is provided to the DHW recirculation loop. The recirculation loop is assumed to have a constant speed pump that runs continuously to ensure that hot water is always available to occupants in any unit. Piping to and from the storage tank and the units is also modeled, so that realistic recirculation losses are included as part of the load to be met by the system.

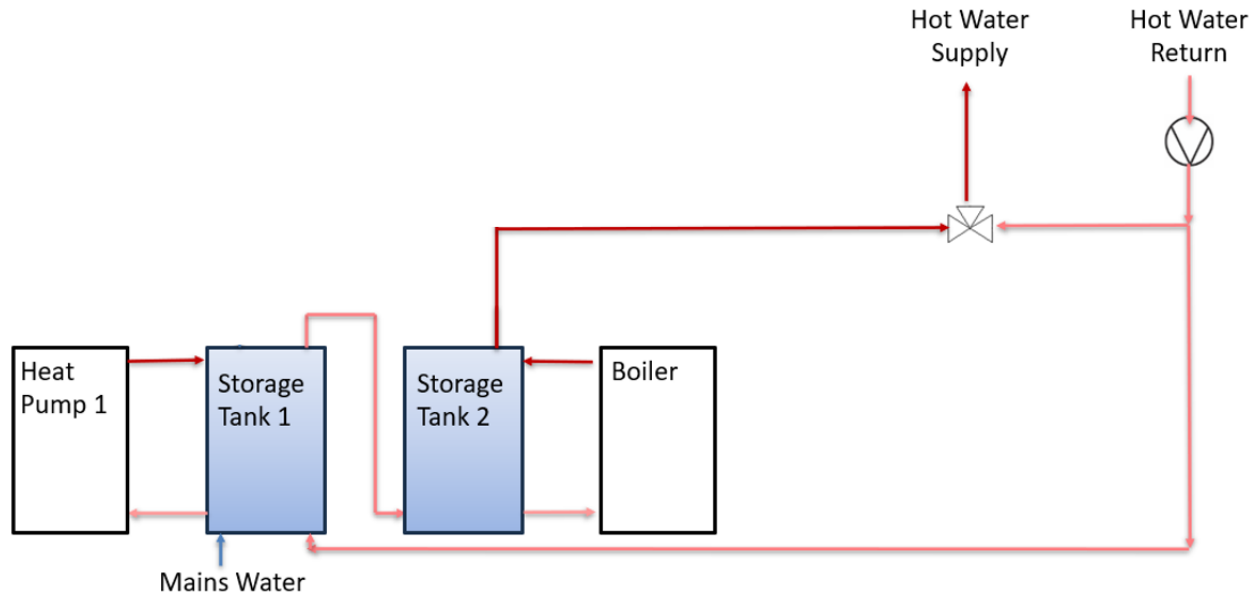
Figure 11: Plumbing diagram of an existing boiler that provides water heating.

Gas-Fired Heat Pump Water Heater

Figure 12 shows the configuration of gas heat pump systems as a retrofit. In this configuration, the boiler is kept in place and the gas heat pump is installed as a preheater. It is paired with a separate storage tank and tries to meet as much of the load as possible. This water then enters the existing pre-retrofit storage tank paired with the existing boiler, which provides any additional heat required to meet the loads.

Not all gas heat pump installations have used this exact configuration. [Some field studies](https://neea.org/resources/robur-heat-pump-field-trial)²⁷ have used the heat pumps to preheat but have used heat exchangers to add heat to existing tanks rather than pairing a new storage tank with the heat pump. The exact configuration that gets installed at any given site is highly dependent on what the existing system looks like. However, a generic layout that broadly represents most installations needs to be assumed for tools such as ResStock that do higher-level stock analysis without detailed information on the baseline configuration of every building this system may be installed in.

²⁷ <https://neea.org/resources/robur-heat-pump-field-trial>

Figure 12: Plumbing diagram of GAHP retrofits that provide water heating.

Setpoints

Residential water heaters are generally set to a temperature somewhere between 120°F and 140°F. Products sized for residential single-family installations ship with a default setpoint of 125°F. When using hot water, occupants generally temper that water to a lower temperature around 105°–110°F, while appliances may draw hot water directly from the water heater. A higher setpoint temperature increases the standby losses, and therefore energy consumption, of the water heater. Higher setpoints around 140°F can also [reduce the risk of Legionella](#),²⁸ the cause of Legionnaire’s disease, growing in the tank. For modeling central systems in this work, a setpoint of 130°F was chosen. Legionella is relatively rare in these types of systems, and instead a setpoint was selected on the lower end but can still provide adequate hot water. Some heat is lost in the distribution system before getting to the end uses for occupants. A 130°F setpoint assumes that even if the temperature of hot water drops by 5°F before reaching the last unit on the loop, they’re still able to get water at the default setpoint of 125°F.

Applicability

This project is modeling a specific product, the [Robur GAHP-A](#)²⁹ (described in more detail in the Gas Heat Pump With Storage Tanks Section). The Robur unit has a nominal heating capacity of 123.5 kBtu/hr. While the “AddSharedWaterHeater” measure can be applied to any multifamily building, from a duplex to a large building with more than 100 units, the

²⁸ <https://pmc.ncbi.nlm.nih.gov/articles/PMC2094925/>

²⁹ <https://www.robur.com/products/gahp-a-heat-pump>. This product was selected for research purposes only; NREL does not endorse any particular commercial product.

Robur is not appropriately sized for small multifamily buildings. GAHPs are only considered as a potential upgrade for buildings with 10 or more units. The Robur unit is generally only applicable to buildings with 20 or more units, but newer products on the market from other manufacturers may be sized for buildings with 10 to 20 units. To try to roughly capture the potential benefits of a GAHP applied to these buildings, GAHPs were modeled as being applicable to these buildings and allowed to run at lower part load (down to 25% part-load ratio), but otherwise using characteristics derived from the lab testing of the Robur unit. For GAHPs sized to meet the full 20 units in a building with > 20 units, the Robur minimum part load ratio was 45%. Additional Robur units are added to the building model for every 20 units in the building until a maximum of 5 GAHPs are installed. Since these units are modeled in series, diminishing returns are seen with multiple units in series, and EnergyPlus limitations on distributing load prevent parallel configurations from being explored, this limit was set. In the event of buildings with over 100 units, any load that can't be met by 5 Robur units is met by the backup boiler retained in place.

Plant Loop Layouts

Central plant loop layout details for the two supported types are given in the sections below. For each, a set of depictions (aided by [OpenStudioApplication](#)³⁰) is given and described. Note the patterns of overlap, in terms of plant loops, across the supported configurations:

- **Supply Loops** always have either a single boiler or GAHP on the supply side and a single storage tank on the demand side.
- **Storage Loop** always has storage tank(s) on the supply side and a heat exchanger (to the **DHW Loop**) on the demand side.
- **DHW Loop** is always present and is the same across configurations 1 and 2.

All plant loops use water as the fluid type and are autosized/autocalculated in terms of their maximum flow rates and volumes. EnergyPlus includes an [autosizing routine](#) for many components. The flow rate calculated for pumps is determined based on the tank volume and a recovery time to go from a cold-water temperature up to a setpoint. The plant loops give even more detail on the exact configuration of the plumbing and anything that affects the energy consumption of the central system.

Boiler With Storage Tanks

This configuration consists of a single supply loop with boiler, and a storage tank that feeds the DHW loop. Table 5 shows the different “PlantLoop” objects used in EnergyPlus, along with a reference to the relevant figures. Note that some configurations use identical loops

³⁰ <https://github.com/openstudiocoalition/OpenStudioApplication>

(for example, a boiler supply loop is used when a GAHP is modeled as the existing equipment is retained).

Table 5: Plant Loop Component Summary for Boiler With Storage Tanks

Loop	Name	Supply Side	Demand Side	Figure
Loop 1	Supply Loop	Boiler	Storage Tank	Figure 13
Loop 2	Storage Loop	Storage Tank	Heat Exchanger	Figure 14
Loop 3	DHW Loop	Heat Exchanger	Hot Water Fixtures	Figure 15

Supply Loop (Boiler)

Figure 13 shows a diagram of the plant loop for a boiler connected to a storage tank. These diagrams are automatically generated by the [OpenStudio application](#)³¹ and then annotated for clarity. By virtue of being automatically generated, they reflect all of the details of any plant loop and are the most thorough way to show the details of how different systems have been configured. For this loop, the boiler is connected directly to a water tank (using the stratified water heater model in EnergyPlus), with no other heat source. The boiler is connected to the source side of the loop with an autosized pump. The boiler is controlled by a setpoint manager that is set to 130°F. Adiabatic pipes are for connections, which assumes that any losses between the boiler and the storage tank are negligible. “Bypass” pipes are included around both the storage tank and boiler. These pipes are generally included by default in OpenStudio in the event that there is flow in the loop when heating is not required. In this implementation, the bypass pipes are kept in place but there is zero flow through them.

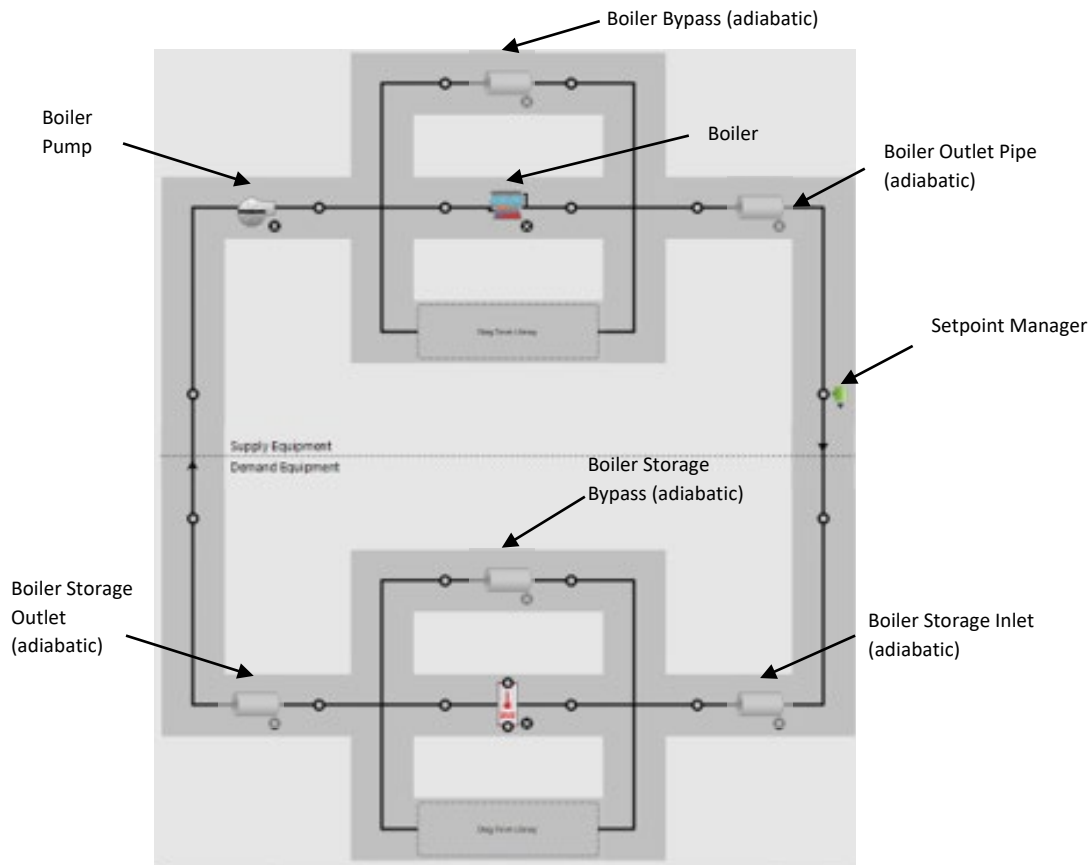
Storage tanks are modeled using the “WaterHeater:Stratified” object in EnergyPlus. This allows for the stratification within the tank to be modeled. When hot water is used, cold water comes into the bottom of the tank, and hot water is drawn from the top. The boiler (or GAHP, in cases including it) draws colder water from the bottom of the tank and returns it to the top, to maintain this stratification. This realistically maximizes the amount of hot water that can be used and allows for faster recovery, as the boiler is controlled. No other heat sources within the tanks (such as burners or electric resistance elements) are modeled. All storage tanks are assumed to be insulated to R-22. The storage tank size and boiler capacities are sized according to the methodology in [ASHRAE Handbook of HVAC Applications](#).³² Sizing is done assuming an average of 2.6 occupants/unit, that the occupants are medium users of hot water, and 60 minutes of peak usage. The boiler can be either condensing or noncondensing, with the efficiency sampled from ResStock directly. Different performance curves are used depending on the type of boiler, to reflect differences in how efficiency changes with temperature for condensing boilers. The boiler

³¹ https://openstudiocoalition.org/getting_started/getting_started/

³² <https://www.ashrae.org/technical-resources/ashrae-handbook/2023-ashrae-handbook-hvac-applications>

flow is allowed to modulate down to 20% of the maximum flow (1:5 turndown ratio). Flow through the boiler is driven by a pump that is autosized using EnergyPlus' built-in routine. This pump, and all pumps used in this workflow, are assumed to have a motor efficiency of 85%. Pump power is then calculated from the calculated flow rate and efficiency. The boiler pump is allowed to operate intermittently.

Figure 13: Supply loop of a storage tank with a boiler.



Storage Loop and DHW Loop

Figure 14 and Figure 15 show the connections between the boiler storage tank and the hot water use. These two loops are connected via an ideal heat exchanger. The heat exchanger has 0 losses and perfectly transfers heat between the two loops. It is primarily included to help support more complicated layouts where both space and water heating loads are being served, which may occur at different temperatures and flow rates, and has no impact on the resulting energy consumption of the system. Combined space and water heating applications are outside the scope of this current project but could be modeled using this workflow in future projects.

Supply and return piping is included between the storage tank and the hot water end uses. Supply piping lengths are calculated based on the floor area of the building, the number of

stories, and the ceiling height of each unit. There's also an assumed 8 ft of piping in the mechanical room. The overall supply length is calculated as:

$$L_{supply} = L_{mech} + h_{ceiling} \times \left(\frac{n_{stories}}{2} \right) + L_{building}$$

$L_{building}$ is calculated based on the area and an assumed aspect ratio. The return length depends on whether the building has a central corridor. If it doesn't, the return length equals the supply length. If it does, the return length is assumed to not include additional pipes across the length of the buildings and is instead calculated as:

$$L_{return} = L_{mech} + h_{ceiling} \times \left(\frac{n_{stories}}{2} \right)$$

Supply piping is assumed to be insulated to R-6, with return piping insulated to R-4.

Water use equipment objects are used to model the water usage of each individual dwelling unit. These are unique hot water usage schedules for each unit up to 10 units (when unit multipliers are applied for computational efficiency). The uses are modeled in parallel, which neglects the length of pipes between units, but helps ensure that all hot water usage loads are met. Each unit uses hot water for showers, sinks, baths, and clothes washers and dishwashers if those are included in the units. Explicit piping within units is not directly modeled, but a heat gain and additional hot water usage amount associated with the in-unit distribution piping is included.

The recirculation pump runs 24/7. Its flow rate is calculated based on a nominal 5°F temperature drop through the supply and return piping with zero usage based on supply and return lengths. The exact flow rate varies based on the number of units in the building and the exact configuration, but it's generally between 2 and 10 gallons per minute.

The storage loop includes a fictitious pump connecting the storage tank to the heat exchanger, and then the heat exchanger loop contains the real recirculation pump. This "Storage Loop Pump" is autosized and consumes no power. Its primary purpose is to maintain equivalent flow between the tank and the heat exchanger and the heat exchanger to the water use.

Figure 14: Storage loop for a boiler serving domestic hot water.

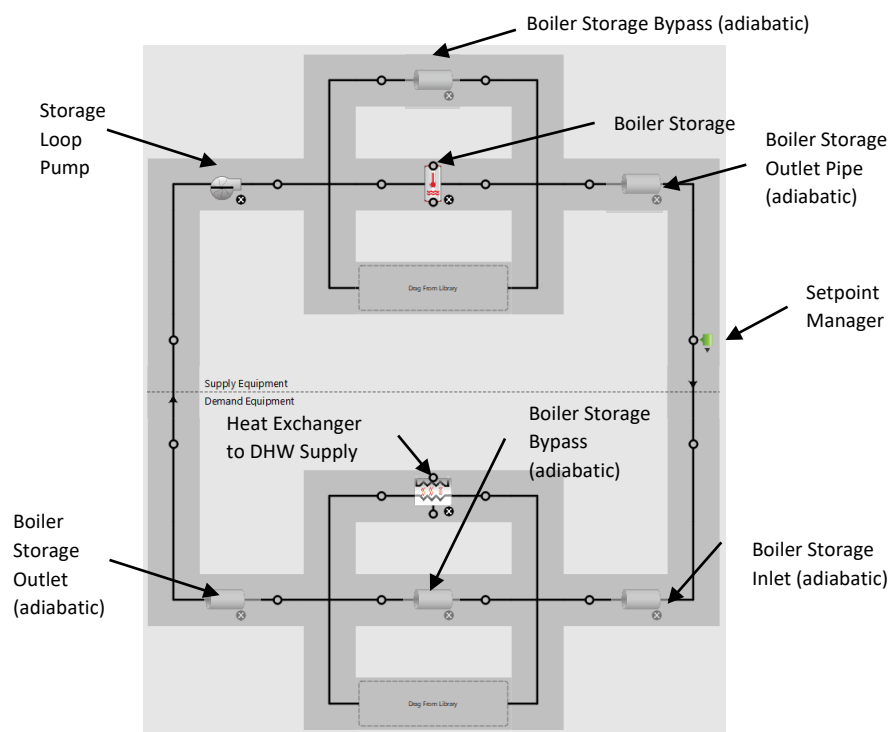
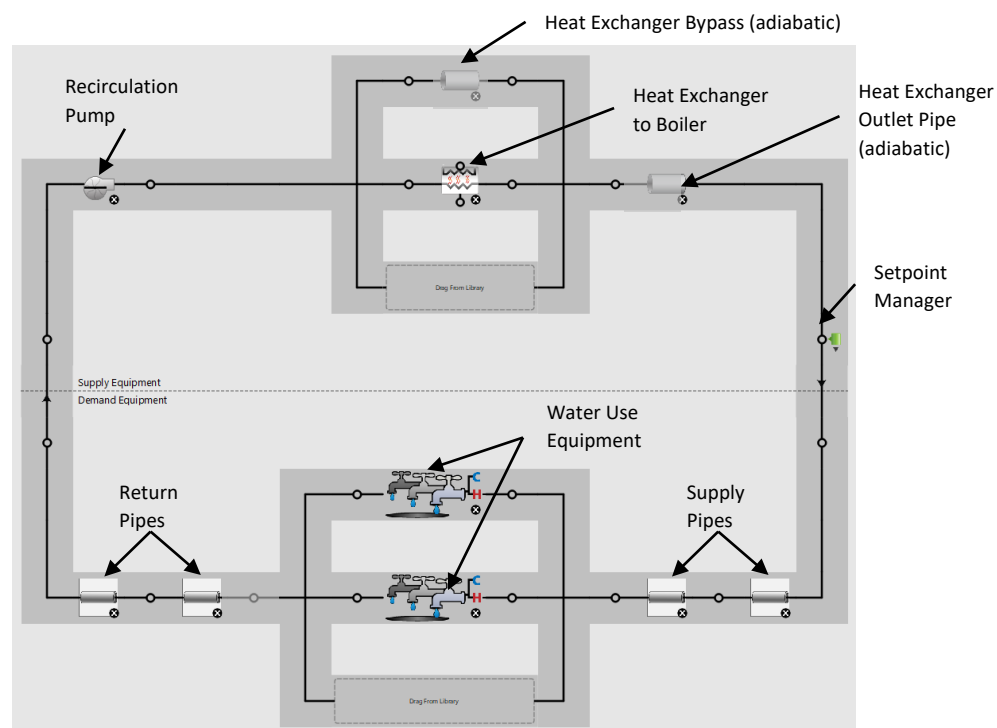


Figure 15: Recirculation loop serving domestic hot water in units.



Gas Heat Pump With Storage Tanks

This configuration consists of a supply loop with GAHP and another supply loop with a boiler, each with a storage tank that feeds the DHW loop.

Table 6: Plant Loop Component Summary for Heat Pump Water Heater With Storage Tanks.

Loop	Name	Supply Side	Demand Side	Figure
Loop 1	Supply Loop 1	GAHP	Storage Tank 1	Figure 16
Loop 2	Supply Loop 2	Boiler	Storage Tank 2	Figure 13
Loop 3	Storage Loop	Storage Tank 1, Storage Tank 2	Heat Exchanger	Figure 21
Loop 4	DHW Loop	Heat Exchanger	Hot Water Fixtures	Figure 15

Supply Loop (GAHP)

Figure 16: Supply loop of a storage tank with a GAHP.

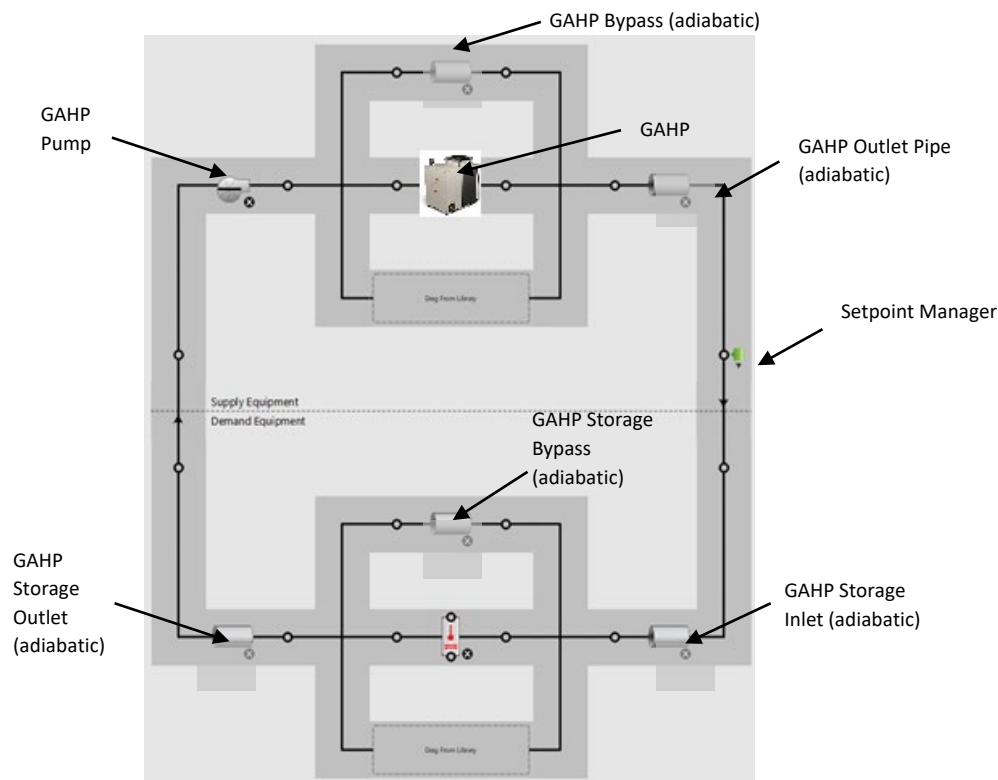


Figure 16 shows the supply loop with a GAHP. This is configured in the same way as the boiler loop, but with the GAHP replacing the boiler. The GAHP has a fixed size of 123.5 kBtu/hr, consistent with the rated capacity of the Robur GAHP-A. It also uses the same

nominal efficiency as the Robur unit (COP =1.29). The GAHP also uses an autosized pump, but the flow is not allowed to modulate, and the GAHP instead uses on/off behavior. The GAHP can only run when the inlet temperature is below 120°F. This allows for 20°F of heating, as the primary constraint on the physical equipment is that the outlet temperature cannot exceed 140°F. The performance curves developed by GTI Energy are used to model the efficiency and capacity of the GAHP in terms of incoming water temperature and ambient (outdoor) air temperature (Guada et al. 2024). Performance maps of capacity and efficiency are shown in Figure 17 and Figure 18, respectively.

Figure 17: GAHP heating capacity correction factor as a function of ambient and return temperature.

Tamb (F) ↓ Tret (F) →	100	110	120
0	0.71	0.6184	0.5812
10	0.796773	0.709404	0.67433
20	0.872851	0.789835	0.757012
30	0.938377	0.85984	0.829391
40	0.993499	0.919564	0.891614
50	1.03836	0.969153	0.943826
60	1.073107	1.008751	0.986172
70	1.097885	1.038505	1.018797
80	1.11284	1.058559	1.041847
90	1.118116	1.06906	1.055468
100	1.11386	1.070152	1.059804
110	1.100217	1.061981	1.055002

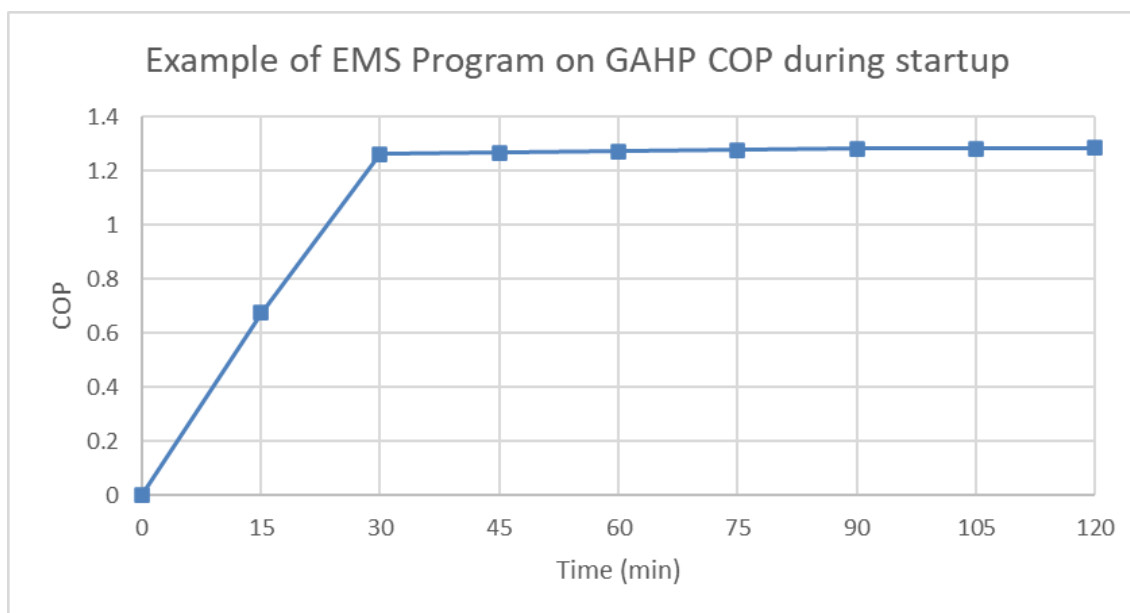
Figure 18: GAHP coefficient of performance (COP) as a function of ambient and return temperature.

Tamb (F) ↓ Tret (F) →	100	110	120
0	0.820008	0.775555	0.735673
10	0.904653	0.859353	0.818373
20	0.994821	0.949772	0.908626
30	1.088226	1.044874	1.004844
40	1.181252	1.141327	1.104013
50	1.268868	1.234196	1.201369
60	1.34488	1.317061	1.290369
70	1.402663	1.382667	1.363233
80	1.436347	1.424167	1.412192
90	1.442162	1.436697	1.431274
100	1.41943	1.418705	1.417981
110	1.370755	1.372408	1.374064

Power input utilization correction factors (not shown) are also used in the GAHP model based on coefficients provided by GTI Energy. These curves, along with a curve for the nominal ancillary electricity consumption, are used to calculate any additional electricity consumption used by this unit for controls, defrost, or any other auxiliary function. All of the model inputs, such as capacity, auxiliary energy use, and more, were set to match the rated performance of the Robur GAHP to try to make the model as exact as possible. The one exception is the nominal COP. When the curves were derived, the nominal COP was “baked in” to the coefficients of the efficiency curve. As a result, the nominal COP is set to 1.0 to avoid double counting this efficiency.

The Robur GAHP also takes roughly 20 minutes to hit its steady-state efficiency. Although part-load curves were derived and used, they do not necessarily capture this effect. Since the system is configured such that the GAHP will cycle on and off, by default during the first few timesteps it will run at a part-load ratio of 100%. To explicitly capture this, a custom EnergyPlus program was written using the built-in scripting language, EMS. This program reduces the efficiency during the first timestep when the GAHP turns on. Since simulations were run at 15-minute timesteps, only the first timestep was impacted, as the startup impacts 15–30 minutes after the unit starts are minimal. An example of this EMS program affecting the efficiency of the GAHP for a single cycle is shown in Figure 19.

Figure 19: Example of the EMS program impacting COP during startup. Without this EMS program, the COP during the first timestep when the GAHP turns on (at 15 minutes) would be near 1.2.

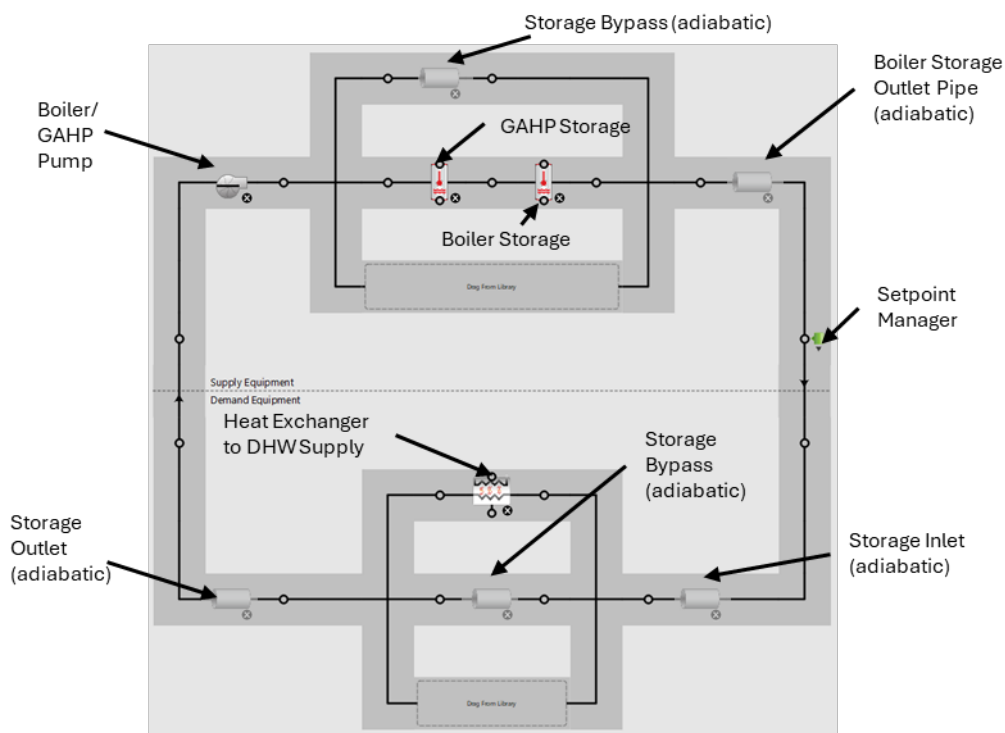


Storage Loop

Figure 20 shows the storage tank configuration for GAHP cases. The GAHP is connected to the first tank in the loop, which acts as a preheat tank. The second tank is the existing tank, connected to the existing boiler, and it meets any load that the GAHP is unable to meet. This configuration allows the GAHP to meet as much load as possible (and at the lowest temperature possible), to try to maximize the usage and efficiency of the GAHP.

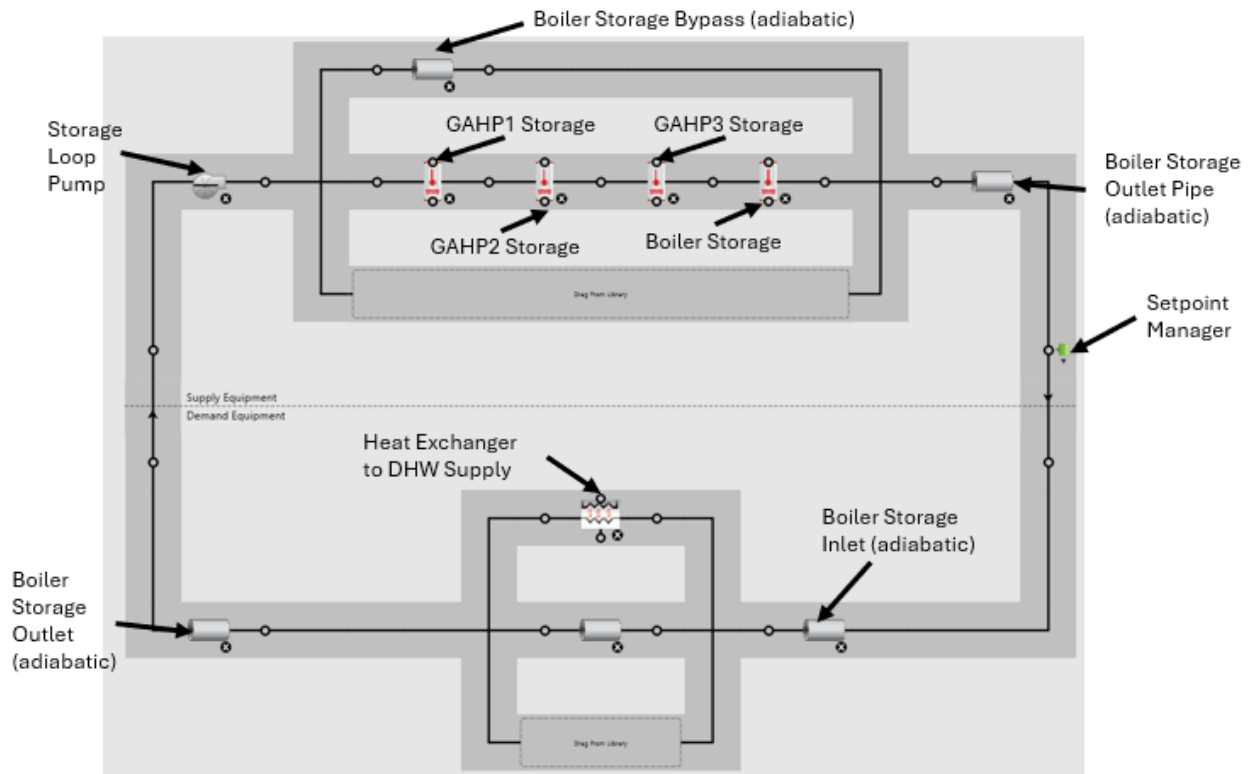
The use side (DHW end uses) is identical to what was previously shown in Figure 15.

Figure 20: Storage loop for cases with a GAHP. The GAHP is coupled with the first storage tank as a preheater, while the existing boiler coupled with a storage tank serves the loads.



For larger buildings, multiple GAHPs can be installed. A GAHP is added for every 20 units, with buildings with 20–40 units having one GAHP, 40–60 having two GAHPs, etc. Each GAHP is paired with a stratified tank, and all the tanks are plumbed in series to heat water. The boiler remains after the last GAHP storage tank to meet any remaining loads during peak usage. An example of the storage tank configuration is shown in Figure 21. Each storage tank is connected to a GAHP as shown in Figure 16.

Figure 21: Storage loop for cases with three GAHPs. Multiple GAHPs are configured in series as preheaters, with one GAHP and an associated storage tank serving as preheaters. The existing boiler remains after the last GAHP storage tank to meet any remaining loads.



Modeling Assumptions and Limitations

The following list contains assumptions and limitations related to the modeling of shared water heating systems. The items in the list reflect the current state of the whole-building workflow and AddSharedWaterHeater measure; they may be changed or improved.

- Whole-building models with shared water heating systems are only created for buildings with 10 or more dwelling units.
- ResStock Parameter|Option combinations that map to “boiler with storage tanks” configurations set the following boiler nominal efficiency values:
 - Water Heater Efficiency|**Natural Gas Standard**: 80% AFUE
 - Water Heater Efficiency|**Natural Gas Premium** and Water Heater Efficiency|**Natural Gas Tankless**: 85% AFUE
 - Water Heater Efficiency|**Natural Gas Premium, Condensing** and Water Heater Efficiency|**Natural Gas Tankless, Condensing**: 90% AFUE

- ResStock Parameter|Option combinations that map to “gas heat pump with boiler and storage tanks” configurations set the following (backup) boiler nominal efficiency values:
 - Water Heater Efficiency|**Natural Gas Heat Pump, Standard:** 80% AFUE
 - Water Heater Efficiency|**Natural Gas Heat Pump, Premium:** 85% AFUE
 - Water Heater Efficiency|**Natural Gas Heat Pump, Premium, Condensing:** 90% AFUE
- Ten unique dwelling units of a multifamily building are modeled, with unit multipliers used to account for buildings with more than 10 dwelling units.
- For every water heating system type configuration, the boiler count is fixed at one and its capacity is calculated based on the methodology in the ASHRAE HVAC Application to meet the full load.
- Each supply plant loop can contain at most one supply component (i.e., boiler or gas-fired heat pump) on its supply side.
- Modeling solar hot water in conjunction with shared water heating systems is currently not supported.

Simulation Outputs and Results

This section presents outputs and results for the six ResStock scenarios after having created, simulated, and processed tens of thousands of building energy models using NREL’s high-performance computing resources. Each simulation is run using typical meteorological year weather data, annual run period, and 15-minute simulation timestep. Simulation data are processed, stored, and queried to summarize outputs and results.

Building Segment Results

The following sections describe the outputs and results for the six scenarios (ResStock Scenarios 1, 2, 3a, 3b, 4a, 4b):

- **Scenario 1:** The baseline/existing California residential multifamily housing stock.
- **Scenario 2:** The 2023 multifamily housing stock reflecting 2022 Title 24/Title 20 code compliance in new, adoption of PV in 1% of the stock, replacement of existing gas water heaters with more efficient options in 20% of the stock, and local electrification measures as of February 2023.
- **Scenario 3a:** The 2026 projected multifamily housing stock reflecting projected 2025 code compliance, PV adoption, and replacement of gas water heaters at the same levels as Scenario 2 and baseline electrification of 1% of the stock.
- **Scenario 3b:** Scenario 3a with gas heat pump water heaters targeting 0.7% market penetration and 0.1% baseline electrification.

- **Scenario 4a:** The 2029 projected multifamily housing stock reflecting estimated 2028 code compliance, PV adoption, and replacement of gas water heaters at the same levels as Scenario 2 and baseline electrification of 1% of the stock.
- **Scenario 4b:** Scenario 4a with gas heat pump water heaters targeting 6.5% market penetration and 0.1% baseline electrification.

Below are scenario outputs and results summaries for (1) energy consumption, (2) emissions, and (3) utility bills. For all types (energy consumption, emissions, or utility bills), the following sets of plots are shown across California:

- Per-dwelling unit average for **net energy use**
- Per-dwelling unit average for **net electricity use**
- Per-dwelling unit average for **natural gas fuel use**.

Additionally, for energy consumption and emissions the following sets of plots are shown:

- Per-dwelling unit average for **hot water energy use**
- Per-dwelling unit average for **hot water electricity**
- Per-dwelling unit average for **hot water natural gas**.

Note that:

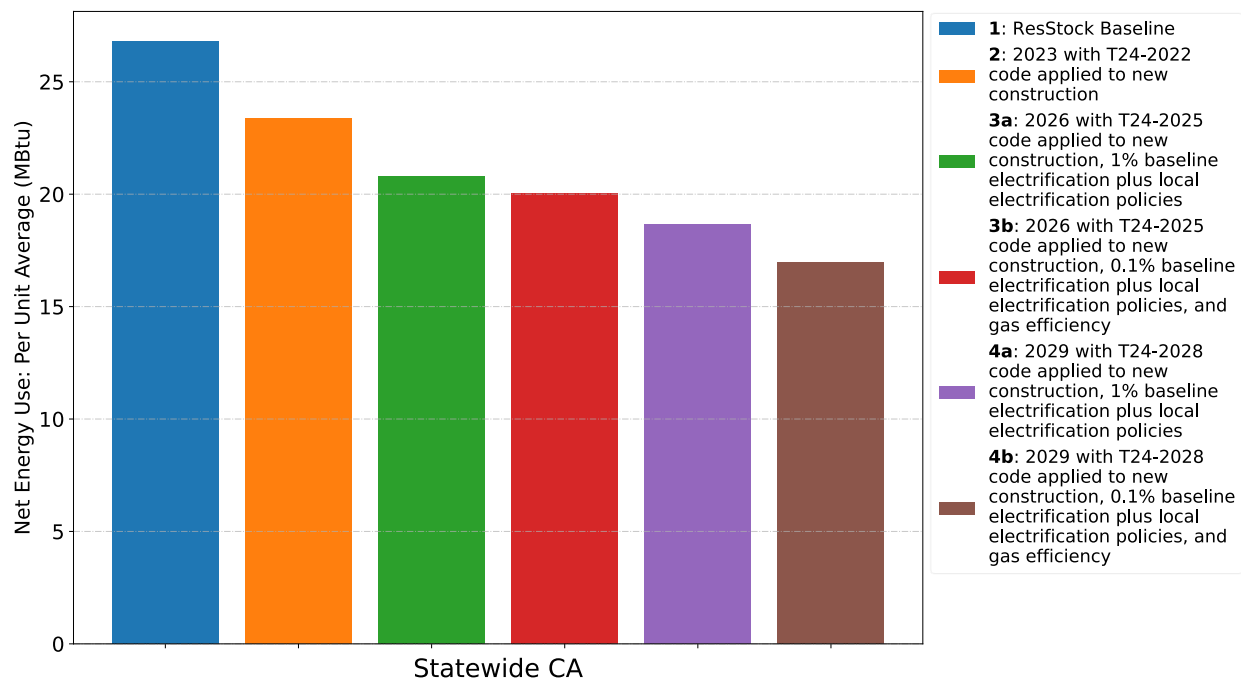
- In each plot, averages are calculated across dwelling units that use the fuel type either generally or for the hot water end use. In other words, zero values are excluded in the calculations of per-dwelling unit averages.
- Energy consumption is measured in units of MBtu (million Btu).
- Net electricity consumption is plotted. This includes any PV generation offsetting electricity use in the buildings.
- CO₂e emissions are measured in units of mt (metric tons).
- Utility bills are measured in units of USD (\$).

Energy Consumption

Figure 22 shows the net energy use per dwelling unit across scenarios for the state. Average energy use decreases every 3 years due to the old units being torn down and new code compliant buildings being erected, along with some electrification. By 2029, the energy intensity of the stock in average is reduced by more than 25%. Introducing gas efficiency measures in 2026 and 2029 do reduce the energy use per unit but are not as impactful as the stock level changes every 3 years. The 2029 gas efficiency improvements

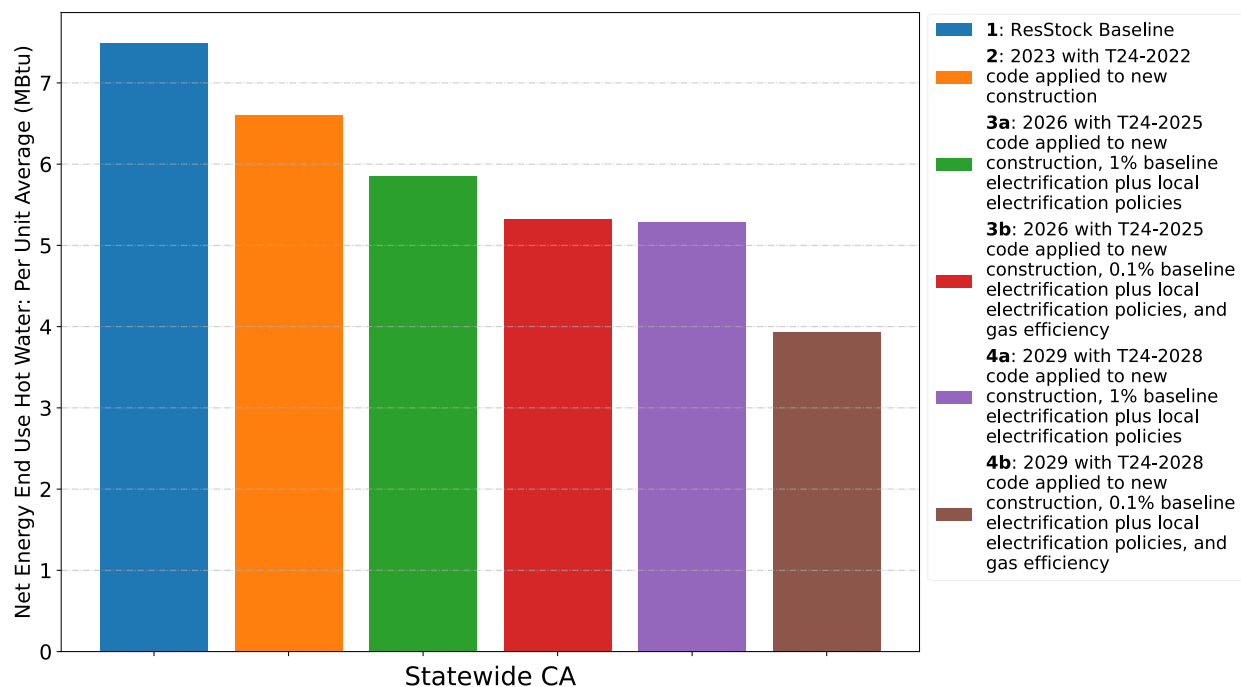
are more impactful as they are assumed to be able to be applied to a larger portion of the stock than the 2026 ones due to more time to plan for the improvements.

Figure 22: Per-unit average net energy use across projection scenarios, for California.



Hot water energy use across scenarios are shown in Figure 23 across the stock. Notably, since the gas efficiency measures apply to water heating, the impact of these scenarios is more notable than when looking at the overall building energy use. The projected 2026 gas efficiency scenario is expected to have a comparable impact on water heater energy consumption to the combined effects of all code changes, new construction, and demolitions anticipated in the 2029 scenario. Adding gas efficiency into the 2029 scenario reduces water heating energy use by more than 20%.

Figure 23: Per-unit average hot water energy use across projection scenarios, for California.



Per-unit total electricity consumption is shown in Figure 24, with per unit water heating electricity consumption in Figure 25. While natural gas is the predominant fuel for water heating in California, there are still some households that use electricity for water heating (see Figure 7). Some electricity is also used for central systems and more efficient gas products to run fans and pumps. Changes in electricity use across different years are roughly proportional to the change in overall energy use in different years. For water heating electricity use, this is due to assumed adoption of residential heat pump water heaters across the stock. Gas efficiency scenarios have minimal impact on electricity use, with the only changes being due to differences in energy used by fans, pumps, and any standby power.

Figure 24: Per-unit average net electricity use across projection scenarios, for California.

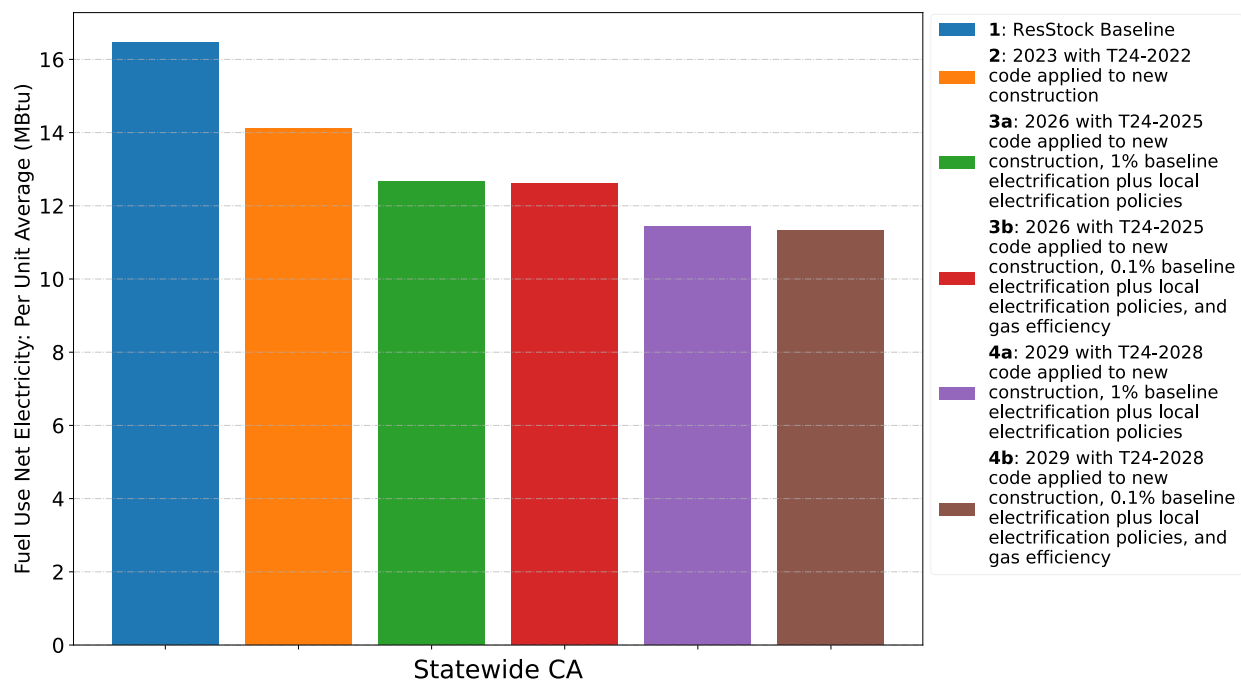


Figure 25: Per-unit average hot water electricity use across projection scenarios, for California.

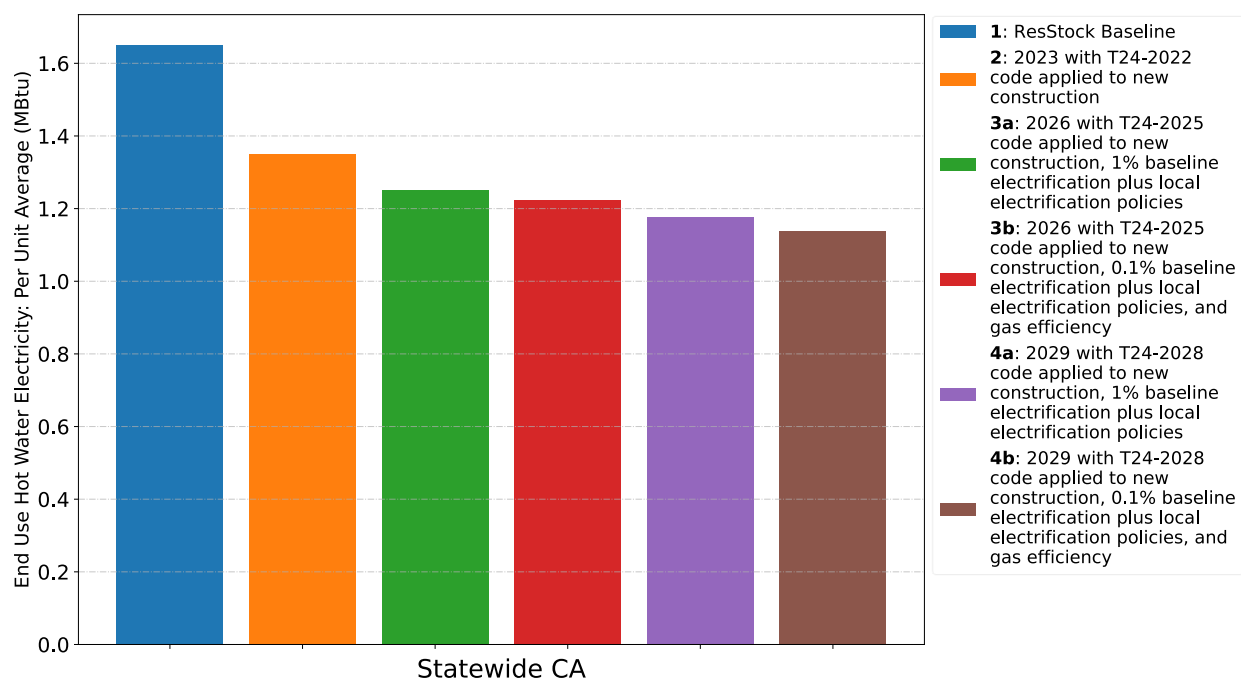


Figure 26 shows the building stock-level natural gas use for all end uses and Figure 27 shows gas use for water heating across the state for each scenario. Water heating accounts for about 55% of the natural gas use in buildings in the state in the baseline, with the rest being associated with space heating, cooking, or uncommon miscellaneous gas loads. Gas efficiency measures in 2026 and 2029 are more impactful than the natural turnover of the stock. Water heating is the largest end use in many climate zones in California, so water heater efficiency measures have the largest impact on gas usage in residential units. The 2029 scenario has a larger impact as it applies to a larger number of buildings. Gas efficiency measures in 2029 can save about 30% on water heating gas use for the stock.

Figure 26: Per-unit average natural gas use across projection scenarios, for California.

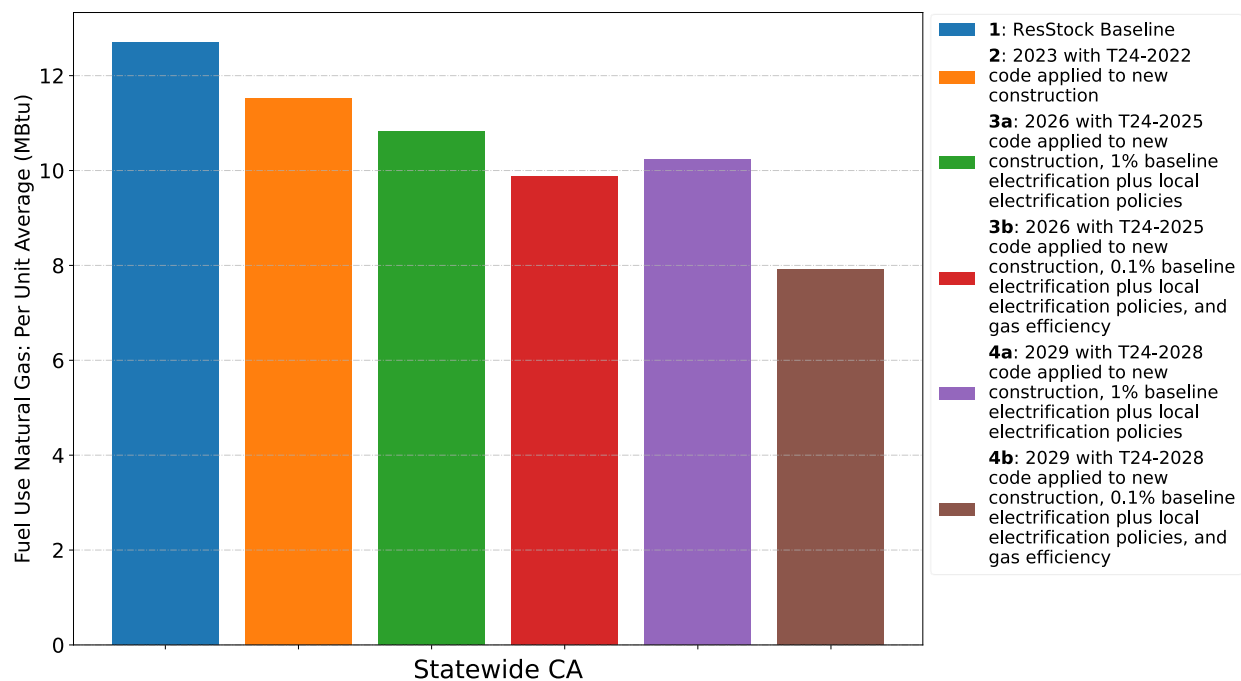
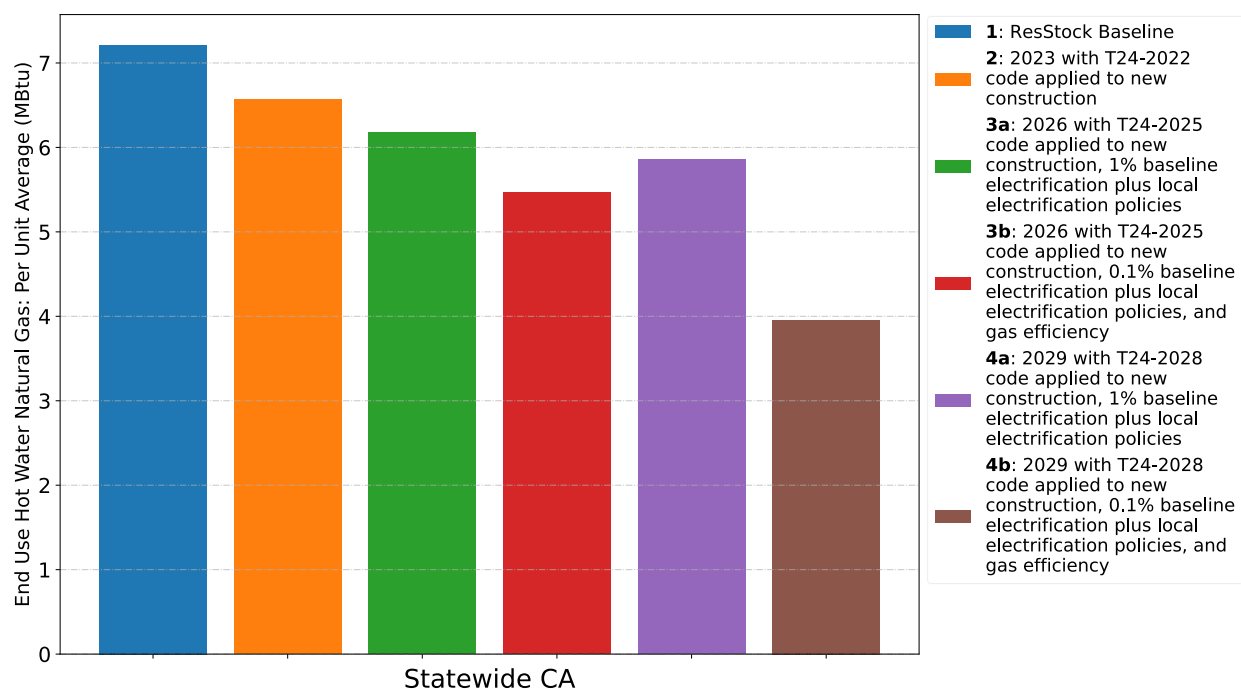


Figure 27: Per-unit average hot water natural gas use across projection scenarios, for California.



Emissions

To determine the emissions associated with electricity consumption in these scenarios, the 2022 version of the [Cambium](https://www.nrel.gov/analysis/cambium.html)³³ database was used for all scenarios regardless of the future year. The Cambium database includes hourly emissions factors for several different scenarios. Notably, it provides the long run marginal emissions rate (LRMER), in addition to average emissions. The LRMER is the change in emissions that would happen when adding or removing a load that would consume energy for a long time (like a building) and would therefore require energy year over year to support it. LRMER is recommended for understanding the impact of efficiency measures on building related emissions,³⁴ because buildings are in place for long periods of time and so the impact of changes in load have an impact over multiple decades. This is different than the short run emissions reported by other sources such as the Environmental Protection Agency's [AVERT](https://www.epa.gov/avert)³⁵ tool. The AVERT emissions are based on the real emissions for a given year, but only for that year, and don't account for how the grid might change in the future as long run emissions do. These future grid changes (e.g., adding more solar and wind, or retiring fuel-fired plants) can substantially change the emissions impact of a load over its lifetime. Cambium estimates this by modeling the future energy grid under several different scenarios out to 2050. The "Mid

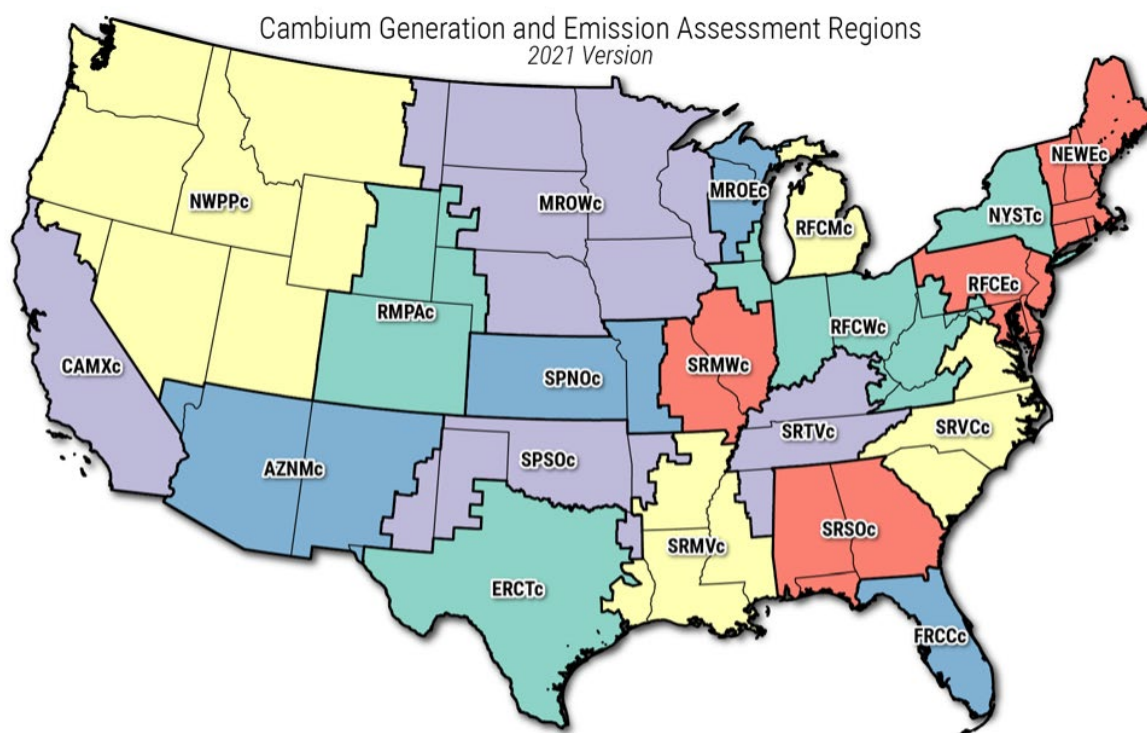
³³ <https://www.nrel.gov/analysis/cambium.html>

³⁴ <https://www.energy.gov/sites/default/files/2025-01/bto-ghg-metrics-011525.pdf>

³⁵ <https://www.epa.gov/avert>

Case” was chosen, which uses central estimates for costs, prices, renewable deployment, and demand growth. Sets of hourly emissions factors are organized by generation and emission assessment (GEA) regions. Figure 28 shows the GEA regions relevant for California. For any situations where PV is net producing, that energy production is assumed to be offsetting an equal amount of grid emissions at that time based on LRMER.

Figure 28: Cambium’s generation and emission assessment (GEA) regions.



Default fuel emissions factors were used (but converted from lb/MBtu to mt/MBtu) from Table 5.1.2(1) *National Average Emission Factors for Household Fuels from ANSI/RESNET/ICC 301 Standard for the Calculation and Labeling of the Energy Performance of Dwelling and Sleeping Units using an Energy Rating Index* to determine associated emissions with the fuel consumption in these scenarios.³⁶

³⁶ See https://openstudio-hpxml.readthedocs.io/en/v1.8.1/workflow_inputs.html#default-values for the specific emissions factor used for each fuel type.

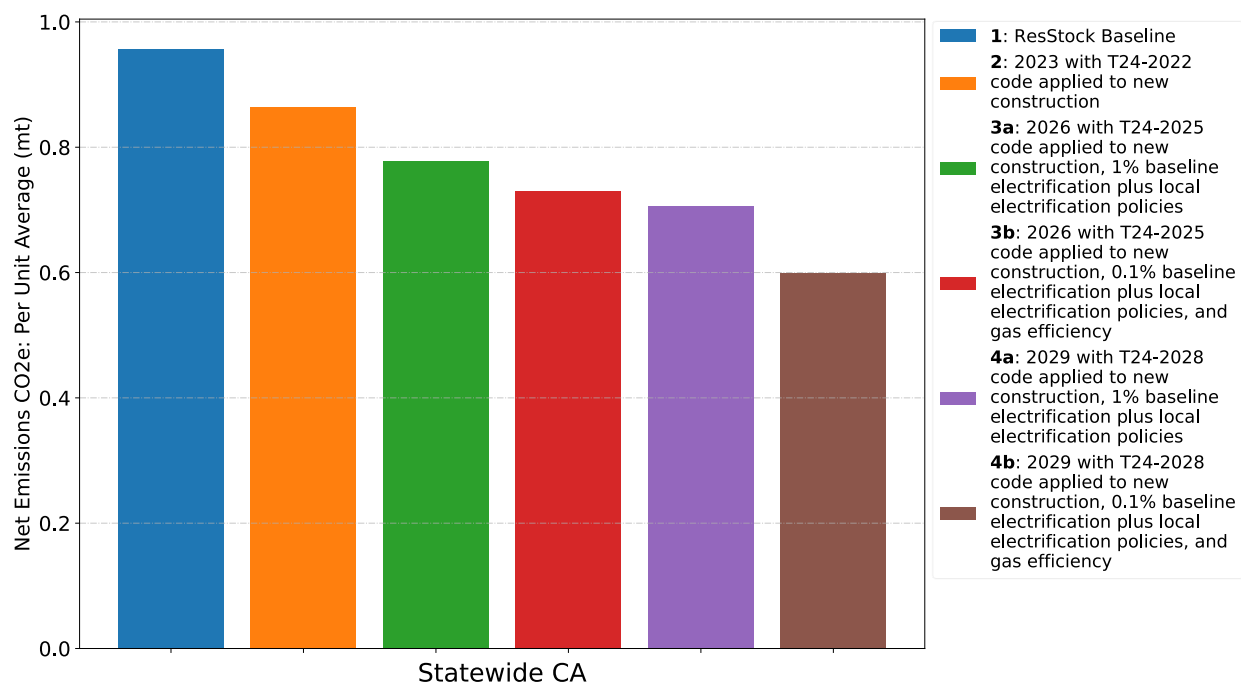
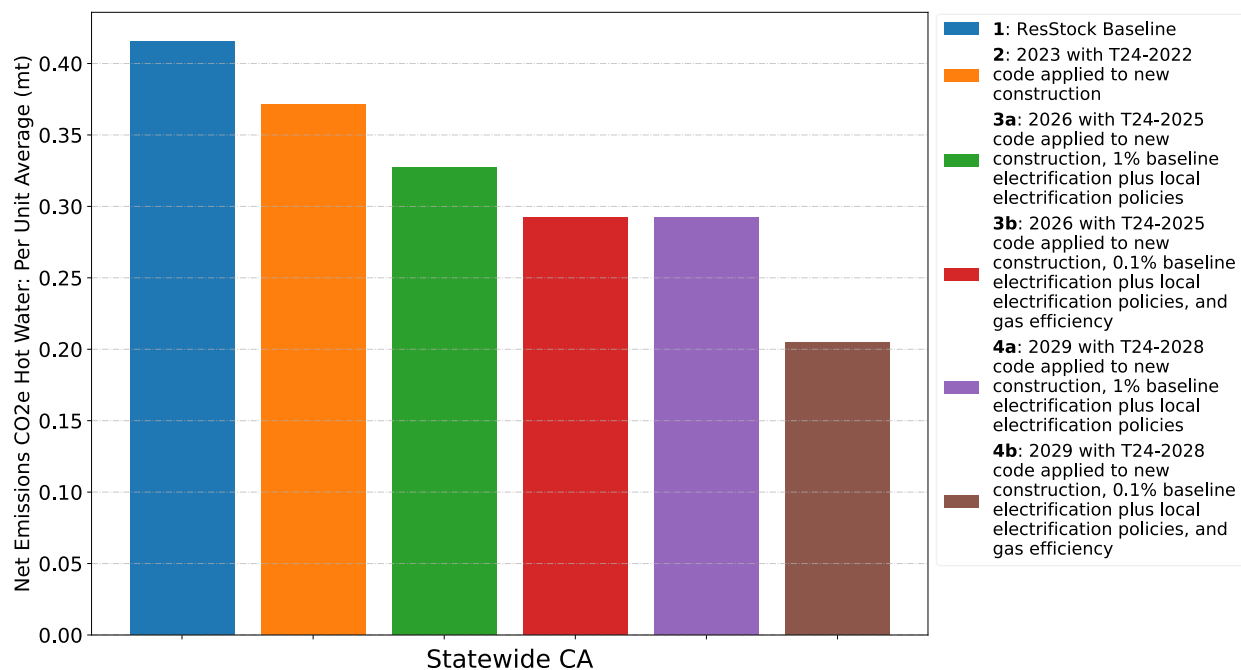
Figure 29: Per-unit average net emissions across projection scenarios, for California.**Figure 30: Per-unit average hot water emissions across projection scenarios, for California.**

Figure 29 show the average per unit emissions for all end uses and Figure 30 shows emissions related to hot water specifically. Total emissions follow the same general trends seen with total energy use. Water heating makes up roughly 40% of the total emissions

related to this sector in the baseline scenario for the state of California. Water heating is more impacted than overall energy use by the upgrade scenarios, particularly when considering gas efficiency. In 2029 gas efficiency has the potential to reduce hot water related emissions by more than 14%.

Figure 31: Per-unit average net electricity emissions across projection scenarios, across California.

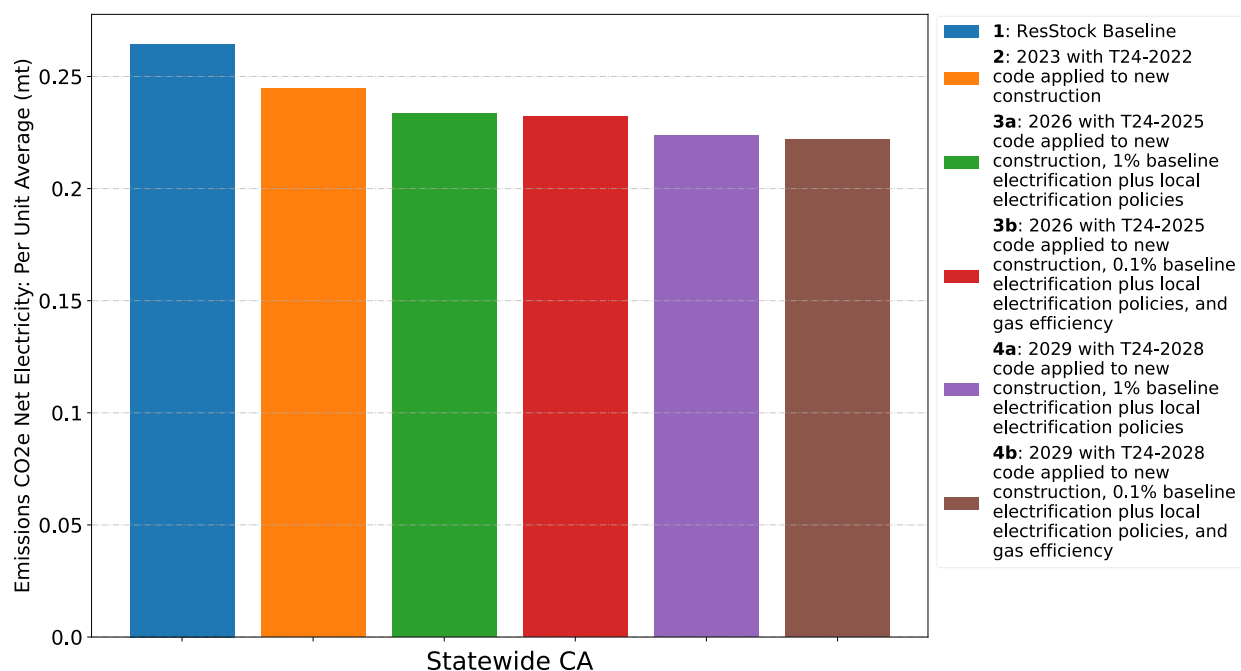


Figure 31 and Figure 32 show the per unit average total electricity use and hot water specific electricity use, respectively. Since most homes in California use natural gas for water heating, less than 10% of the emissions related to home electricity use is due to water heating. Trends generally follow those seen for electric energy use, indicating that the differences in timing of emissions associated with the grid in California don't substantially change the impact between electricity use and the associated grid emissions.

Figure 32: Per-unit average hot water electricity emissions across projection scenarios, across California.

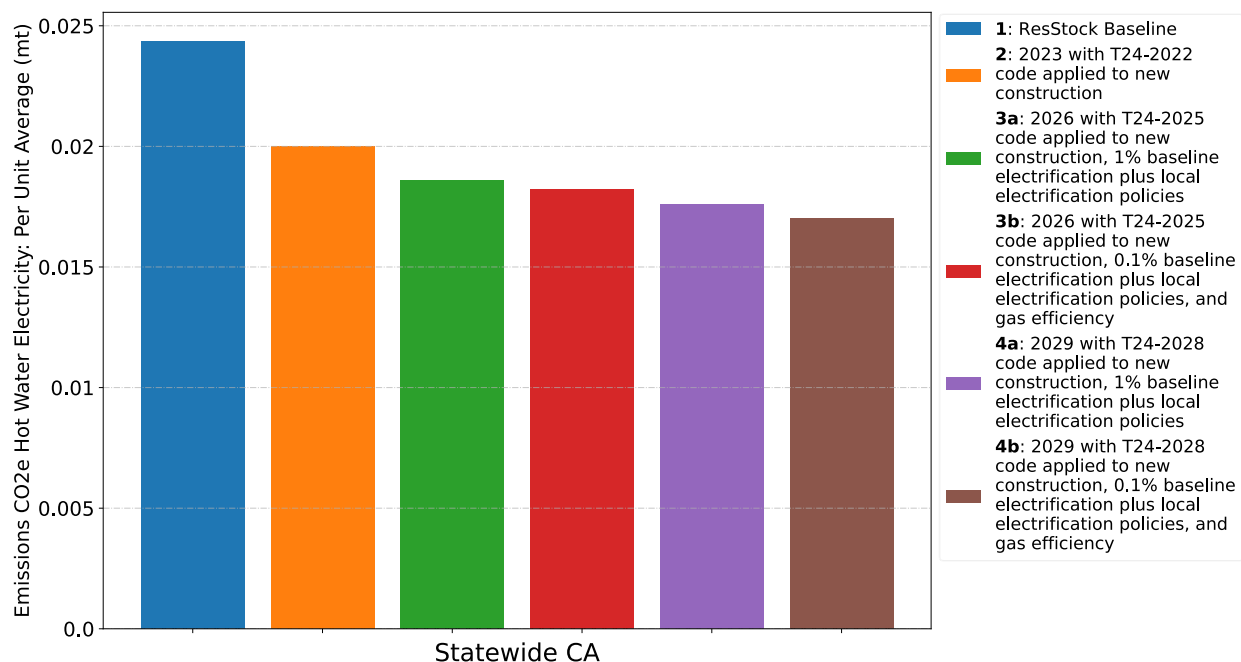


Figure 33 and Figure 34 show the per unit average emissions related to gas use in buildings overall and specifically related to water heating, respectively. As gas emissions don't vary based on the time of year or time of day when natural gas is used, the emissions are directly proportional to the energy consumption results discussed in the prior section.

Figure 33: Per-unit average natural gas emissions across projection scenarios, across California.

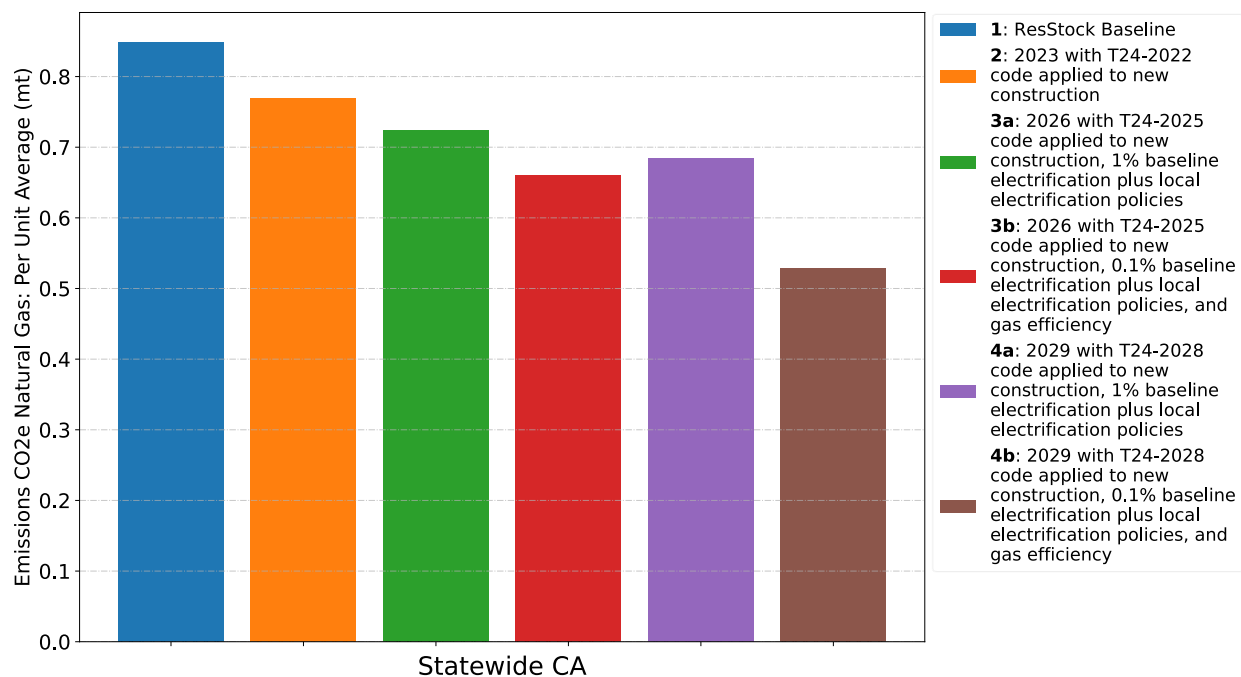
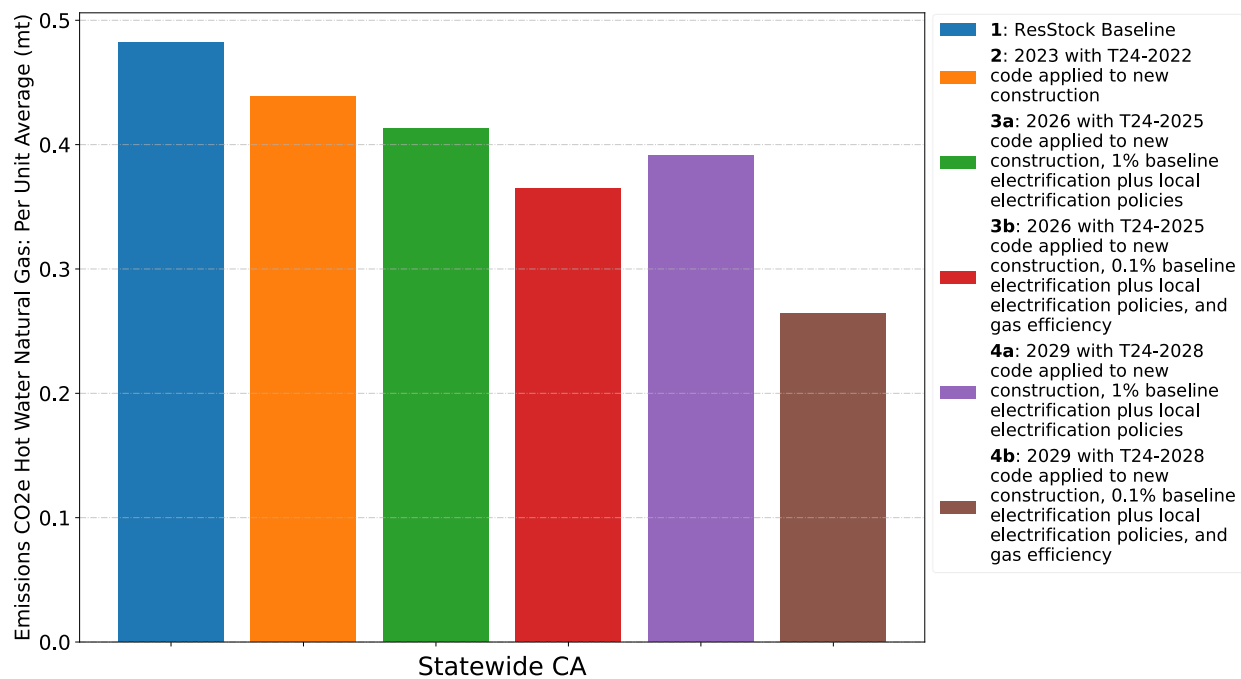


Figure 34: Per-unit average hot water natural gas emissions across projection scenarios, across California.



Utility Bills

Simple utility rate structures were used for calculating electricity, natural gas, and propane utility bills. Inputs used are a fixed monthly charge and a marginal rate. Default fixed monthly charges (\$12/month for both electricity and natural gas, and \$0/month for propane) and marginal rate (approximately \$0.24/kWh for electricity, \$1.65/therm for natural gas, and \$3.11/gal for propane) values were used for Scenario 1.³⁷

At the direction of ICF, a 0%/year gas and propane escalation rate and a 10%/year escalation for electricity marginal rate³⁸ was used (\$0.32/kWh for Scenario 2, \$0.43/kWh for Scenario 3a and 3b, and \$0.57/kWh for Scenario 4a and 4b). Furthermore, the PV compensation type follows the default net-metering approach in which a user-specified \$0.03/kWh annual excess sellback rate is used.³⁹ Rates are assumed to be state average based on EIA data, and do not account for different prices at different times of day. This also does not fully reflect the details of the current net energy metering (NEM) policy, [NEM 3.0](#), in California.

Figure 35 shows the state average utility bills for all fuels across scenarios, while Figure 36 and Figure 37 show the bills associated with electricity and gas, respectively. Overall bills increase, driven by many factors including renewables requirements, wildfire protection requirements and NEM costs. Gas efficiency measures only have a modest impact on the stock level energy bills, as natural gas only accounts for about 10–20% of the total energy bills for the home. Note that individual dwellings that do have gas efficiency measures applied would have their bills lowered by more than the overall stock level savings shown here, as even the 2029 scenario only assumes adoption of gas efficiency by a minority of the total stock.

³⁷ Default marginal rates for California used per 2022 EIA State Energy Data System referenced in https://openstudio-hpxml.readthedocs.io/en/v1.8.1/workflow_inputs.html#electricity-rates and https://openstudio-hpxml.readthedocs.io/en/v1.8.1/workflow_inputs.html#fuel-rates.

³⁸ The electricity escalation rate comes from the Public Advocates Office at the California Public Utilities Commission <https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/press-room/reports-and-analyses/240722-public-advocates-office-q2-2024-electric-rates-report.pdf>.

³⁹ Default PV compensation type and annual excess sellback rate referenced in https://openstudio-hpxml.readthedocs.io/en/v1.8.1/workflow_inputs.html#pv-compensation.

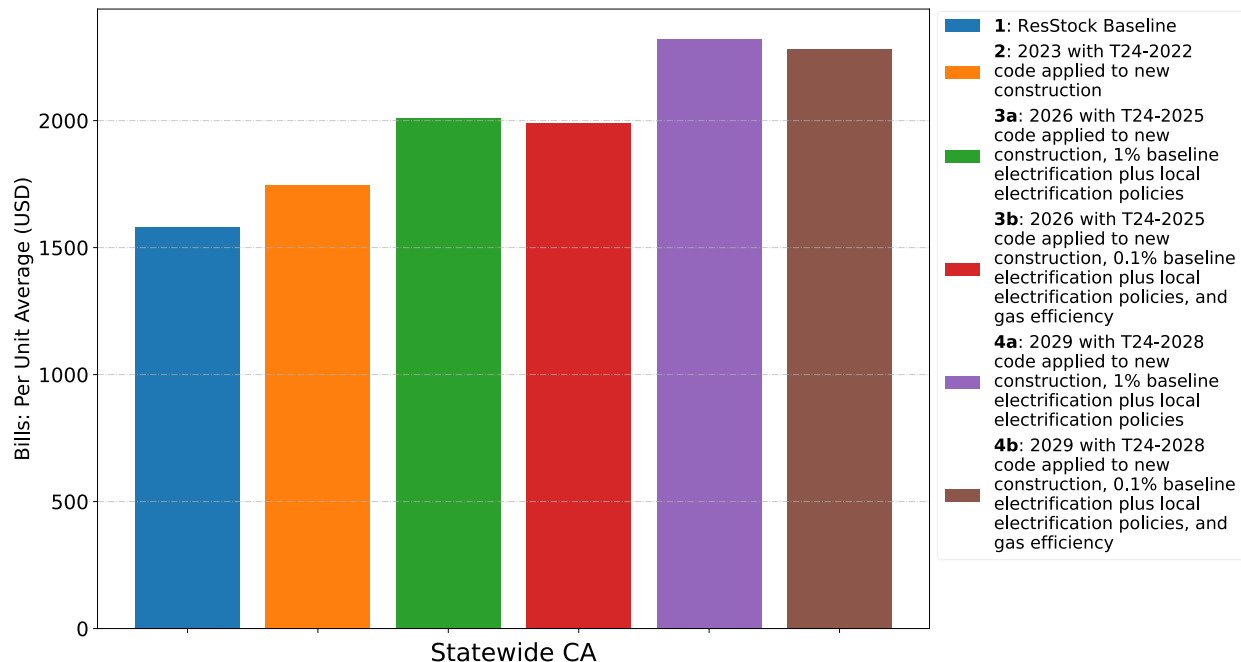
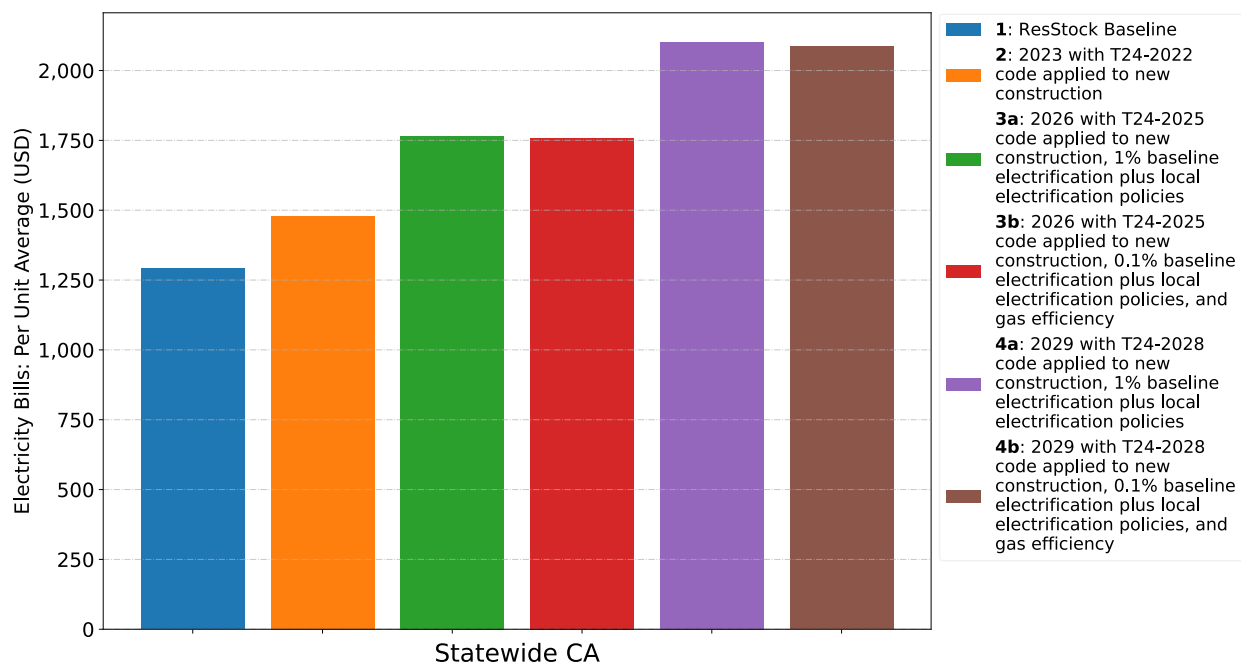
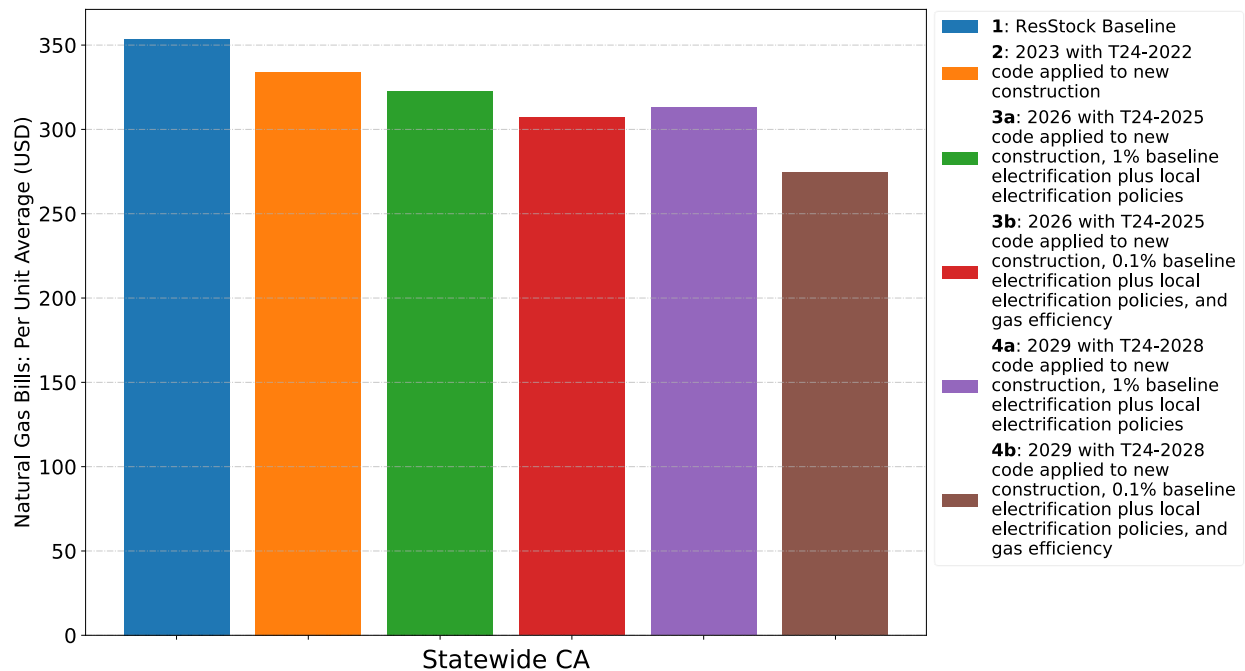
Figure 35: Per-unit average bills across projection scenarios, for California.**Figure 36: Per-unit average electricity bills across projection scenarios, across California.**

Figure 37: Per-unit average natural gas bills across projection scenarios, across California.



GAHP Upgrade Results

Simulation data summarized in the following plots are down-selected from the broader 2029 data set to only those dwelling units in multifamily buildings with:

- A shared boiler in the baseline building
- The same boiler (as backup) plus GAHP(s) installed as a retrofit in the upgrade building.

For year 2029, there were approximately 5,500 buildings that were modeled with a shared boiler in the baseline building and the GAHP with backup in the upgrade building; after scaling simulation output using representative sample weights, these models represent approximately 47,000 actual multifamily buildings across the state of California.

The following collection of bar plots and scatterplots report hot water electricity combined with hot water natural gas (MBtu) for Scenarios 4a and 4b. For each figure, savings that the GAHP can offer are shown by comparing **2029** (Scenario 4a) and **2029 with Gas Efficiency** (Scenario 4b).

Figure 38 shows histograms of the total and per-unit average energy consumption across different climate zones for Scenario 4a and 4b, in which a GAHP is installed as a retrofit. Across the multifamily stock, a GAHP upgrade can offer substantial savings over a baseline

boiler. The simulations performed here are configured to ensure that the GAHPs are able to achieve long run times (over an hour) that minimize the impact of startup losses. Actual savings can be highly dependent on the exact configuration of the GAHP as backup, how much load it meets, and how frequently it cycles.

Figure 38: Bar plot of total (top) and per-unit average (bottom) hot water (electricity + natural gas) energy consumption across baseline/upgrade scenarios, broken out by CEC climate zone.

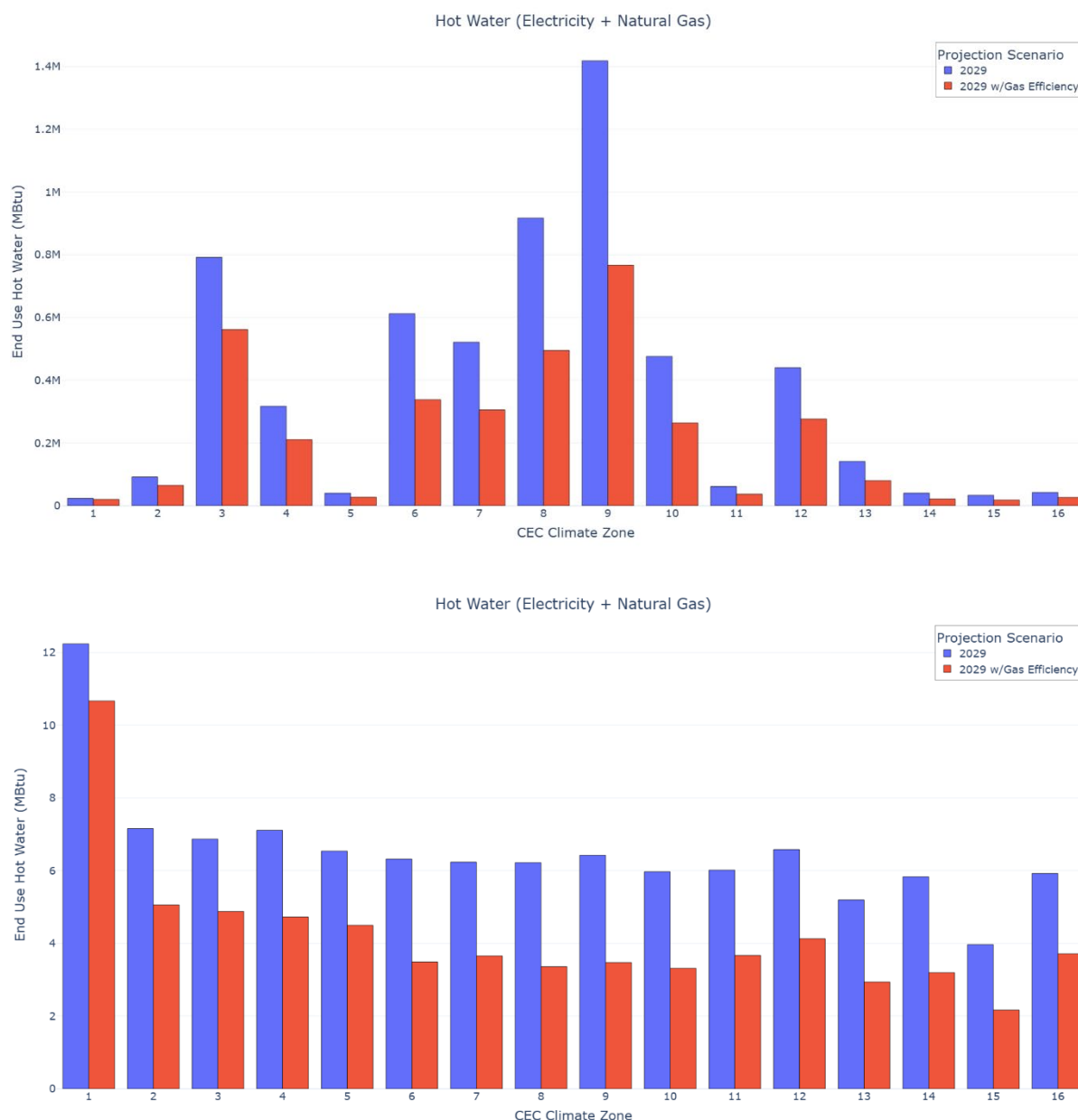


Figure 39 shows the results across buildings with different numbers of dwelling units. The results show decreasing savings with increasing building size. As more heat pumps are installed, savings are reduced because the heat pumps are either unable to keep up with the peak loads and the boiler runs more frequently, or the heat pumps feed warmer water into each other, reducing the efficiency and runtime of some of the GAHPs.

Figure 39: Bar plot of total (top) and per-unit average (bottom) hot water (electricity + natural gas) energy consumption across baseline/upgrade scenarios, broken out by number of dwelling units per building.

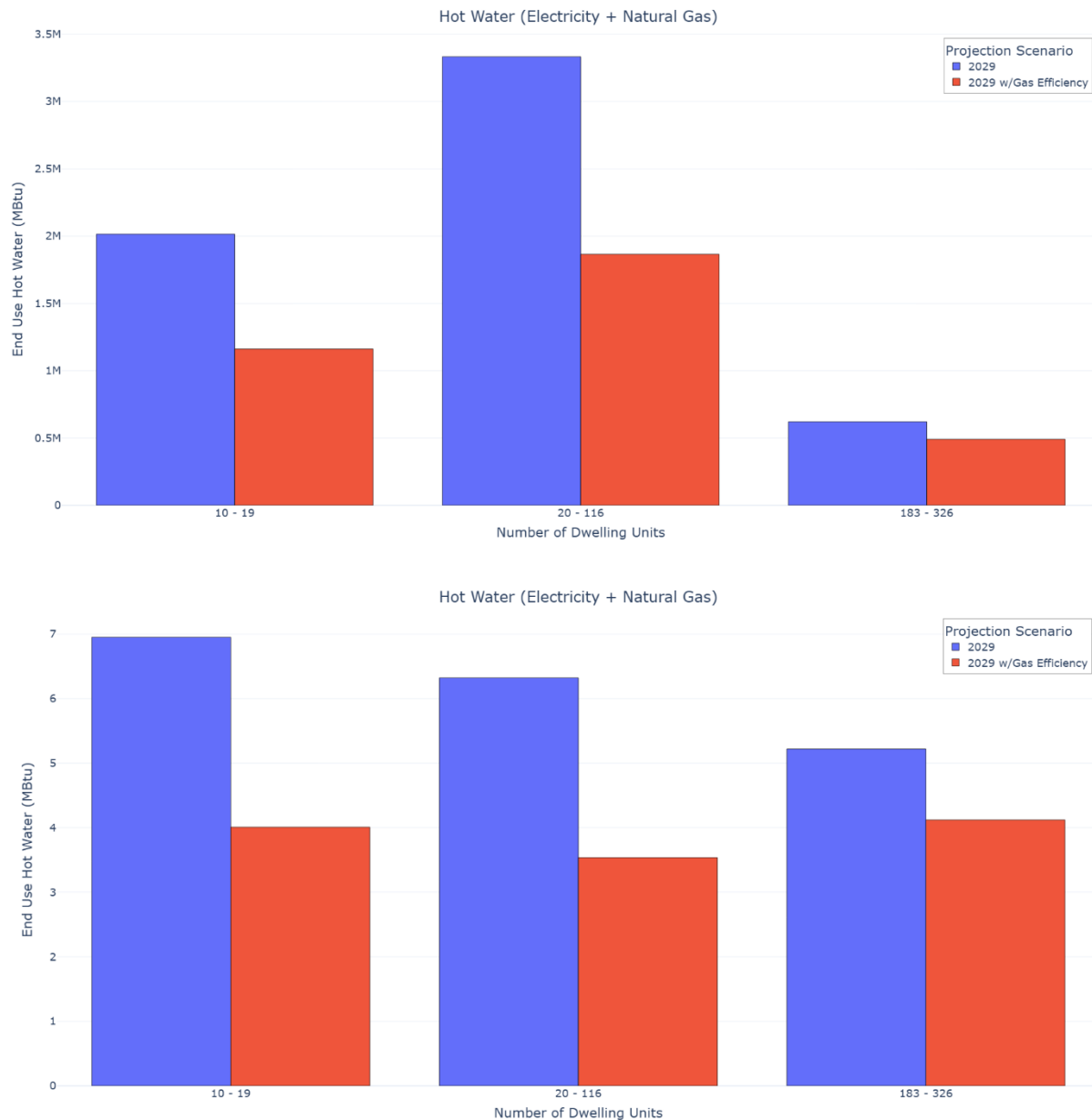
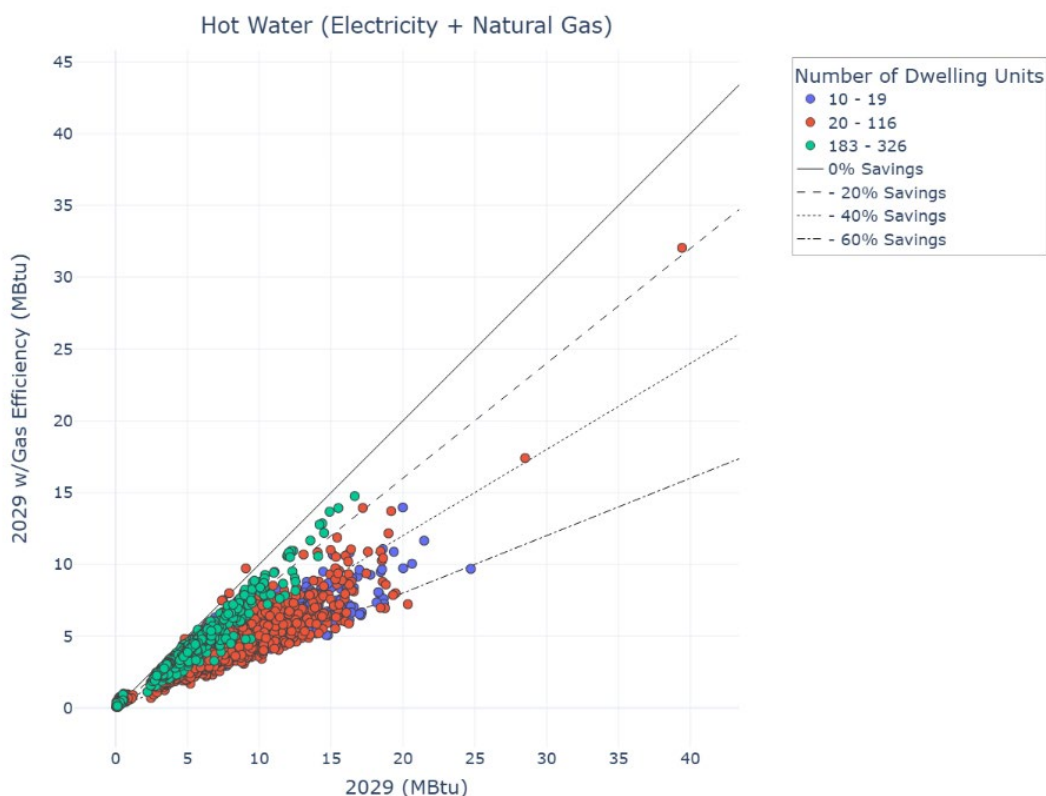


Figure 40 shows the baseline and upgrade energy savings on a per-unit basis for each dwelling unit, binned by the number of dwelling units in the building in 2029. Smaller buildings can have the largest per-unit baseline energy consumption due to the impact of recirculation losses and other parasitic energy use that does not directly serve the load, such as electricity used for controls and pumps to circulate to the boiler but may also save a substantial amount of energy. Larger buildings (more than 116 units) generally have less savings, as multiple GAHPs can be less efficient and there can be more boiler run time required to meet peak loads. However, there is substantial spread and overlap in the savings across the simulation results. The climate zone, number of occupants, and occupant preferences (high vs. low users of hot water) all have a substantial impact on energy use and potential savings.

Figure 40: Scatterplot of per-unit hot water (electricity + natural gas) energy consumption across baseline/upgrade scenarios, in year 2029.



GAHPs save energy in almost every case, although in cases with minimal loads (generally a combination of a mild climate, few units, and few occupants in those units and/or some vacant units) the GAHP may run so infrequently that it ultimately ends up increasing energy consumption. As it takes 20 minutes to reach steady state, frequent cycling can substantially reduce the efficiency of the GAHP. However, cases with minimal loads make up a small portion of the overall stock in California.

Conclusions and Future Work

This report evaluates the impact of emerging gas-fired heat pump technologies on energy consumption, greenhouse gas emissions, and utility bills. The analysis included all California climate zones and covered the residential multifamily building segment. The following scenarios were developed for this analysis:

- **Scenario 1:** The baseline/existing California residential multifamily housing stock.
- **Scenario 2:** The 2023 multifamily housing stock reflecting 2022 Title 24/Title 20 code compliance in new construction, local electrification measures as of February 2023, adoption of PV by 1% of the stock, and adoption of higher efficiency gas water heaters by 20% of the relevant portion of the stock.
- **Scenario 3a:** The 2026 projected multifamily housing stock reflecting projected 2025 code compliance in new builds, adoption of new PV and gas water heaters at the same levels as Scenario 2, and baseline electrification of 1% of the stock.
- **Scenario 3b:** Scenario 3a with gas heat pump water heaters targeting 0.7% market penetration and 0.1% baseline electrification.
- **Scenario 4a:** The 2029 projected multifamily housing stock reflecting estimated 2028 code compliance in new builds, adoption of PV and gas water heaters and baseline electrification of 1% of the stock.
- **Scenario 4b:** Scenario 4a with gas heat pump water heaters targeting 6.5% market penetration and 0.1% baseline electrification.

Scenario 3a, 3b, 4a, and 4b reflect possible market and policy changes on both the electric and gas side, including electrification and increased penetrations of gas-efficient systems. Scenario 3a and 4a used an end-use electrification rate of 1%, whereas Scenario 3b and 4b used 0.1%. A 10%/year marginal utility rate escalation for electricity was used.

Substantial enhancements were made to the ResStock tool for supporting whole-building models with shared water heating systems. A bug in EnergyPlus related to the way the GAHP uses curves was also identified and fixed as part of this project. Custom scripts were also created to account for the startup losses associated with this heat pump, which takes up to 20 minutes to reach steady-state efficiency. ResStock samples determined to be served by a gas-fired shared water heating system were modeled with either a shared boiler and storage tanks (baseline case) or shared gas heat pump water heater (upgrade case). Shared systems were configured using supply, storage, and DHW (recirculation) plant loops.

After simulating Scenario 1, 2, 3a, 3b, 4a, and 4b, a series of plots were generated for summarizing not only the estimated impact of installing the gas heat pump water heater as

a building retrofit, but the overall impact across California and CEC climate zones in terms of energy consumption, emissions, and utility bills. Results generally show a decreasing trend in energy consumption, utility bills, and emissions across scenarios, and that the gas heat pump water heater can offer substantial savings over the baseline boiler, especially for smaller multifamily buildings.

As described in the Shared Water Heater Modeling Section, each gas heat pump water heater was paired with a stratified tank, and all the tanks were plumbed in series to heat water. An alternative plumbing configuration is to have all paired stratified tanks in parallel. Continued investigation into how this can be achieved using OpenStudio/EnergyPlus is required; it is currently unknown how to appropriately split the water heating loads. The series configuration also has some impact on the result that there is less savings in buildings that require multiple GAHPs. These parallel configurations are also a potential area of future work.

The adoption and overturning of local electrification policies in new construction continues to evolve in California cities and counties. As a parameter for Scenario 3a–4b, these policies directly affect the ResStock samples used in this analysis. For the most accurate reflection of local electrification policy, ResStock samples should be consistent with the most up-to-date rates of electric sampled options.

Future work using this workflow could look at different GAHPs from other manufacturers. The GAHP model could also be used to model different system types, such as those sized more for single-family detached residential buildings. The workflow for modeling central water heating systems could also be adopted to model central heat pump water heaters through adding a swing tank, curves representative of a large heat pump water heater, and changing the object used to model the heat pump. This could provide an all-electric counterfactual to compare against gas efficiency scenarios. Combined space and water heating applications for multifamily buildings could also be modeled by adding a space heating distribution loop.

Appendix A. Title 24/20 Mapping

A.1 Code Adoption

In ResStock, options need to be set for each feature of a building that affects energy consumption, such as wall insulation, ceiling insulation, heating system type and efficiency, etc. To be able to model upgrades of the housing stock to current and future versions of code in California, the 2022 version of Title 24 and Title 20 was analyzed. [Title 24](#)⁴⁰ is the statewide building code specifying the minimum efficiency features in the envelope of a building, including all residential buildings. [Title 20](#)⁴¹ gives the minimum efficiency level of appliances and equipment installed in buildings. In some cases, existing options in ResStock were sufficient to cover what is included in these codes, while in other categories new options were added to ResStock to match what code prescribes.

In many (but not all) cases, what is prescribed by code depends on which climate zone the building is located in. California defines its [own climate zones](#)⁴² for the purposes of code and analysis within the state (as opposed to the [IECC climate zones](#)⁴³ used for building energy code in the rest of the country). The California Energy Commission (CEC) designates these climate zones to account for the diversity seen across the state. There are 16 different climate zones in California, as shown in Figure 41. Efficiency options will be shown by climate zone to account for this dependency. Other dependencies (such as the number of stories, whether a unit has ducts, central vs. in-unit systems, etc.) will also be shown where appropriate.

Title 24, like most other building energy codes, provides two major types of compliance pathway: a performance-based approach and a prescriptive approach. The Title 24 performance-based approach requires the building design to reach a certain time-dependent valuation budget⁴⁴, as calculated through an accredited tool. The advantage of this approach is it allows more flexibility in what efficiency features are used. A building design may include a super-tight envelope but slightly less efficient water heater, for example, so long as that water heater meets a minimum standard. The prescriptive approach is more rigid and outlines all the efficiency features required in the home for compliance. In this analysis, the prescriptive approach was used to determine compliance. This has the advantage of not requiring a baseline time-dependent valuation budget (or really any time-dependent valuation) to be calculated. OpenStudio-HPXML (which is used

⁴⁰ <https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards>

⁴¹ <https://www.energy.ca.gov/rules-and-regulations/appliance-efficiency-regulations-title-20>

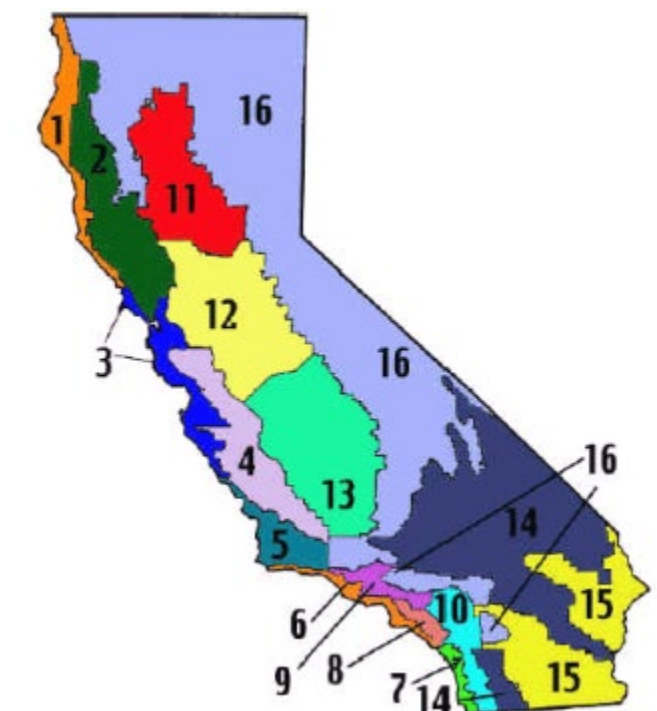
⁴² <https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/climate-zone-tool-maps-and>

⁴³ <https://codes.iccsafe.org/content/IECC2021P1/chapter-3-ce-general-requirements>

⁴⁴ In the 2025 version of Title 24, time dependent valuation was replaced with long term system cost factors: <https://localenergycodes.com/content/october-2024#section-1>

by ResStock) is also not an accredited tool and so cannot be used for code compliance purposes. Unless otherwise noted, the options described below reflect the 2022 version of Title 24 and the current version of Title 20 at the time of publication.

Figure 41: California Energy Commission climate zones.



A.2 2022 Prescriptive Path Code-Compliant Equipment Options

Table 7 shows the code-compliant heating, ventilating, and air conditioning (HVAC) options. For in-unit systems, the 2022 version of the code explicitly requires an electric heat pump in most climate zones (except for climate zone 16, the coldest one) when following the prescriptive path for new construction. The exact efficiency of that heat pump is set in Title 20. In ResStock, ducted central heat pumps and ductless (mini-split) heat pumps are differentiated, leading to a dependence on whether the building has ducts or not. This is done to minimize construction costs, because adding ducts to a dwelling unit without ducts will generally be more costly than installing a set of mini-split heads. Because code very explicitly requires “a heat pump,” when following the prescriptive path, a GAHP that provides space conditioning (not the focus of this report) would comply with Title 24.⁴⁵ Note that because the prescriptive path in the 2022 version of Title 24 identifies electric heat pumps in most climates zones, if those buildings used fuel for space heating before

⁴⁵ https://www.energy.ca.gov/sites/default/files/2022-12/CEC-400-2022-010_CMF.pdf

code is applied, fuel switching is assumed. However, fuel water heating options are described in the code, and so fuel switching is not assumed.

Table 7: California Code HVAC Options

ASHP = air-source heat pump; SEER = seasonal energy efficiency ratio; MSHP = mini-split heat pump; AFUE = annual fuel utilization efficiency; HSPF = heating seasonal performance factor

			Climate Zone		
			1	2–15	16
1–3 Stories	Has Ducts**	HVAC Type/ Efficiency	ASHP: SEER 15, 8.8 HSPF	ASHP: SEER 15, 8.8 HSPF	Furnace: 80% AFUE; Central AC: SEER 15*
	Ductless	HVAC Type/ Efficiency	MSHP: SEER 15, 8.8 HSPF	MSHP: SEER 15, 8.8 HSPF	Wall Furnace: 80% AFUE; Room AC: SEER 15*
4+ Stories	Has Ducts**	HVAC Type/ Efficiency	Dual-Fuel ASHP: SEER 15, 8.8 HSPF	ASHP: SEER 15, 8.8 HSPF	Dual-Fuel ASHP: SEER 15, 8.8 HSPF*
	Ductless	HVAC Type/ Efficiency	Wall Furnace: 80% AFUE; Room AC: SEER 15*	MSHP, SEER 15, 8.8 HSPF	Wall Furnace: 80% AFUE; Room AC: SEER 15*

*If all-electric, ASHP or MSHP with SEER 15, 8.8 HSPF

** If ducts are included, they are 12% leakage, R6 insulation in all climate zones

Table 8 gives the water heater modeled in code-compliant buildings. The prescriptive path for water heating identifies code compliant gas options, unlike for space heating. For water heaters, ResStock also includes some buildings with “Other” fuel for water heating. The water heating fuel distribution is based on data from the Residential Energy Consumption Survey (RECS), where “Other” may include solar thermal, wood, or some unspecified energy source generally not modeled in ResStock. These homes are modeled as having no water heater in ResStock, but account for <1% of the dwelling units in California. Solar water heaters are required in the prescriptive path for new construction in the 2022 version Title 24 for central gas water heaters as a way to meet a portion of the water heating load. Note that there are separate requirements for central heat pump water heaters that do not require solar, meaning that the GAHP systems modeled in this project will not require supplemental solar water heating to meet code as they still meet the “heat pump” requirement and code does not distinguish between the fuel source of the heat pump. The code requirement for solar water heaters is also not the exact square footage of collector area required by ResStock for the physics-based model of the solar water heater but instead specifies a solar savings fraction by climate zone (0.2 in climate zones 1–9 and 0.35 in climate zones 10–16). Rather than calculating an exact area for the collector by climate

zone to meet this minimum exactly, the collector areas chosen here provide at least the minimum solar savings fraction in the worst-case scenario, with slightly higher solar savings fractions in the other climate zones in each bin.

Table 8: California Code Water Heating Options

			Climate Zone		
			1–9	10–15	16
In-Unit Water Heater	Electricity	Water Heater Efficiency	Electric Heat Pump, 3.45 UEF	Electric Heat Pump, 3.45 UEF	Electric Heat Pump, 3.45 UEF
	Natural Gas	Water Heater Efficiency	Natural Gas Tankless	Natural Gas Tankless	Natural Gas Tankless
	Propane	Water Heater Efficiency	Propane Tankless	Propane Tankless	Propane Tankless
	All Fuels	Hot Water Distribution	R-7.7, Demand	R-7.7, Demand	R-7.7, Demand, Drain Water Heat Recovery
Central Water Heater	Electricity	Water Heater Efficiency	Electric Heat Pump, 80 gal, 3.45 UEF, in unit	Electric Heat Pump, 80 gal, 3.45 UEF, in unit	Electric Heat Pump, 80 gal, 3.45 UEF, in unit
	Natural Gas	Water Heater Efficiency	Natural Gas Tank	Natural Gas Tank	Natural Gas Tank
	Propane	Water Heater Efficiency	Propane Tank	Propane Tank	Propane Tank
	All Fuels	Hot Water Distribution	R-7.7, Demand	R-7.7, Demand	R-2, Demand, Drain Water Heat Recovery
	Natural Gas or Propane	Solar Hot Water	25 sqft/unit, South, Latitude	33 sqft/unit, South, Latitude	33 sqft/unit, South, Latitude

The current approach to modeling central water heaters in ResStock has some important implications for this project. Since ResStock has taken the approach of modeling individual units in a building rather than the whole building simultaneously, this makes it difficult to account for the whole balance of system associated with a large central water heater. This includes (1) the recirculation loop to make up for recirculation losses when draws are low, and (2) the storage tank and heat pump may be separate pieces of equipment. The current approach in ResStock simply applies assumptions in the latest version of the [ANSI/RESNET 301](#)⁴⁶ standard, which slightly adjust water heater energy use to try to account for these factors without requiring the whole building to be simulated simultaneously. Aggregating units into a whole building and more thoroughly modeling the complexities associated with central water heating is an important part of this project.

Table 9 lists the requirements for lighting and appliances. These standards are taken directly from Title 20 and in many cases correspond to the current federal minimum efficiency standard, rather than being more stringent in California. Note that not every dwelling will have every appliance. ResStock includes probability distributions for whether units will have clothes washers/dryers and an additional freezer.

Table 9: Lighting and Appliance Options

Climate Zone		ALL
Lighting		100% LED (light-emitting diode)
Appliances	Refrigerator	392 kWh/yr ^a
	Clothes Washer	IMEF = 1.84 ^b
	Electric Clothes Dryer	CEF = 3.73 ^c
	Gas Clothes Dryer	CEF = 3.3 ^c
	Dishwasher	307 kWh/yr
	Electric Cooking Range	Electric Standard ^d
	Gas Cooking Range	Gas Standard ^d
	Misc Freezer	310 kWh/yr ^e

^a Assuming an Adjusted Volume of 20.9 ft³, integrated refrigerator/freezer

^b IMEF = Integrated Modified Energy Factor. Assumed "standard," not compact, and front loading

^c CEF = Combined Energy Factor, Assuming "standard," not "compact"

^d Calculated according to [ANSI/RESNET 301](#)

^e Assuming chest freezer, Adjusted Volume of 27.7

Photovoltaic (PV) panels are required in new construction under Title 24. The exact size of the PV panels depends on the building size and climate zone. Title 24 distinguishes between

⁴⁶ https://www.resnet.us/wp-content/uploads/ANSIRESNETICC301-2022_resnetpblshd.pdf

multifamily buildings with three or fewer stories and those with four or more. For smaller buildings, the minimum PV size is calculated according to Equation 1.

Equation 1: Minimum PV sizing for buildings with four or more stories under Title 24

$$kW_{PV} = \frac{(CFA \times A)}{1000} + (N_{DU} \times B)$$

Where:

kW_{PV} = kW_{dc} size of the PV system

CFA = Conditioned floor area

N_{DU} = Number of dwelling units

A = CFA adjustment factor

B = Dwelling unit adjustment factor

Values for A and B are given in Table 10. For buildings with four or more stories, the PV is sized with Equation 2, but without an adjustment for the number of dwellings.

Equation 2: PV sizing for buildings with four or more stories

$$kW_{PV} = \frac{(CFA \times A)}{1000}$$

Values for A are given in Table 11.

These equations have been directly implemented into ResStock, so a code-compliant PV system will automatically be installed depending on the building size, climate zone, and number of dwellings.

Batteries are also required for buildings with four or more stories. The battery can either be controlled to maximize self-consumption or for energy arbitrage with a time-of-use rate. In this analysis, the batteries are modeled as maximizing self-consumption by charging when the PV is generating more energy than the building consumes and discharging when the building is net consuming. The batteries are sized according to Equation 3.

Table 11: 2022 Title 24 Parameters for Minimum PV Size for Buildings With Three or Fewer Stories.

Climate Zone	A (Conditioned floor area, or CFA)	B (Units)
1	0.793	1.27
2	0.621	1.22
3	0.628	1.12
4	0.586	1.21
5	0.585	1.06
6	0.594	1.23
7	0.572	1.15
8	0.586	1.37
9	0.613	1.36
10	0.627	1.41
11	0.836	1.44
12	0.613	1.40
13	0.894	1.51
14	0.741	1.26
15	1.560	1.47
16	0.590	1.22

Table 10: 2022 and 2025 Title 24 PV Capacity Factors for Buildings With Four or More Stories.

Climate Zone	A (CFA)
1, 3, 5, 16	1.82
2, 4, 6–14	2.21
15	2.77

Equation 3: Battery sizing based on PV capacity

$$kWh_{batt} = kW_{PV} \times \frac{B}{D^{0.5}}$$

$$kW_{batt} = kW_{PV} \times C$$

Where:

kWh_{batt} = Rated usable energy capacity of the battery in kWh

kW_{PV} = PV capacity as calculated by the prior equations

B = Energy capacity factor

D = Rated round-trip efficiency

kW_{batt} = Power capacity of the battery

C = Power capacity factor

Values of B and C are specified by building type. For multifamily dwellings, B has a value of 1.03 and C has a value of 0.26. The round-trip efficiency in ResStock uses a default value of 92.5%. These equations have also been directly implemented with ResStock so each building that requires a battery will automatically be assigned one of the appropriate size.

A.3 2022 Prescriptive Path Code-Compliant Envelope Options

Table 12: 2022 Title 24 Envelope Options.

	Climate Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Walls	Wood Stud Walls	R-20					R-13		R-20									
	Brick and CMU Walls	U=0.253	U=0.650				U=0.690					U=0.650	U=0.184	U=0.253	U=0.211	U=0.184	U=0.160	
Roofs	Attic Insulation	R-38	R-30										R-38					
	Radiant Barrier	No	Yes														No	
	Roof Insulation	U=0.028		U=0.034	U=0.028	U=0.034		U=0.039	U=0.028									
	Roof Solar Reflectance	NR*								0.63			NR*	0.63		NR*		
Windows	U-factor	0.30						0.34		0.30								
	SHGC, three or less habitable stories	NR*	0.23	NR*	0.23	NR*	0.23										NR*	
	SHGC, four or more habitable stories	0.35	0.23															
Doors	Doors	R5, Steel																
Foundation	Slab	Uninsulated														R7		
	Basement	R-19 Ceilings																
Infiltration	ACH50	2																
Mechanical Ventilation	Ventilation Type	Balanced, HRV		Balanced									Balanced, HRV					

* NR = no rating

Table 12 lists all the Title 24 compliant envelope options. In some cases, there were existing options that directly corresponded to code, but for the majority of cases new options needed to be created. For wood stud walls, an overall U-value is specified in code, which can be met with either just cavity insulation or cavity insulation plus continuous sheathing. It was assumed that builders would opt for additional cavity insulation. For massive walls, new options were created for both brick and concrete masonry unit (CMU) walls that correspond to these U-values. While the properties of both finishes are not substantially different, they do have different costs in ResStock. For roofs, most multifamily buildings will have flat roofs, but some smaller multifamily buildings (like duplexes or triplexes) do have attics. For windows, new code-minimum options were created with the exact U-value and solar heat gain coefficient (SHGC) specified. In cases where SHGC is not specified, the SHGC of the pre-existing option with the closest U-value was used to try to accurately represent real products.

Maximum infiltration rates are not specified in Title 24. Rather, deference is given to adequate ventilation to ensure good indoor air quality. The 2 ACH₅₀ value used here is an assumption that efforts will be taken to reasonably air-seal new construction buildings. Along with this air-sealing, balanced ventilation is assumed to ensure the indoor air quality

is maintained. The exact ventilation rate for each unit is calculated according to ASHRAE 62.2, which is directly referenced in Title 24. ASHRAE 62.2 does allow for an infiltration credit when calculating the ventilation rate based on the ACH (air changes per hour) value of each unit, which is considered when ResStock is modeling each unit. As a result of applying balanced ventilation to each unit, the assumption about infiltration rate has a minimal impact on results, and the models will ensure that the indoor air quality is maintained consistent with the code.

A.4 Future Code Years

For this project, there's also a desire to model the impact that future code cycles might have on new buildings as they are added to the stock. There are two future code cycles within the scope of this project: 2025 and 2028. The 2025 Title 24 code is not complete (when this work was initiated), but [draft proposals](#)⁴⁷ have been made for most categories of options. This project implements these draft proposals, assuming they will all be adopted as-is. For the 2028 code cycle, estimates must be made about changes in future years. For 2025, a summary of the updated options is shown in Table 3.

Table 13: 2025 Title 24 Code Updates.

Category	Option	2022 Value	2025 Value	Climate Zones
Envelope	Windows	U=0.30	U=0.28	1, 3–5, 11, 13–16
	Windows	U=0.34	U=0.30	8
	Roof Solar Reflectance	No Rating	0.63	2, 4, 6–8, 12
HVAC	ASHP	Default Backup Controls	Lower Backup Temperature	All
	ASHP	Default Crankcase Heater	No Crankcase Heater	All
Ventilation	Ventilation Type	Balanced	Balanced, HRV	4
Pool/Spa Heater	Heater Type	Default	Heat Pump	All
PV	System Size	2022 Sizing Algorithm	2025 Sizing Algorithm (Includes Cooling Efficiency)	All
Battery	Capacity, Power	2022 Sizing Algorithm	2025 Sizing Algorithm	All

⁴⁷ <https://title24stakeholders.com/measures/building-types/multifamily/2025/>

The 2025 code assumes slight increases in envelope efficiency in most climate zones, reducing the window U-value, and requiring a higher solar reflectance for roofs. For HVAC, air-source heat pumps (ASHPs) with backup heat are required to only use backup heat below 35°F outdoor temperature and minimize crankcase heater energy consumption. The lower crankcase heater energy consumption is modeled in ResStock by removing crankcase heater energy entirely, as opposed to the 50-W heater modeled by default when the outdoor air temperature is below 50°F. For ventilation modeling, balanced ventilation had already been chosen—since Title 24 provides multiple ways to meet the infiltration and ventilation requirements—so the only change required was a heat recovery ventilator (HRV) in one climate zone. Any spas (which exist in ResStock for a very small number of multifamily units) are modeled as having heat pump heater rather than an electric resistance heater. Lastly, PV panels continue to be required in new construction under Title 24. The exact size of the PV panels depends on the building size and climate zone. Title 24 distinguishes between multifamily buildings with three or fewer stories and those with four or more. For smaller buildings, the minimum PV size is calculated according to Equation 4.

Equation 4: Minimum PV sizing for buildings with four or more stories under Title 24 which factors in EER2

$$kW_{PV} = \frac{(CFA \times A)}{1000} + (N_{DU \times B}) - \frac{(CFA \times C \times EER2_{Adj})}{1000}$$

Where:

kW_{PV} = kW_{dc} size of the PV system

CFA = Conditioned floor area

N_{DU} = Number of dwelling units

A = CFA adjustment factor

B = Dwelling unit adjustment factor

C = EER2 adjustment factor coefficient

EER2Adj = EER2 adjustment factor = (EER2 – 7); or

$$= 4.7 \text{ if } (EER2 - 7) > 4.7$$

Values for A, B, and C are given in Table 14. For buildings with four or more stories, the PV is sized according to 2022 Title 24.

Table 14: 2025 Title 24 Parameters for Minimum PV Size for Buildings With Three or Fewer Stories.

Climate Zone	A (CFA)	B (units)	C (EER2)
1	0.793	1.27	0.000
2	0.628	1.22	0.002
3	0.629	1.12	0.000
4	0.629	1.21	0.009
5	0.587	1.06	0.000
6	0.596	1.23	0.000
7	0.575	1.15	0.001
8	0.612	1.37	0.005
9	0.645	1.36	0.007
10	0.696	1.41	0.015
11	0.965	1.44	0.027
12	0.668	1.40	0.012
13	1.029	1.51	0.029
14	0.833	1.26	0.020
15	1.892	1.47	0.071
16	0.591	1.22	0.000

Batteries are, again, also required for buildings with four or more stories. The battery can either be controlled to maximize self-consumption or for energy arbitrage with a time-of-use rate. In this analysis, the batteries are modeled as maximizing self-consumption by charging when the PV is generating more energy than the building consumes, and discharging when the building is net consuming. The batteries are sized according to Equation 5.

Equation 5: Battery sizing based on floor conditions

$$kWh_{batt} = \frac{(CFA \times B)}{(1000 \times C^{0.5})}$$

$$kW_{batt} = \frac{kWh_{batt}}{4}$$

Where:

kWh_{batt} = Rated usable energy capacity of the battery in kWh

CFA = Conditioned floor area

B = Energy capacity factor

C = Rated round-trip efficiency

kW_{batt} = Power capacity of the battery

Values for B are given in Table 15.

The round-trip efficiency in ResStock uses a default value of 92.5%. These equations have also been directly implemented with ResStock, so each building that requires a battery will automatically be assigned one of the appropriate size.

For the 2028 code, it is unknown how Title 24 (and Title 20) will need to change to account for the future building stock. Because the 2028 code cycle will not start by the time this project is completed, estimates were made as to what may happen based on what changed in 2025. Most major equipment (HVAC and water heaters) are either currently undergoing or recently underwent a federal standard update, with proposed updates to their efficiency coming into effect before the 2028 code cycle. Infiltration is likely to be as tight as possible without raising indoor air quality concerns for occupants. This left envelope improvements as a potential upgrade. Modest increases were proposed in the R-value of walls and ceilings, with a 5%–10% increase, as being representative of what a future code cycle might look like absent any additional data. Our estimated 2028 code changes are shown in Table 16.

Table 15: 2025 Title 24 Battery Energy Capacity Factors for Buildings With Four or More Stories.

Climate Zone	B (CFA)
1, 3, 5, 16	1.88
2, 4, 6–14	2.27
15	2.85

Table 16: Estimated 2028 Title 24 Code Charges

Category	Option	2022 Value	2028 Value	Climate Zones
Envelope	Wood Stud Walls (2x4)	R-13	R-17	6, 7
	Wood Stud Walls (2x6)	R-20	R-17	1–5, 8–16
	Roofs	U=0.034	U=0.031	3, 5, 6
	Roofs	U=0.039	U=0.035	7
	Roofs	U=0.028	U=0.025	1, 2, 4, 8–16
	Attic Insulation	R-30	R-33	2–10
	Attic Insulation	R-38	R-41	1, 11–16
HVAC	Furnace	80% AFUE	95% AFUE	16

Appendix B. Electrification

B.1 Options for Fuel-Switching

Table 17 lists all ResStock Parameter/Option combinations that may be updated to their electric counterparts. Note this does not correspond to upgrading to Title 24 compliance, and just switches fuel to the closest electric counterpart. This approach for “fuel-switching” corresponds to both baseline and local electrification.

Table 17: List of All Sampled Parameter/Options That Are Updated to Corresponding Electric Options.

Parameter	Sampled Option	Updated Option
Cooking Range	Gas	Electric
	Propane	
Clothes Dryer	Gas	Electric
	Propane	
Misc. Gas Fireplace	Gas Fireplace	None
Misc. Gas Grill	Gas Grill	
Misc. Gas Lighting	Gas Lighting	
Water Heater Efficiency	Natural Gas Standard	Electric Resistance, Standard
	Fuel Oil Standard	
	Propane Standard	
	Fuel Oil Indirect	
	Other Fuel	
	Natural Gas Premium	Electric Resistance, Premium
	Fuel Oil Premium	
	Propane Premium	
	Natural Gas Premium, Condensing	
	Propane Premium, Condensing	
	Natural Gas Tankless	Electric Tankless
	Propane Tankless	
	Natural Gas Tankless, Condensing	
	Propane Tankless, Condensing	

Parameter	Sampled Option	Updated Option
Water Heater Fuel	Natural Gas	Electricity
	Fuel Oil	
	Propane	
	Other Fuel	
Misc. Hot Tub Spa	Gas	Electric
Misc. Pool Heater	Gas	
HVAC Heating Efficiency	Fuel Furnace, 60% AFUE	Electric Furnace, 100% AFUE
	Fuel Furnace, 76% AFUE	
	Fuel Furnace, 80% AFUE	
	Fuel Furnace, 92.5% AFUE	
	Fuel Boiler, 76% AFUE	Electric Boiler, 100% AFUE
	Fuel Boiler, 80% AFUE	
	Fuel Boiler, 90% AFUE	
	Fuel Wall/Floor Furnace, 60% AFUE	Electric Wall Furnace, 100%
	Fuel Wall/Floor Furnace, 68% AFUE	
	Fuel Wall/Floor Furnace, 80% AFUE	
	Dual-Fuel ASHP, SEER 15, 8.8 HSPF Gas	ASHP, SEER 15, 8.8 HSPF
	Dual-Fuel ASHP, SEER 15, 8.8 HSPF Oil	
	Dual-Fuel ASHP, SEER 15, 8.8 HSPF Propane	
HVAC Shared Efficiencies	Boiler Baseboards Heating Only, Natural Gas	Boiler Baseboards Heating Only, Electricity
	Boiler Baseboards Heating Only, Propane	
	Fan Coil Heating and Cooling, Natural Gas	Fan Coil Heating and Cooling, Electricity
	Fan Coil Heating and Cooling, Propane	
Heating Fuel	Natural Gas	Electricity
	Fuel Oil	
	Propane	
	Other Fuel	

B.2 New Construction Local Electrification Locations

From Sierra Club's guidance for cities and counties in California⁴⁸ that have adopted building codes to reduce their reliance on gas, Table 18, Table 19, and Table 20 list all the applicable ResStock options for City and County. The approach is to assume the same measure for every location: a local electrification policy for an applicable location encourages all electric installations for new construction. Note that the options for City and County reflect applicable locations and ordinances as of February 2023 and may have since been overturned.

Table 18: List of ResStock–Sampled Cities for Which Local Electrification Policies Are Applied in Years 2026 and 2029 for New Construction.

City	City
CA, Alameda	CA, Petaluma
CA, Berkeley	CA, Pleasanton
CA, Campbell	CA, Redwood City
CA, Carlsbad	CA, Richmond
CA, Cupertino	CA, Riverside
CA, Daly City	CA, Sacramento
CA, Davis	CA, San Bruno
CA, Dublin	CA, San Francisco
CA, Encinitas	CA, San Jose
CA, Glendale	CA, San Leandro
CA, Hayward	CA, San Luis Obispo
CA, Irvine	CA, San Mateo
CA, Livermore	CA, San Rafael
CA, Los Angeles	CA, Santa Barbara
CA, Martinez	CA, Santa Clara
CA, Milpitas	CA, Santa Cruz
CA, Mountain View	CA, Santa Monica
CA, Oakland	CA, Santa Rosa
CA, Palo Alto	CA, South San Francisco
CA, Pasadena	CA, Sunnyvale

Table 19: List of ResStock–Sampled Counties for Which Local Electrification Policies Are Applied in Years 2026 and 2029 for New Construction.

County
CA, Contra Costa County
CA, Marin County
CA, San Mateo County
CA, Santa Clara County
CA, Ventura County

⁴⁸ <https://www.sierraclub.org/articles/2021/07/californias-cities-lead-way-pollution-free-homes-and-buildings>.

Because ResStock does not explicitly sample City options for which the number of dwelling units does not exceed a given minimum threshold, County and PUMA were used to estimate local electrification policy locations for a small number of cities. Table 20 lists the places where the adoption of local electrification policies was approximated for a small set of cities in California.

Table 20: List of Places (County and PUMA) for Which Local Electrification Policies Are Applied in Years 2026 and 2029 for New Construction.

City	County	County and PUMA
In Another Census Place ⁴⁹	CA, Los Angeles County	G0600370, G06003726
In Another Census Place ⁵⁰	CA, Alameda County	G0600010, G06000102 G0600010, G06000105 G0600010, G06000101 G0600010, G06000103
In Another Census Place ⁵¹	CA, Sonoma County	G0600970, G06009701 G0600970, G06009701
In Another Census Place ⁵²	CA, Santa Barbara County	G0600830, G06008303

⁴⁹ Agoura Hills

⁵⁰ Albany, Emeryville, Piedmont

⁵¹ Healdsburg, Windsor

⁵² Carpinteria

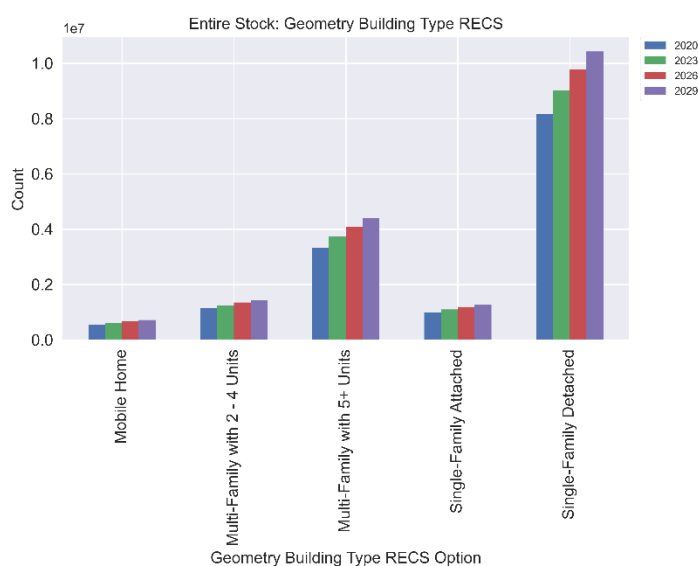
Appendix C. Dwelling Unit Counts

C.1 Multifamily Buildings

The following sequence of figures depicts the process of down-selecting to the ResStock typology of interest (i.e., all dwelling units in multifamily buildings for all regions of California).

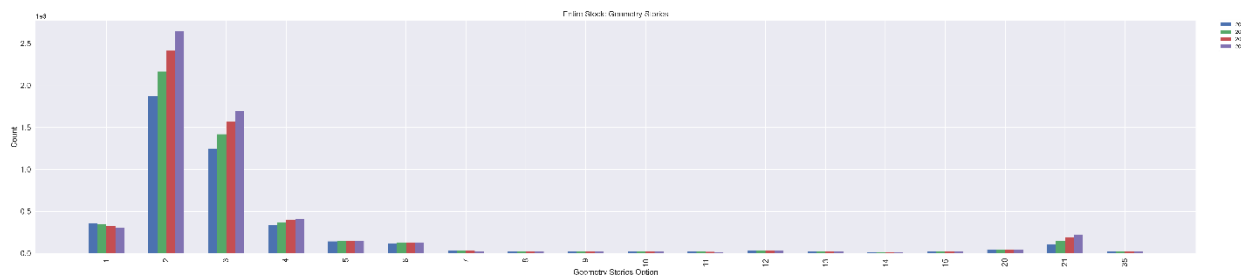
Starting with all dwelling units for California, Figure 42 shows dwelling units counts broken out by ResStock building type.

Figure 42: Counts of total dwelling units across projection years, broken out by building type.



After further down-selecting to only the two “Multi-Family” building types shown in the figure above (i.e., “Multi-Family with 2–4 Units” and “Multi-Family with 5+ Units”), Figure 43 shows counts of total dwelling units for multifamily buildings broken out by number of building stories.

Figure 43: Counts of total dwelling units across projection years for multifamily buildings, broken out by building stories.



The counts corresponding to 2020 in Figure 43 represent the final down-selected segment that is the basis of this analysis. Table 21 summarizes these total counts across building stories and CEC climate zones, respectively.

Table 21: Counts of Total Dwelling Units and Buildings, Across Building Stories, for the Multifamily Segment in 2020.

Geometry Stories	Dwelling Units	Buildings
1	358,608	80,400
2	1,869,176	368,815
3	1,243,224	135,902
4	340,256	17,327
5	142,352	4,610
6	119,536	2,808
7	30,752	1,071
8	25,544	376
9	23,560	384
10	26,040	214
11	19,840	165
12	35,712	294
13	21,576	167
14	14,632	106
15	21,824	218
20	41,416	505
21	106,392	808
35	24,800	212
Total	4,465,240	614,382

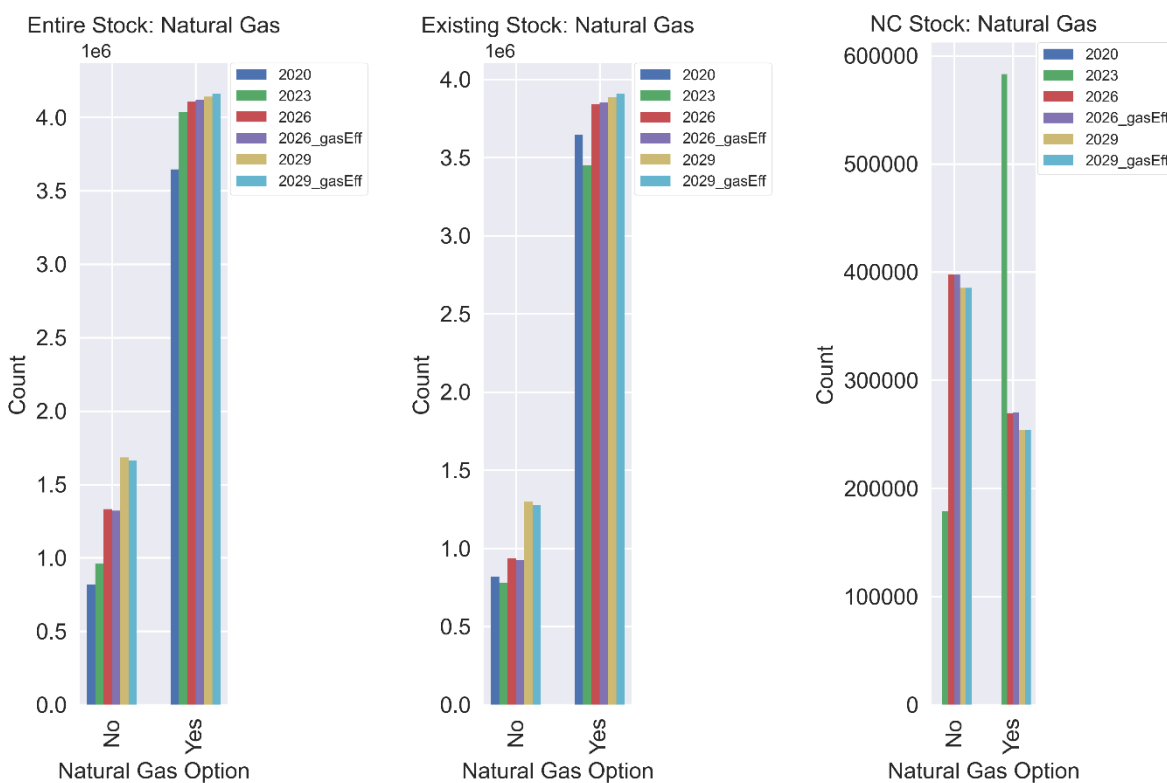
Table 22: Counts of Total Dwelling Units and Buildings, Across the CEC Climate Zones, for the Multifamily Segment in Year 2020.

CEC Climate Zone	Dwelling Units	Buildings
1	14,136	3,226
2	81,096	13,796
3	673,816	103,535
4	244,528	28,275
5	33,728	6,707
6	486,080	64,887
7	33,7776	38,492
8	570,896	79,501
9	928,760	99,537
10	287,928	36,942
11	77,624	14,086
12	39,7048	58,799
13	168,640	34,551
14	52,824	10,478
15	71,424	14,247
16	38,936	7,322
Total	4,465,240	614,382

C.2 Natural Gas

Figure 44 shows the total counts of dwelling units that have at least one end use consuming natural gas.

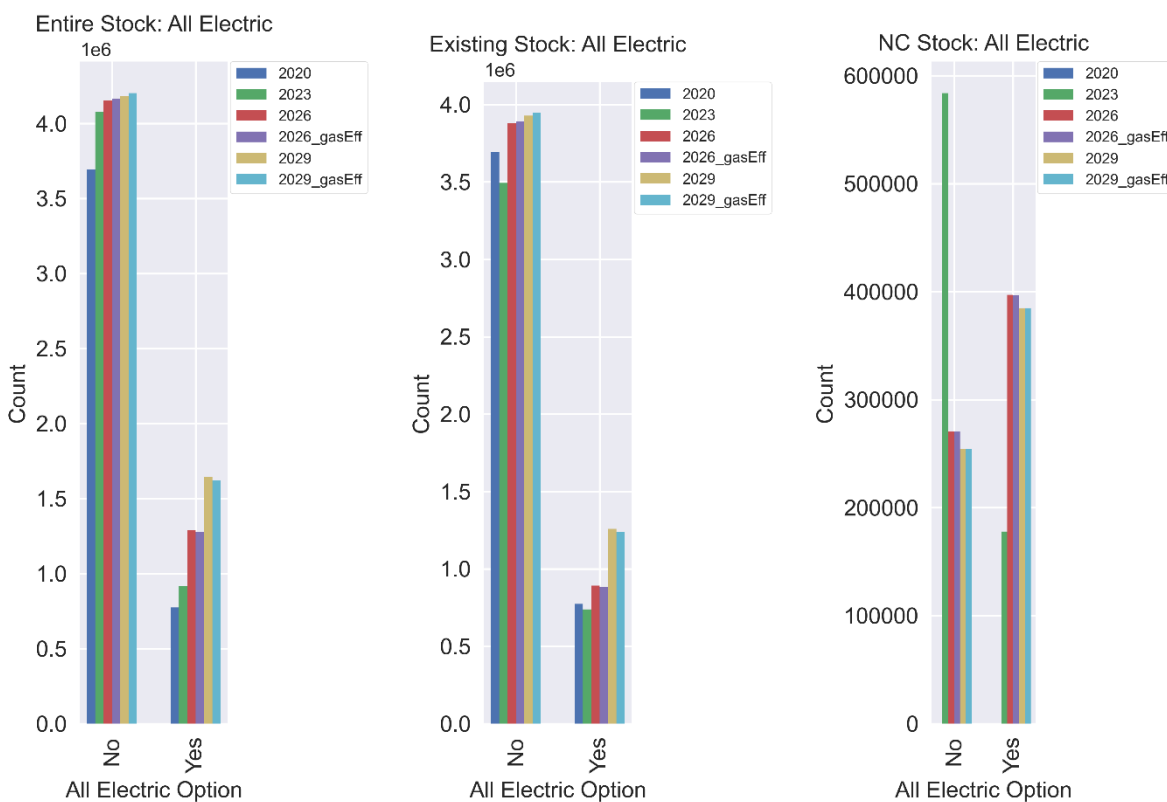
Figure 44: Counts of total dwelling units, across projection scenarios, having at least one gas consuming end use.



C.3 All-Electric

Figure 45 shows the total counts of dwelling units that can be considered all-electric (i.e., have no end uses that use anything other than electricity).

Figure 45: Counts of total dwelling units, across projection scenarios, for which all end uses consume only electricity.



Appendix D. Additional Building Segment Results

Following the same presentation of scenario outputs and results summaries in the Building Segment Results Section, this section presents plots of annual totals across California, as well as annual totals and per-dwelling unit averages broken out by CEC climate zone. Note that for Figure 47 and Figure 51 in Section D.1, negative energy use can be attributed to solar energy consumption.

D.1 Energy Consumption

Figure 46: Total net energy use across projection scenarios, for California.

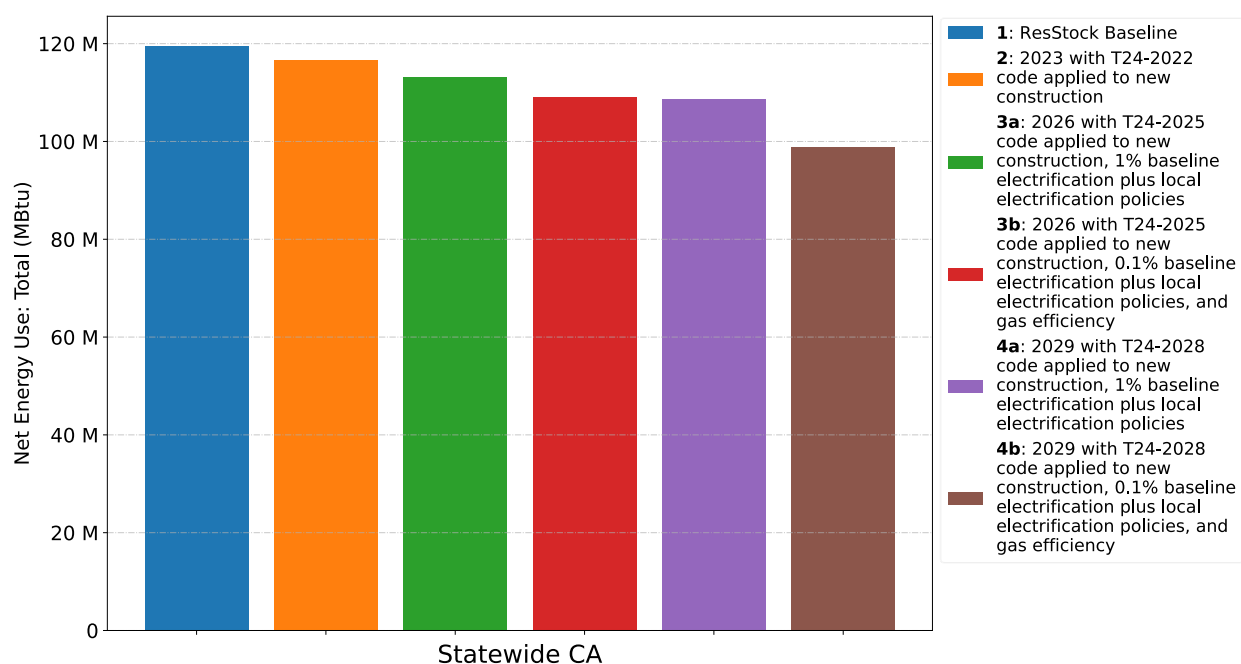


Figure 47: Total (top) and per-unit average (bottom) net energy use across projection scenarios, broken out by CEC climate zone.

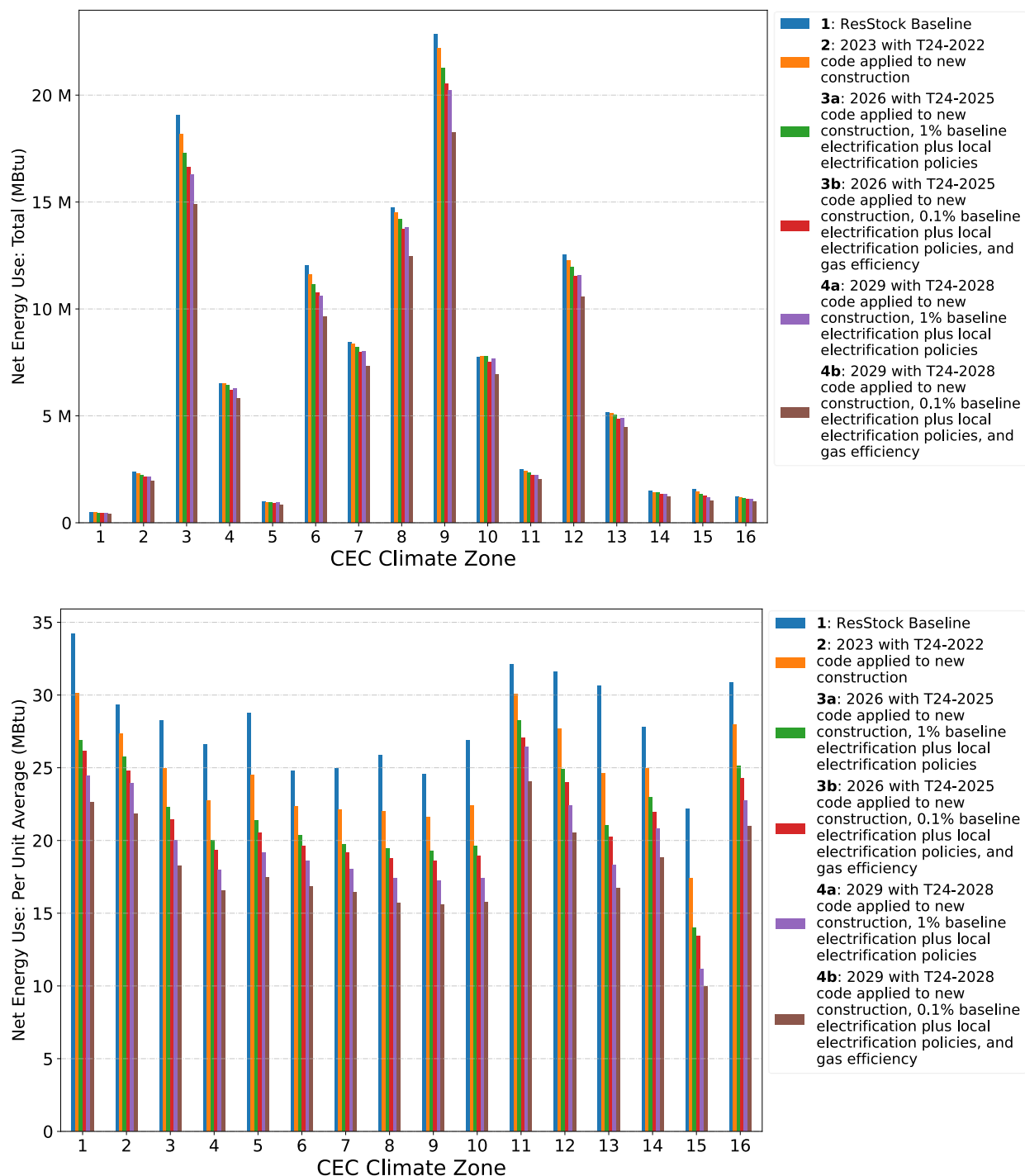


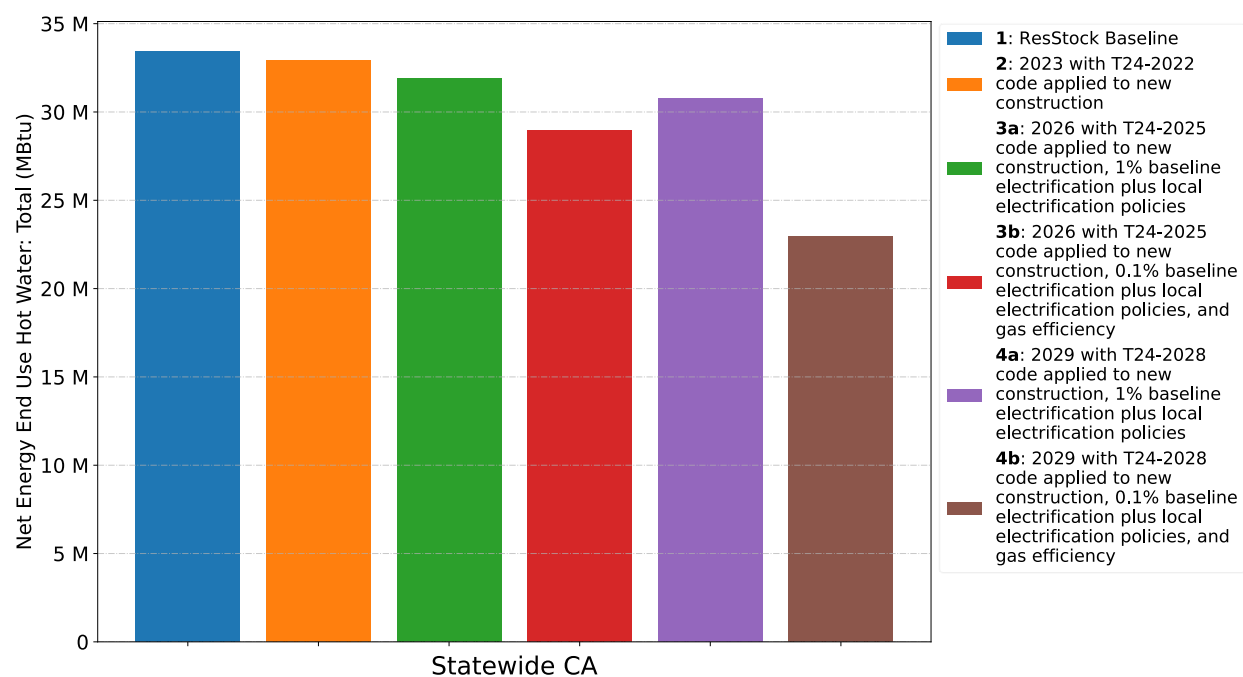
Figure 48: Total hot water energy use across projection scenarios, for California.

Figure 49: Total (top) and per-unit average (bottom) hot water energy use across projection scenarios, broken out by CEC climate zone.

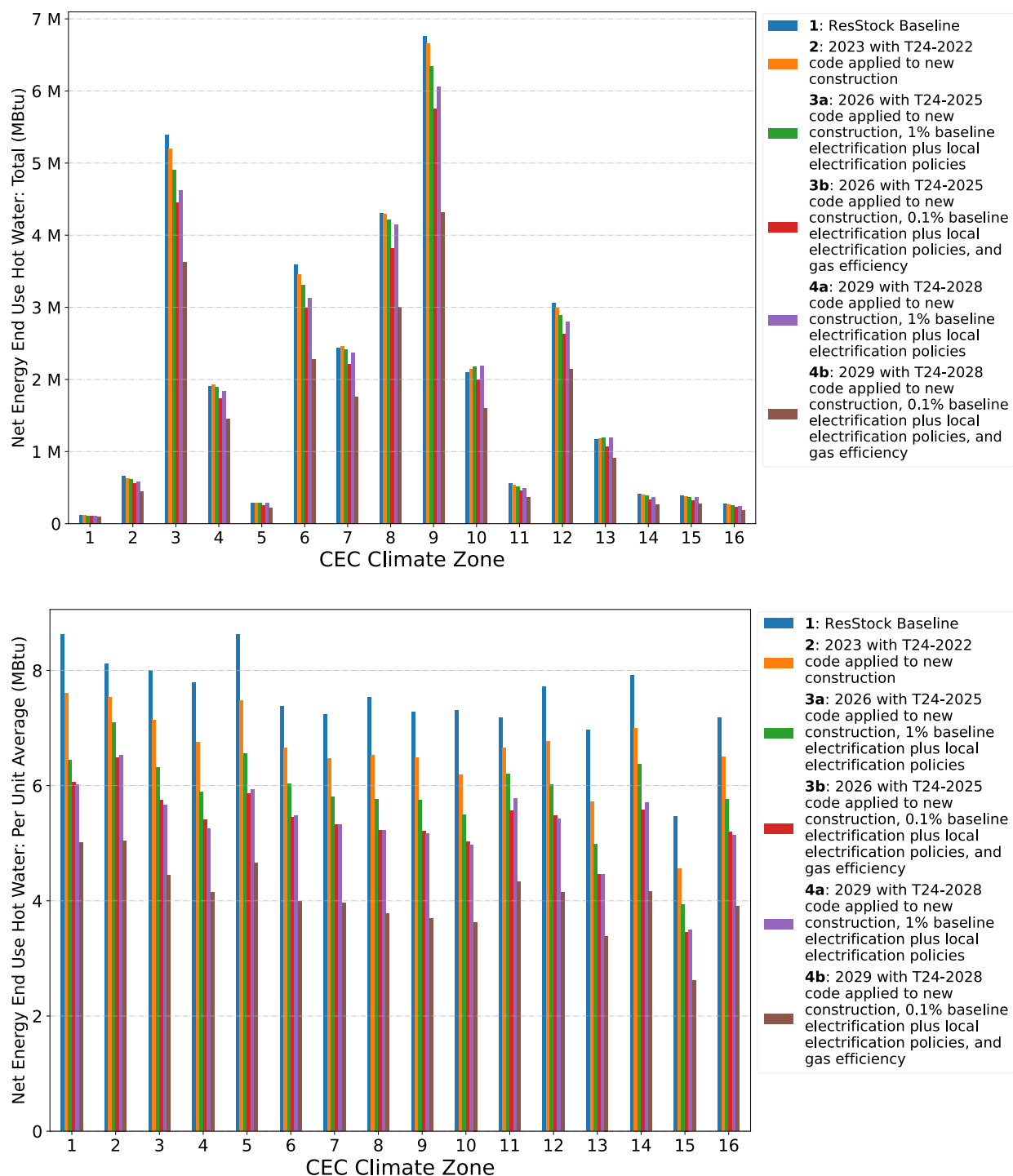


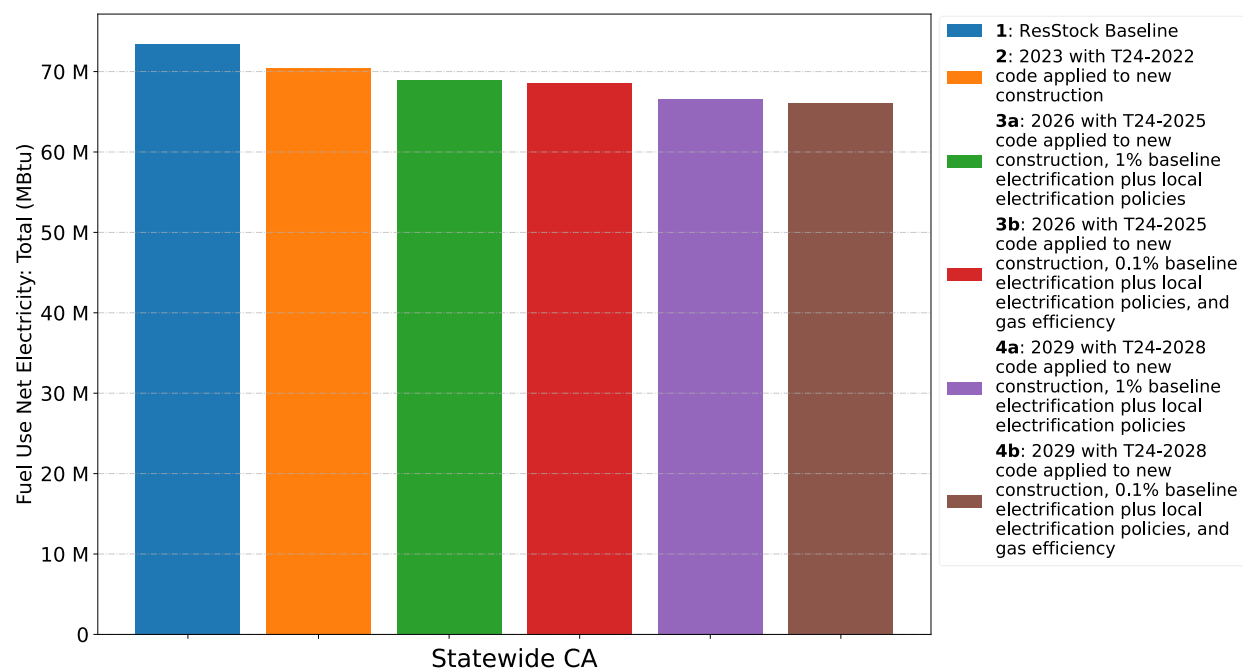
Figure 50: Total net electricity use across projection scenarios, for California.

Figure 51: Total (top) and per-unit average (bottom) net electricity use across projection scenarios, broken out by CEC climate zone.

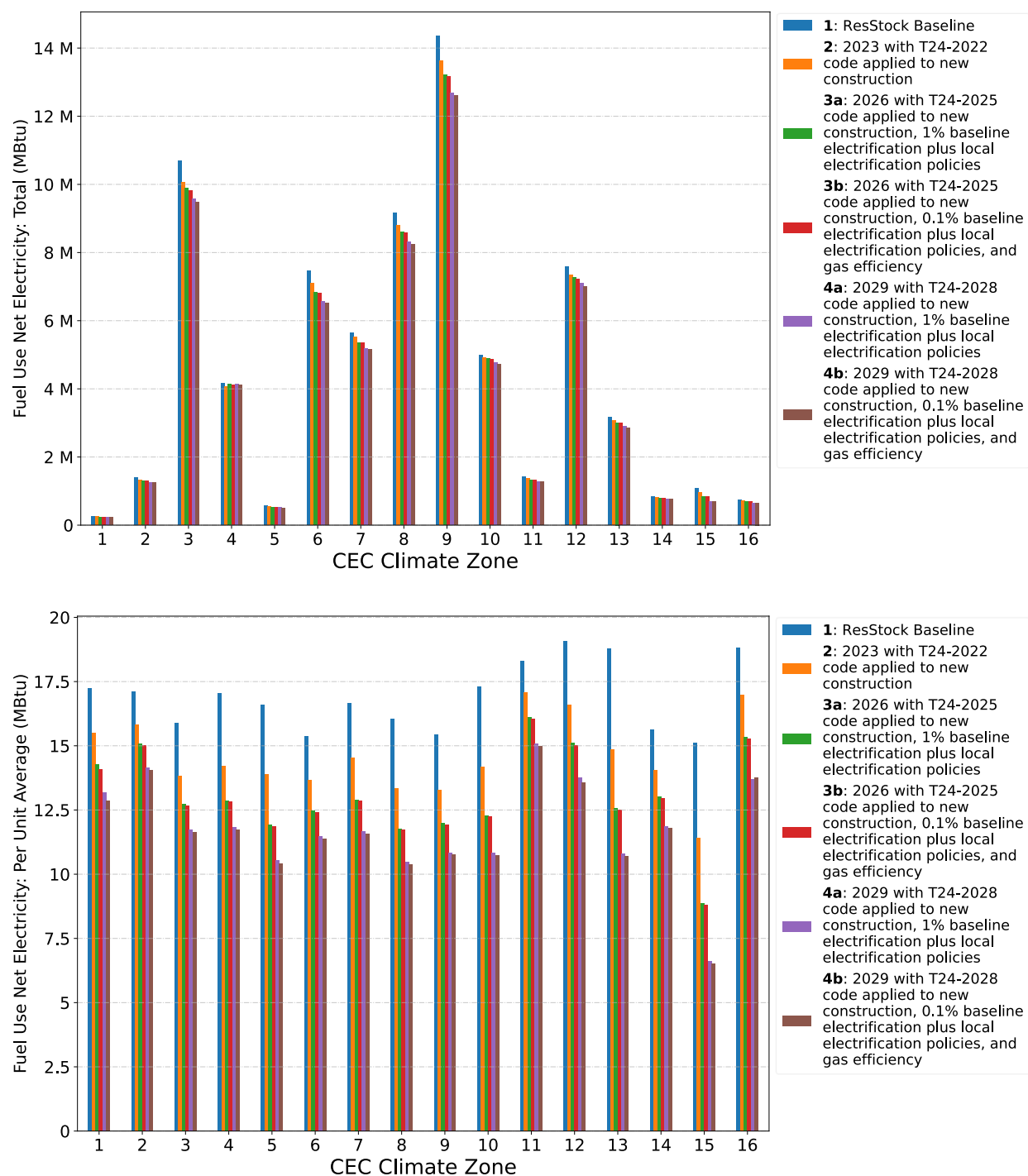


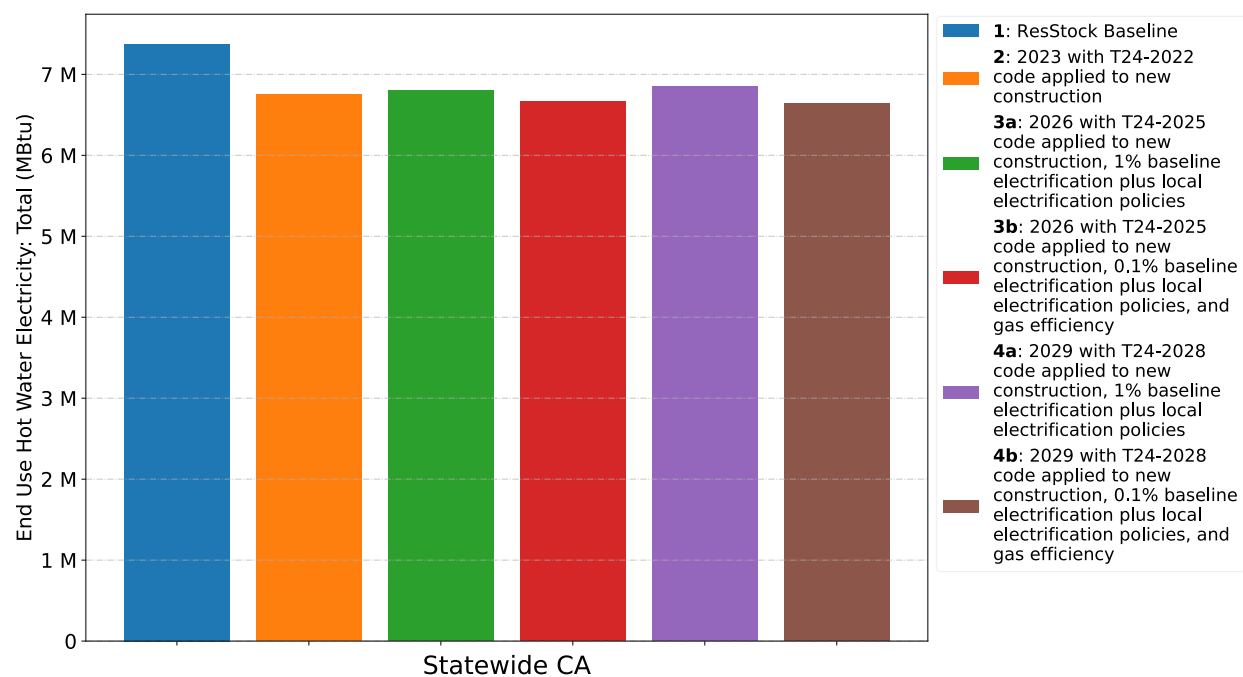
Figure 52: Total hot water electricity use across projection scenarios, for California.

Figure 53: Total (top) and per-unit average (bottom) hot water electricity use across projection scenarios, broken out by CEC climate zone.

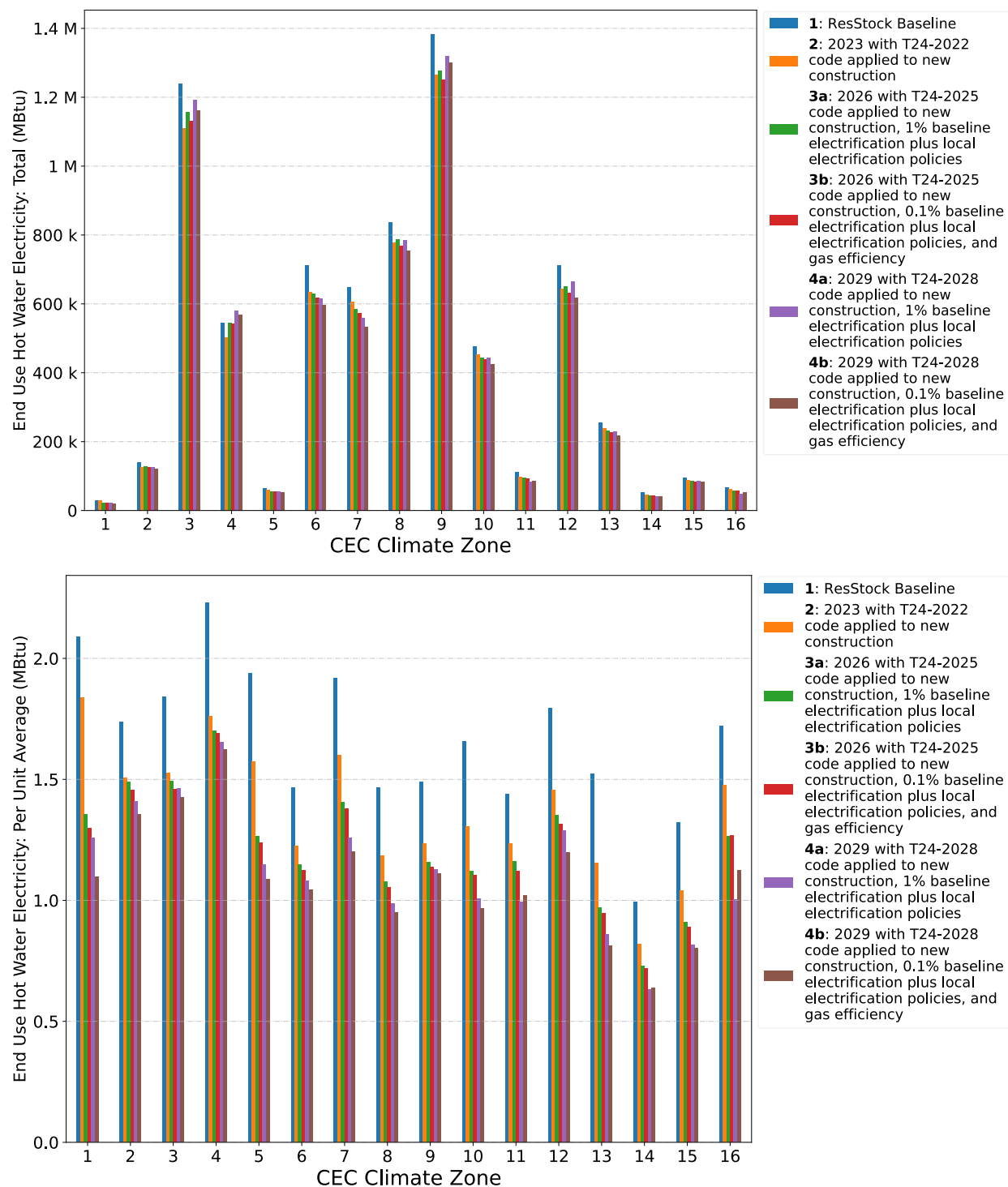


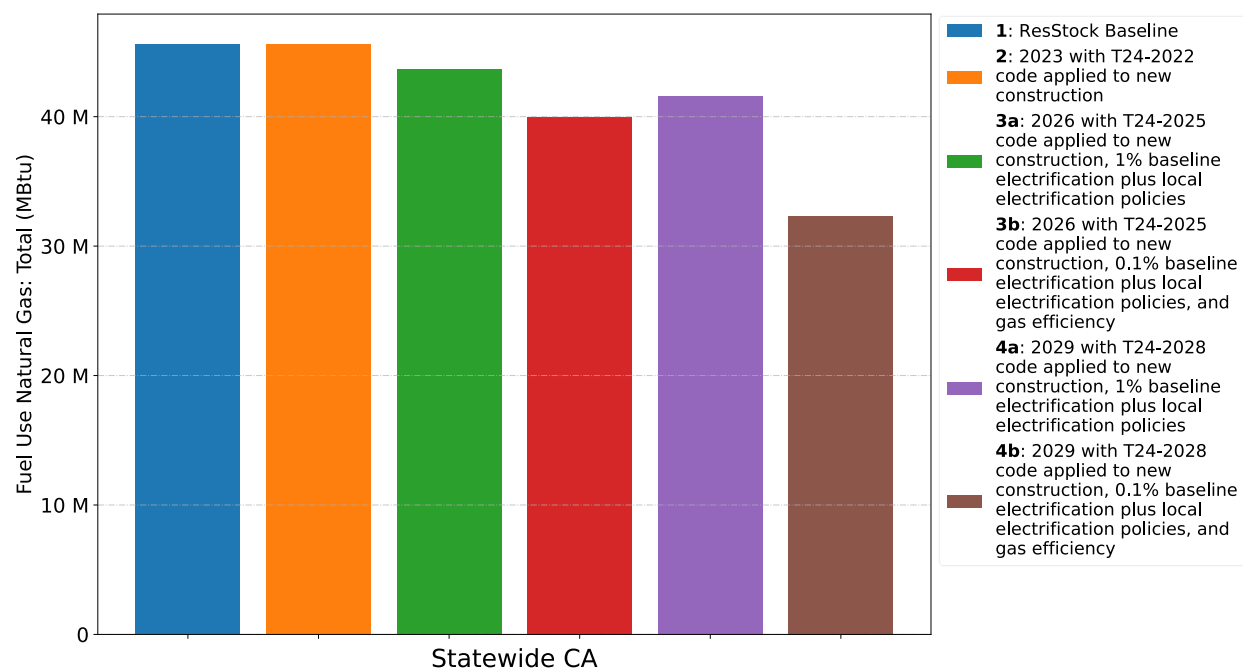
Figure 54: Total natural gas use across projection scenarios, for California.

Figure 55: Total (top) and per-unit average (bottom) natural gas use across projection scenarios, broken out by CEC climate zone.

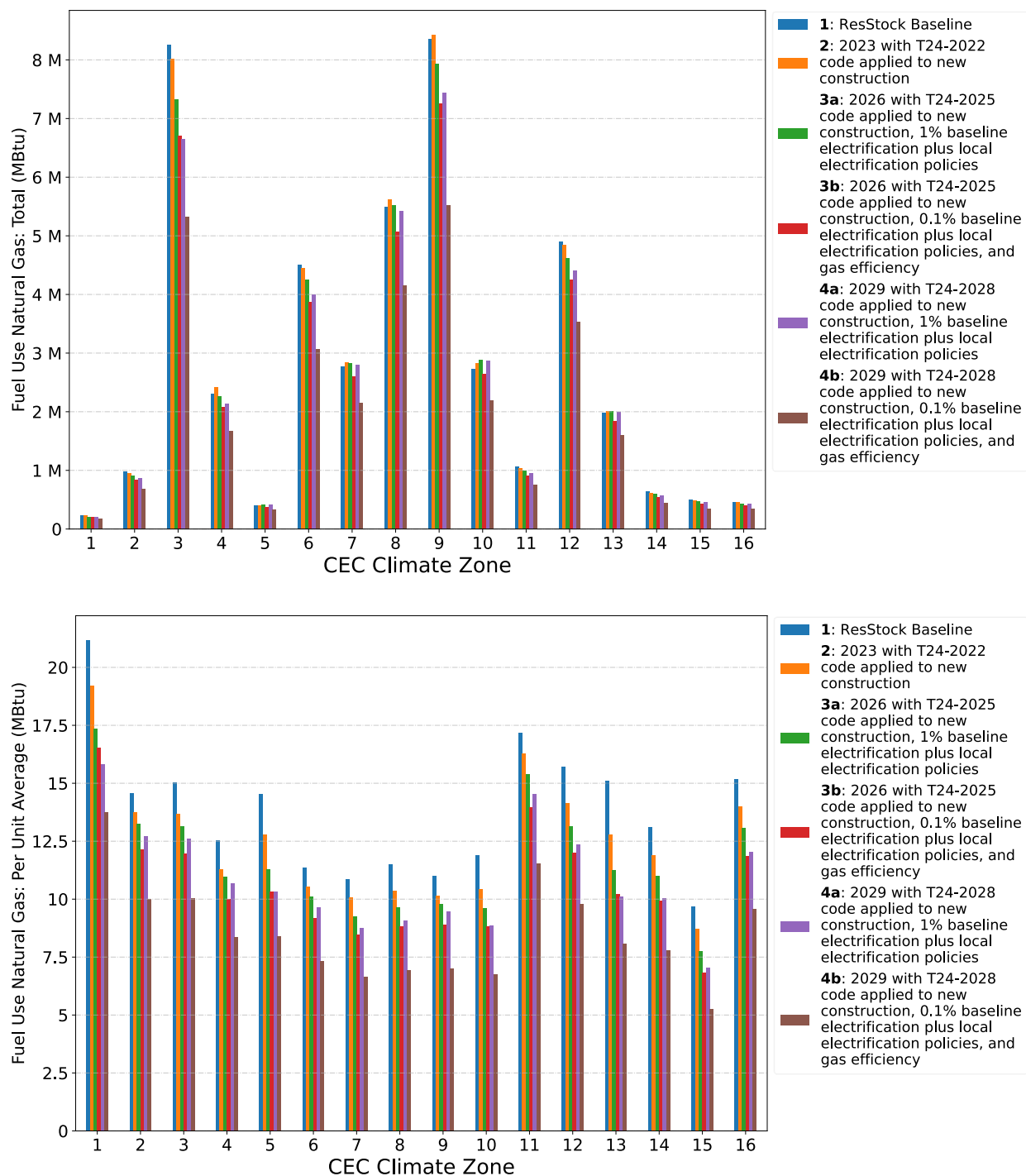


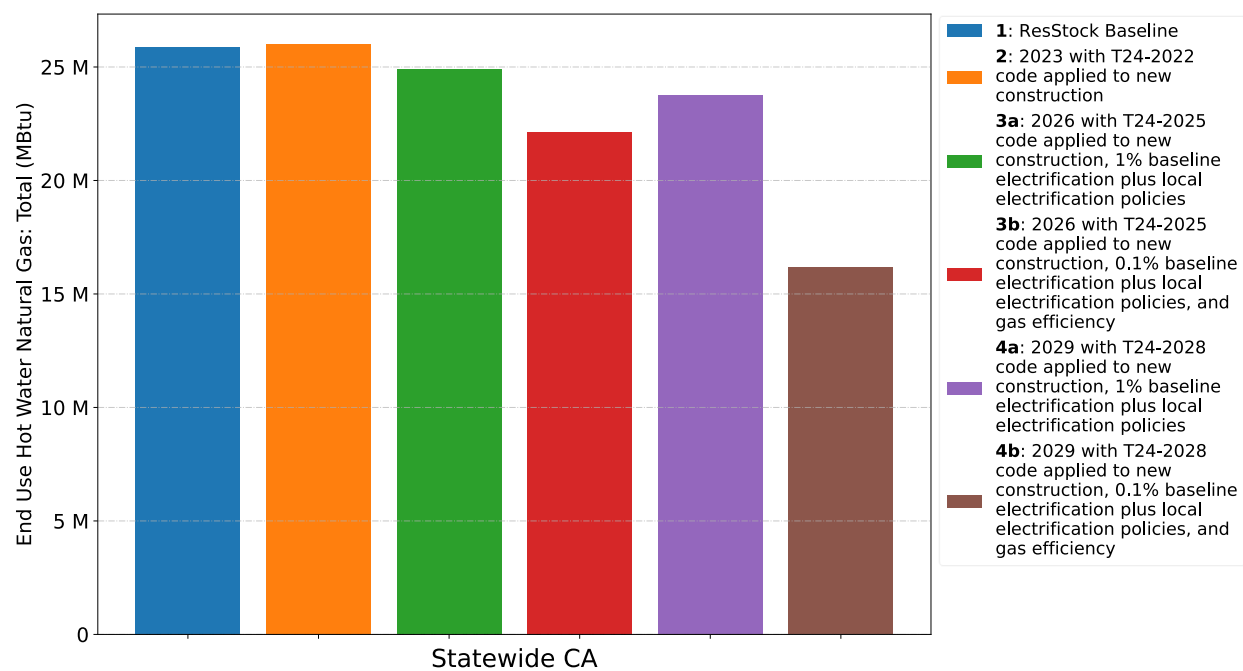
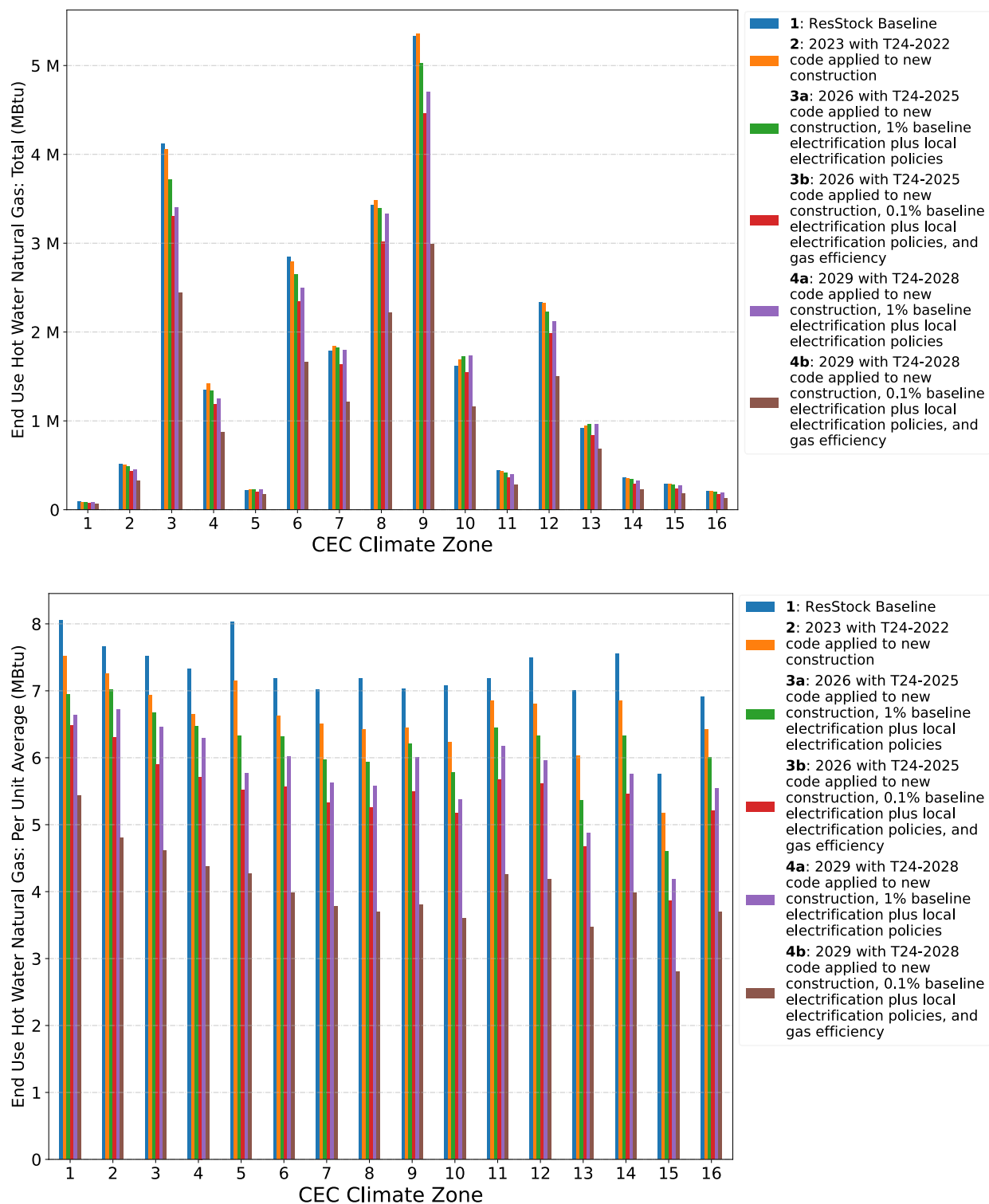
Figure 56: Total hot water natural gas use across projection scenarios, for California.

Figure 57: Total (top) and per-unit average (bottom) hot water natural gas use across projection scenarios, broken out by CEC climate zone.



D.2 Emissions

Figure 58: Total net emissions across projection scenarios, for California.

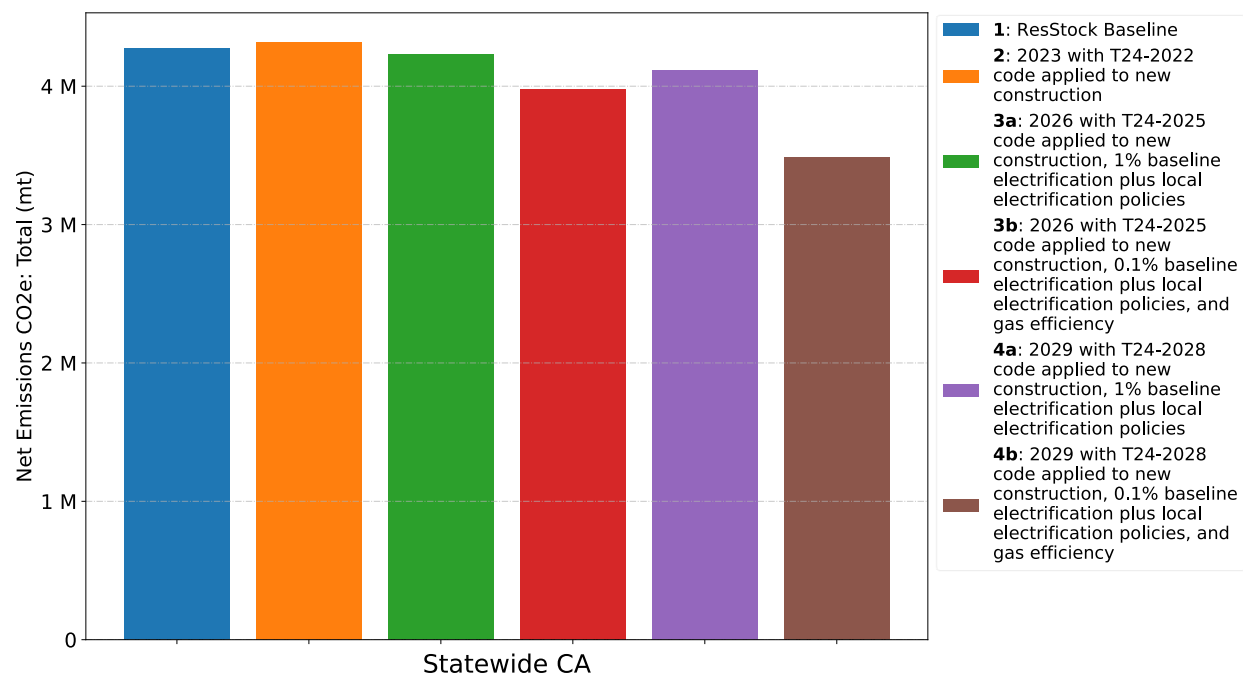


Figure 59: Total (top) and per-unit average (bottom) net emissions across projection scenarios, broken out by CEC climate zone.

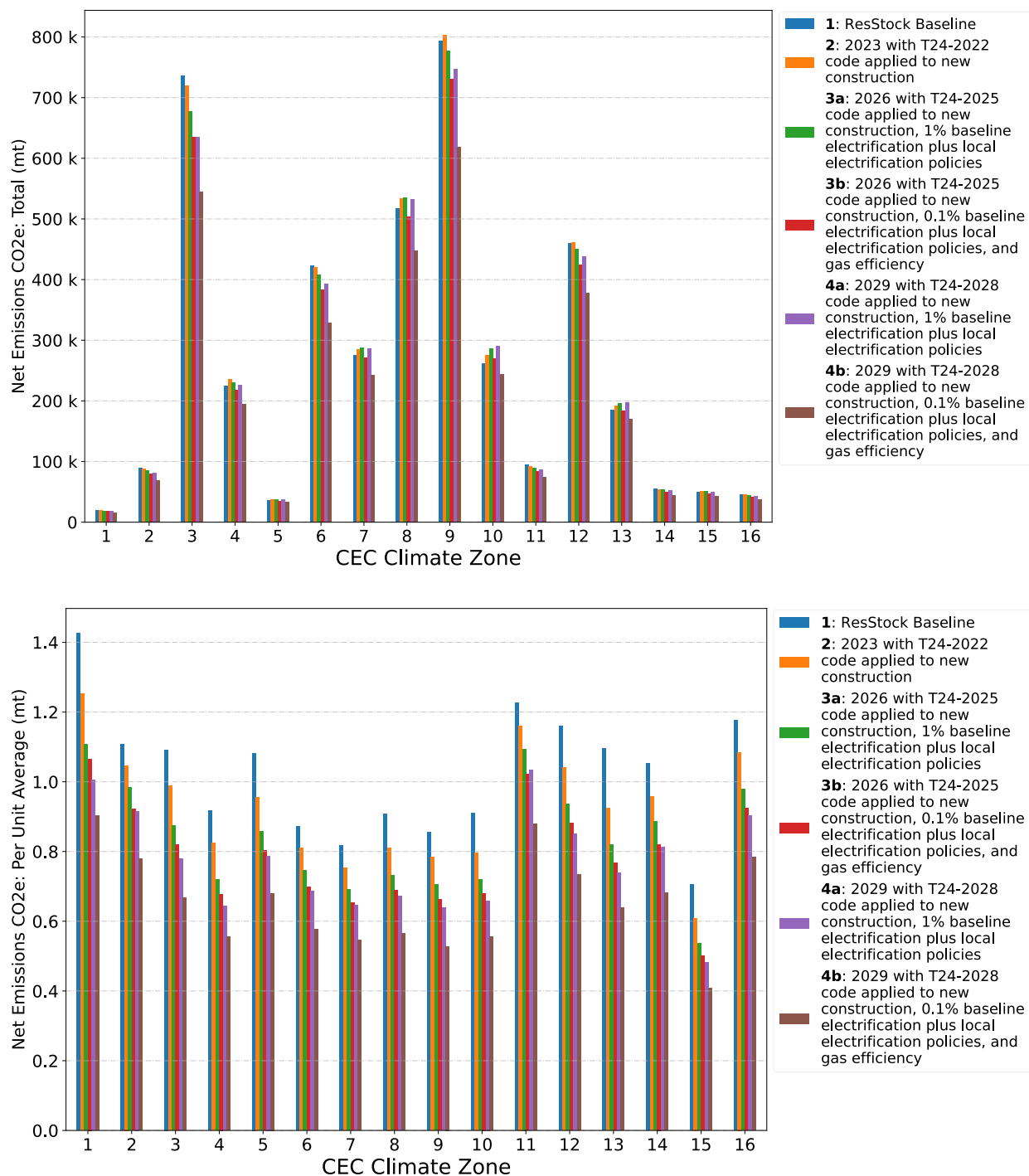


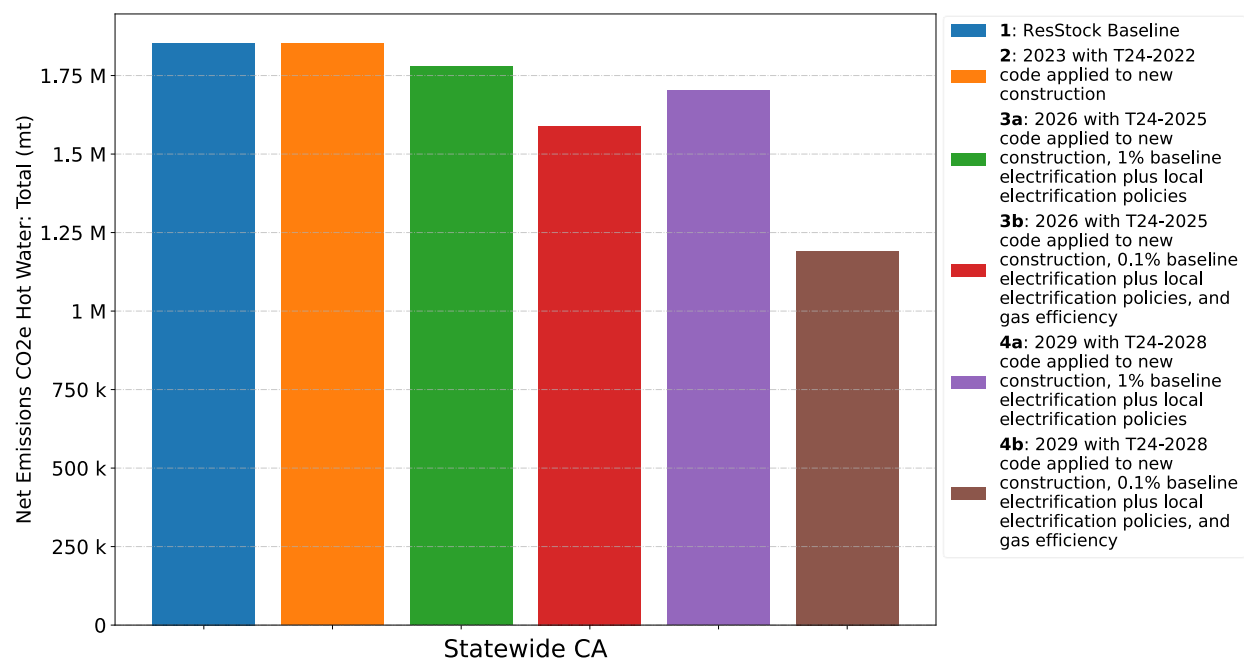
Figure 60: Total hot water emissions across projection scenarios, for California.

Figure 61: Total (top) and per-unit average (bottom) hot water emissions across projection scenarios, broken out by CEC climate zone.

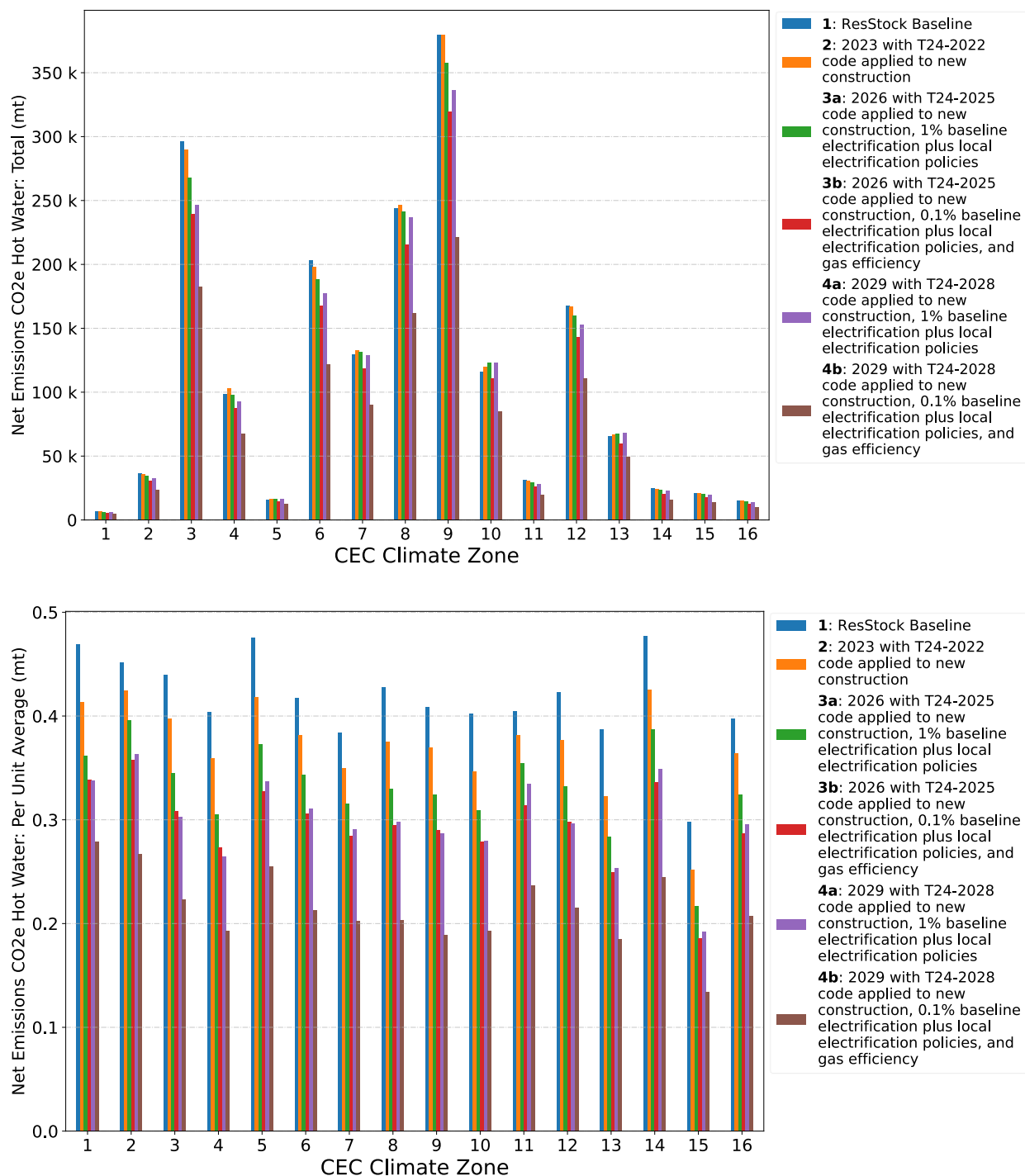


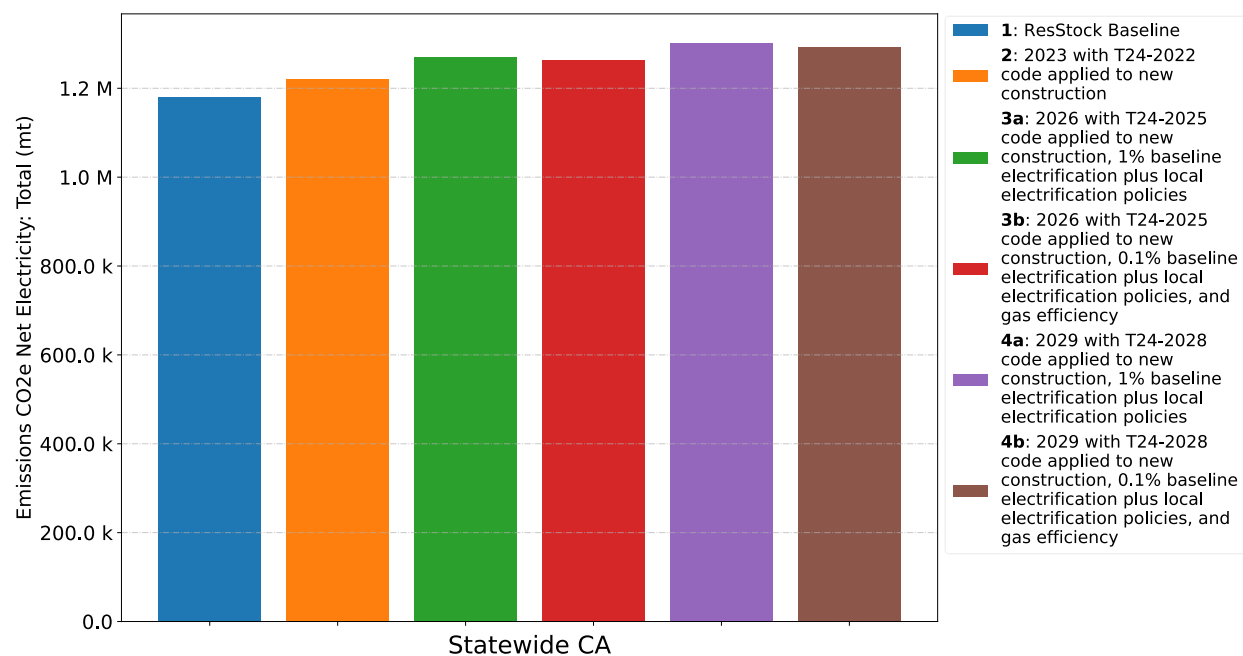
Figure 62: Total net electricity emissions across projection scenarios, across California.

Figure 63: Total (top) and per-unit average (bottom) net electricity emissions across projection scenarios, broken out by CEC climate zone.

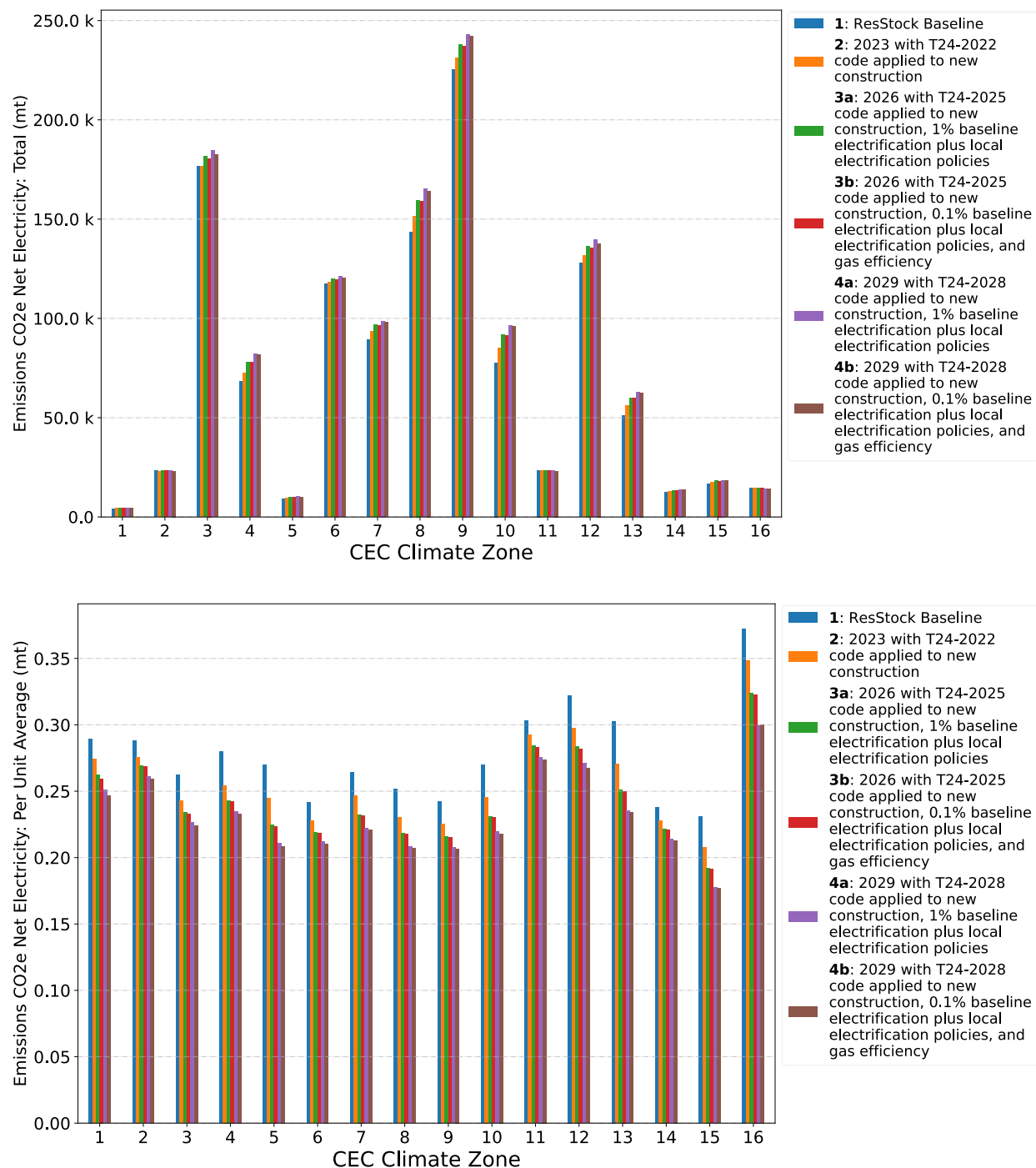


Figure 64: Total hot water electricity emissions across projection scenarios, across California.

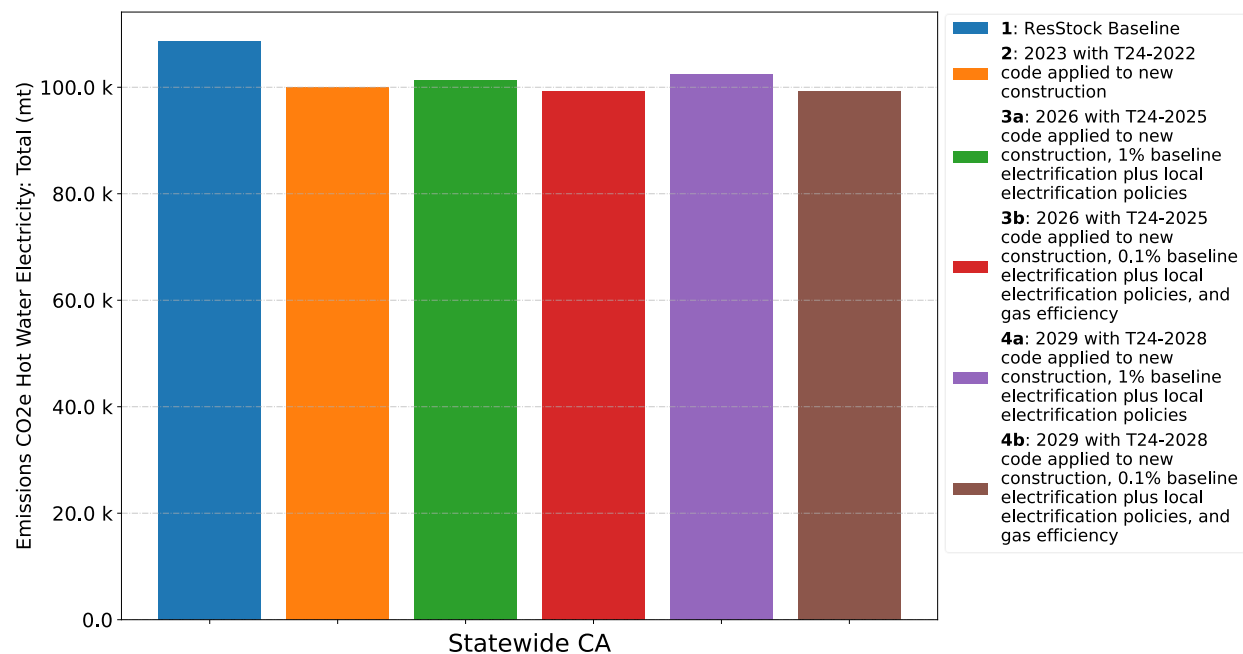


Figure 65: Total (top) and per-unit average (bottom) hot water electricity emissions across projection scenarios, broken out by CEC climate zone.

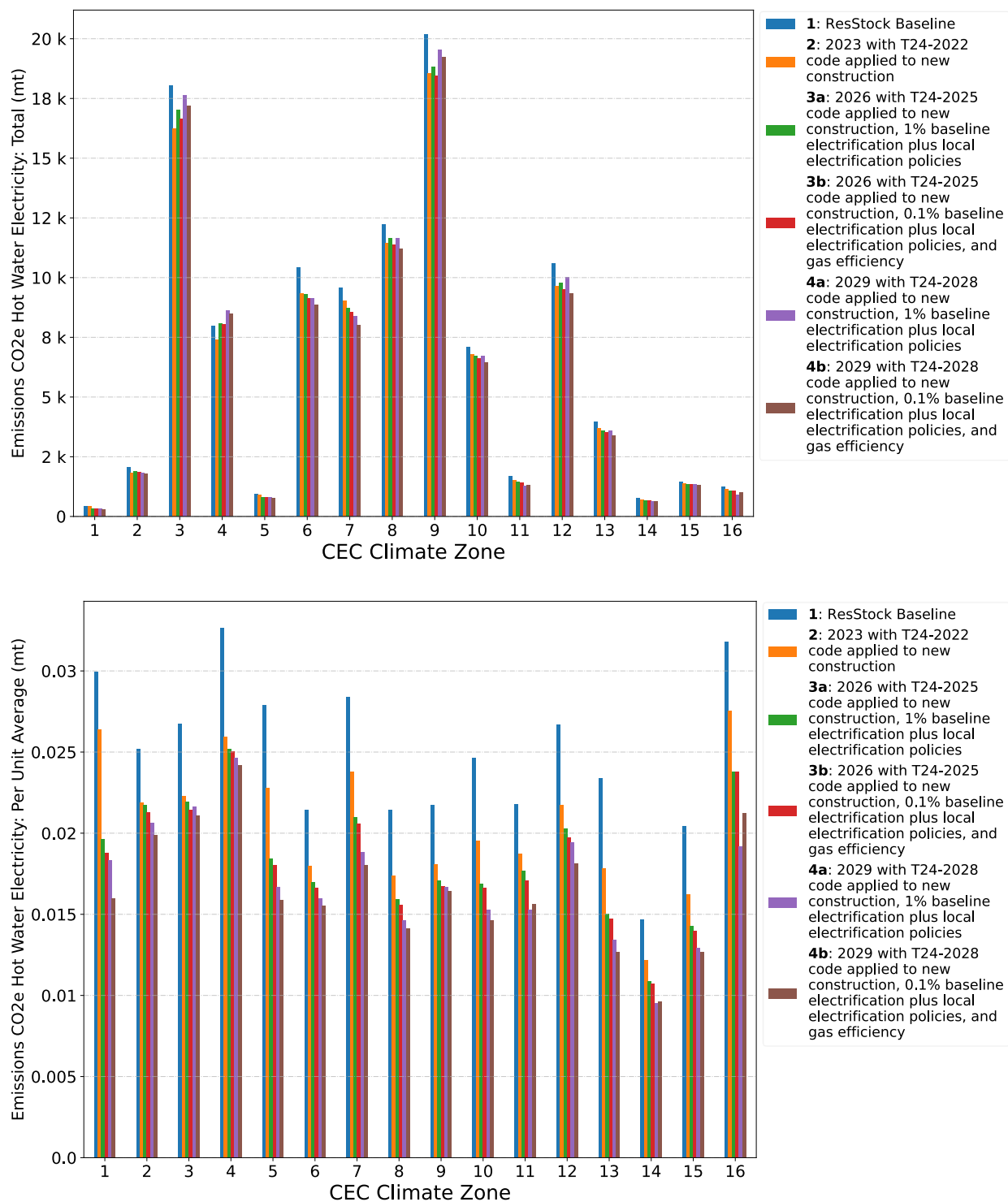


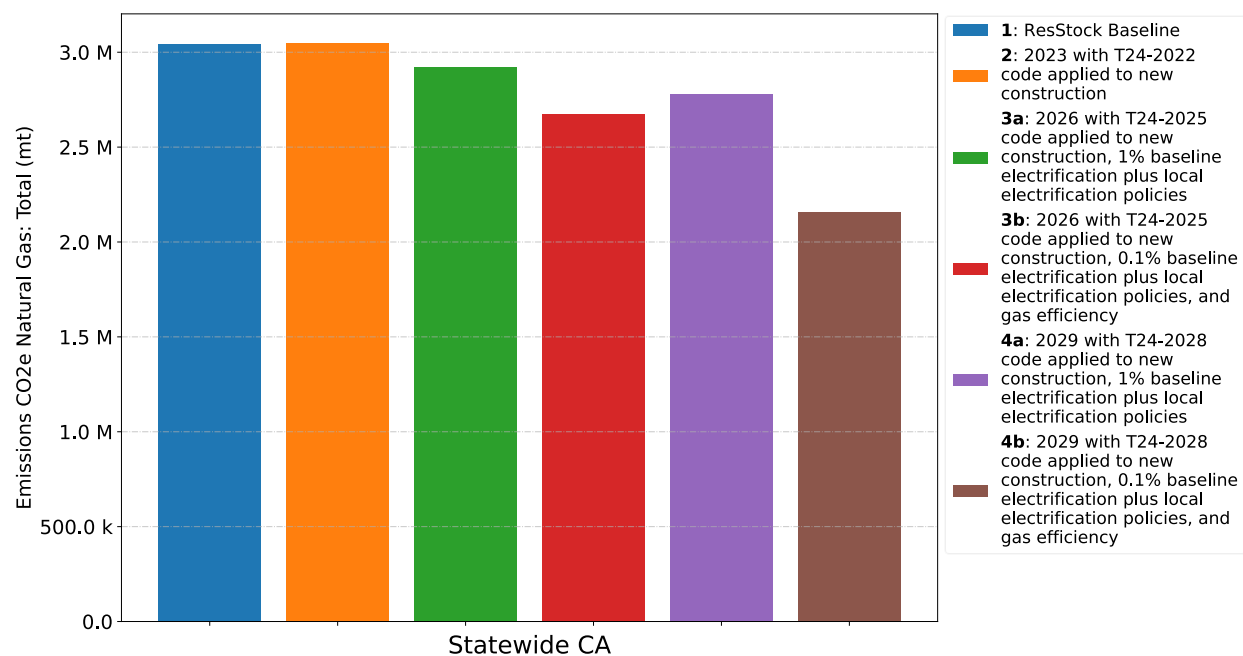
Figure 66: Total natural gas emissions across projection scenarios, across California.

Figure 67: Total (top) and per-unit average (bottom) natural gas emissions across projection scenarios, broken out by CEC climate zone.

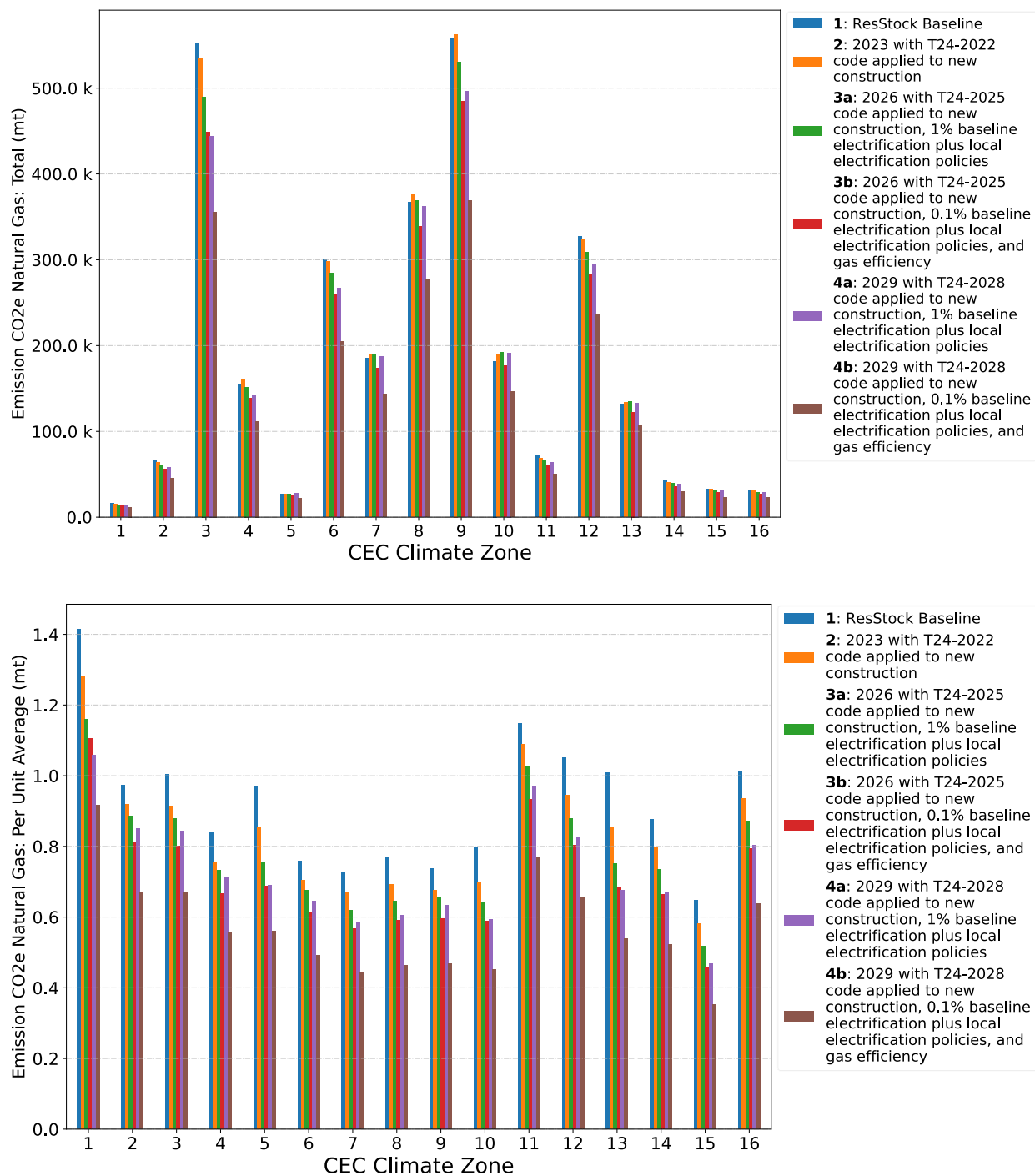


Figure 68: Total hot water natural gas emissions across projection scenarios, across California.

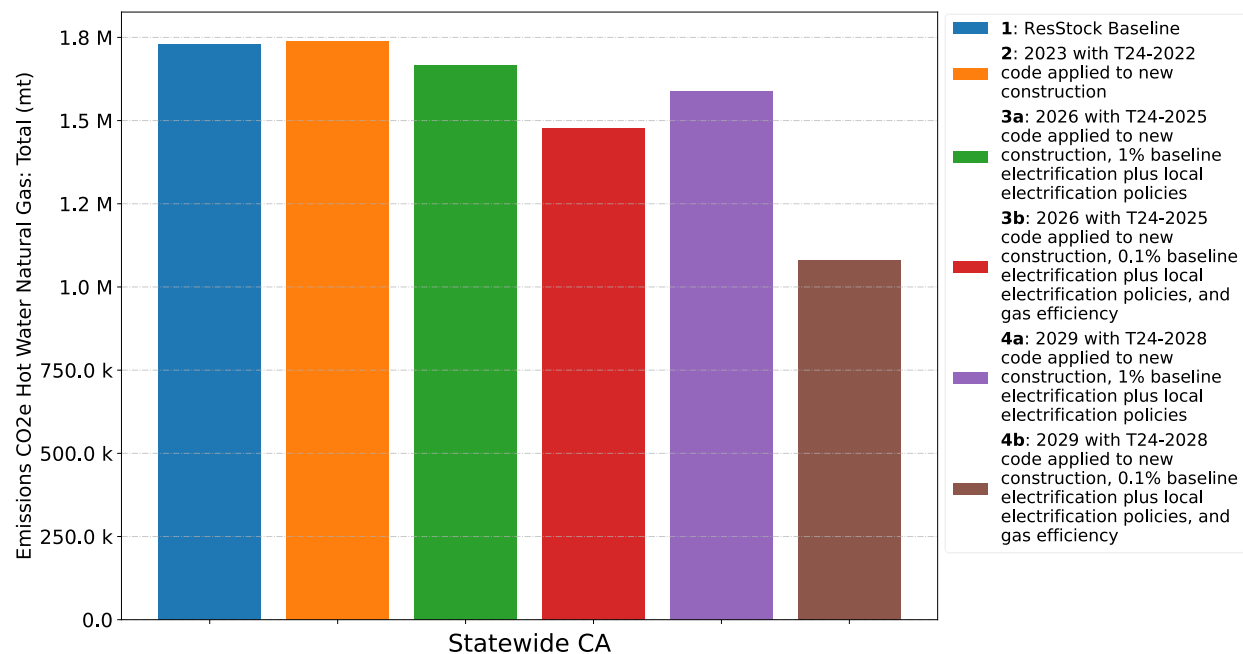
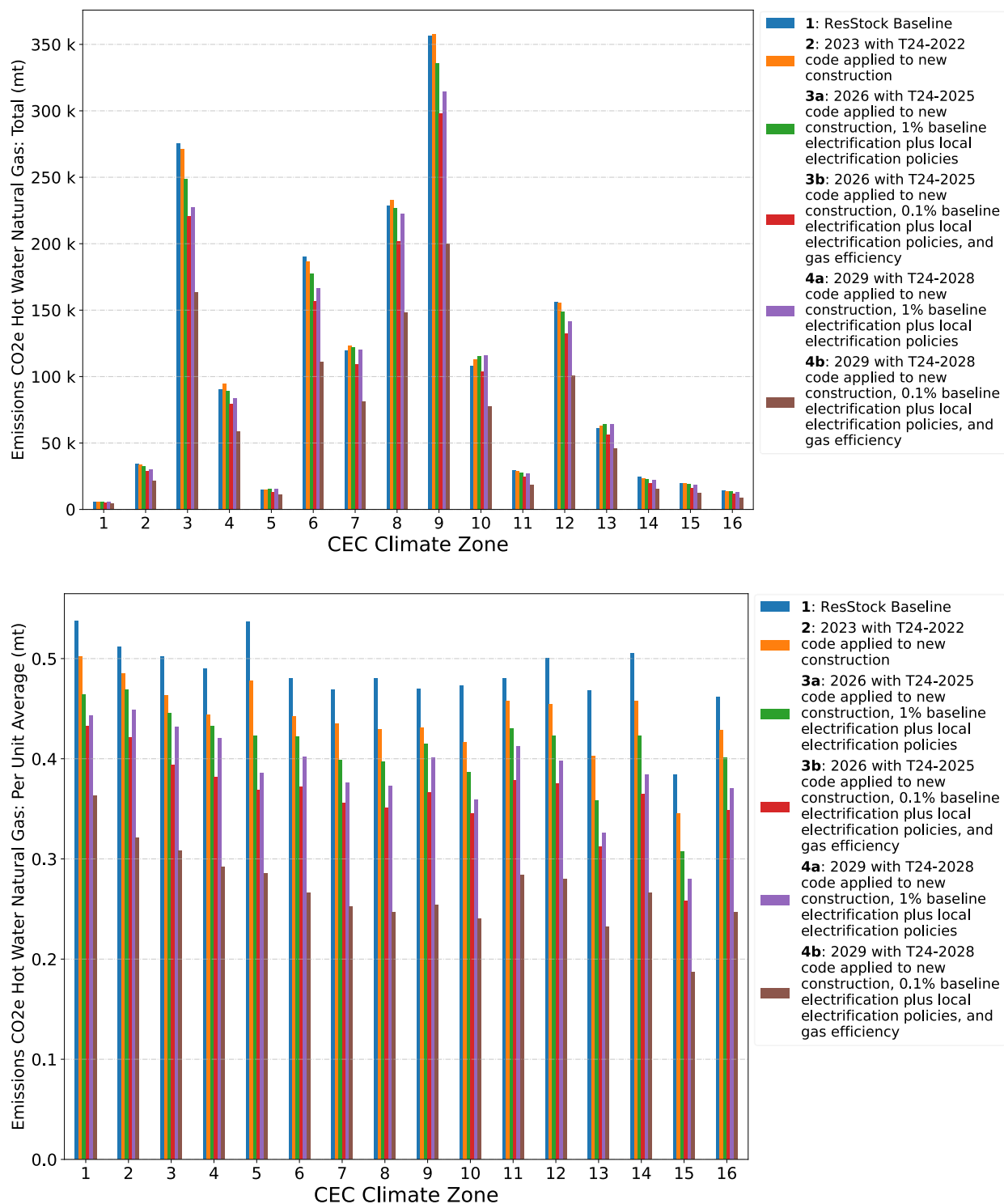


Figure 69: Total (top) and per-unit average (bottom) hot water natural gas emissions across projection scenarios, broken out by CEC climate zone.



D.3 Utility Bills

Figure 70: Total bills across projection scenarios, for California.

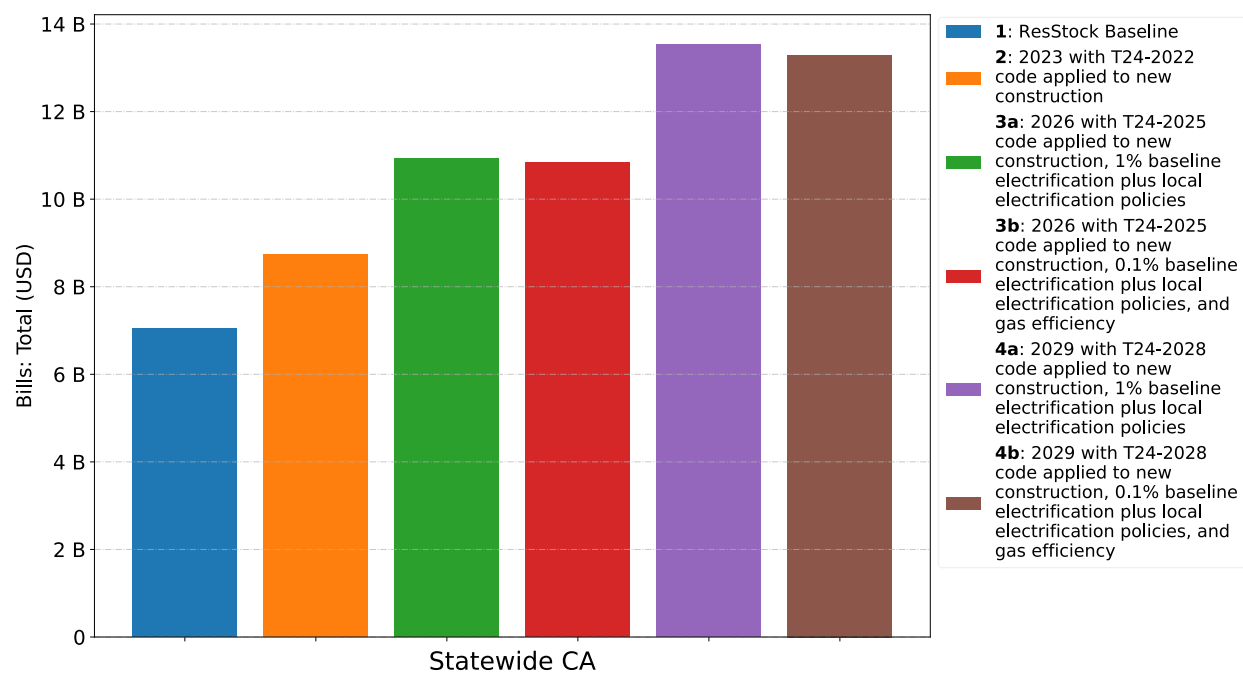


Figure 71: Total (top) and per-unit average (bottom) bills across projection scenarios, broken out by CEC climate zone.

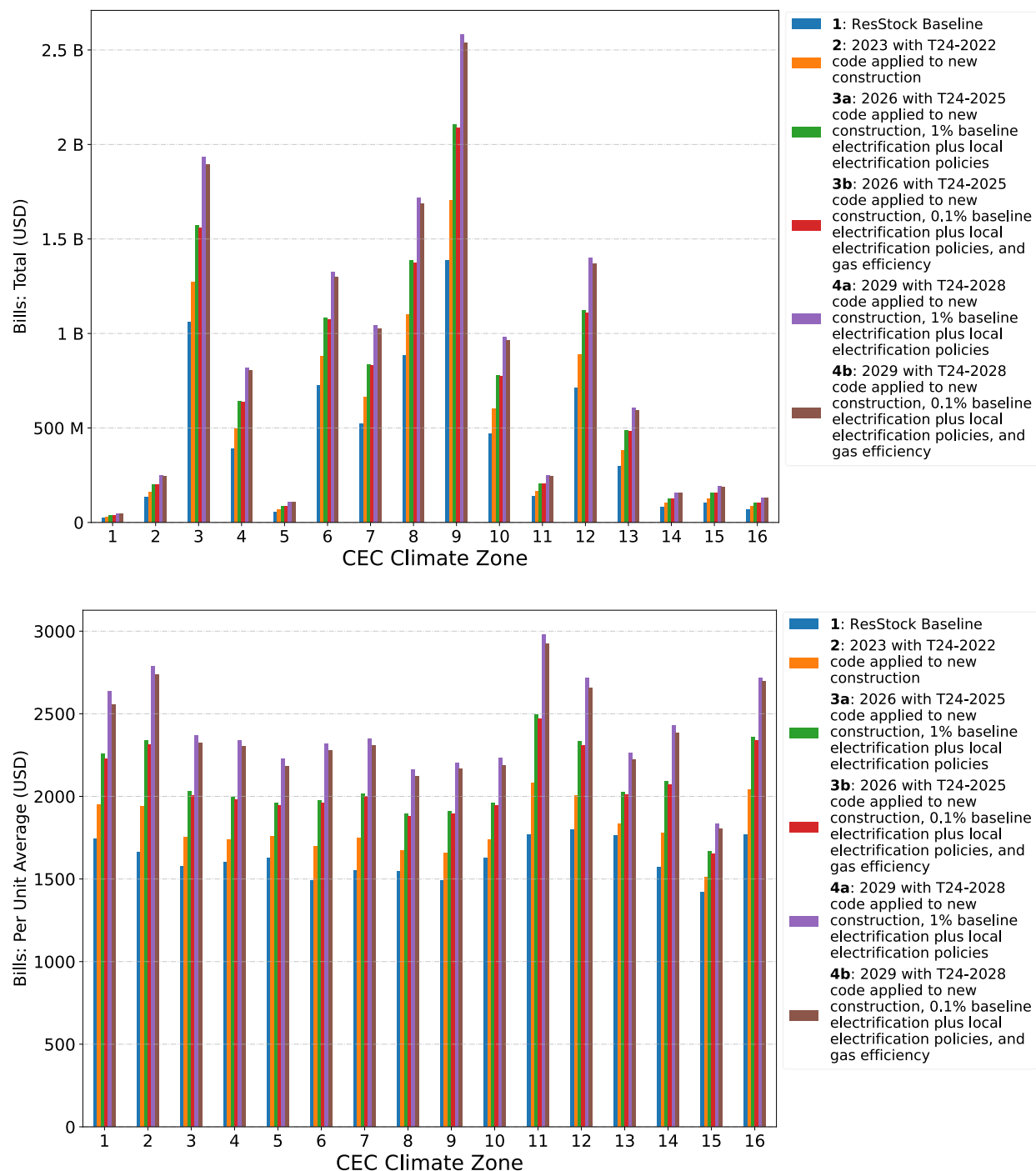


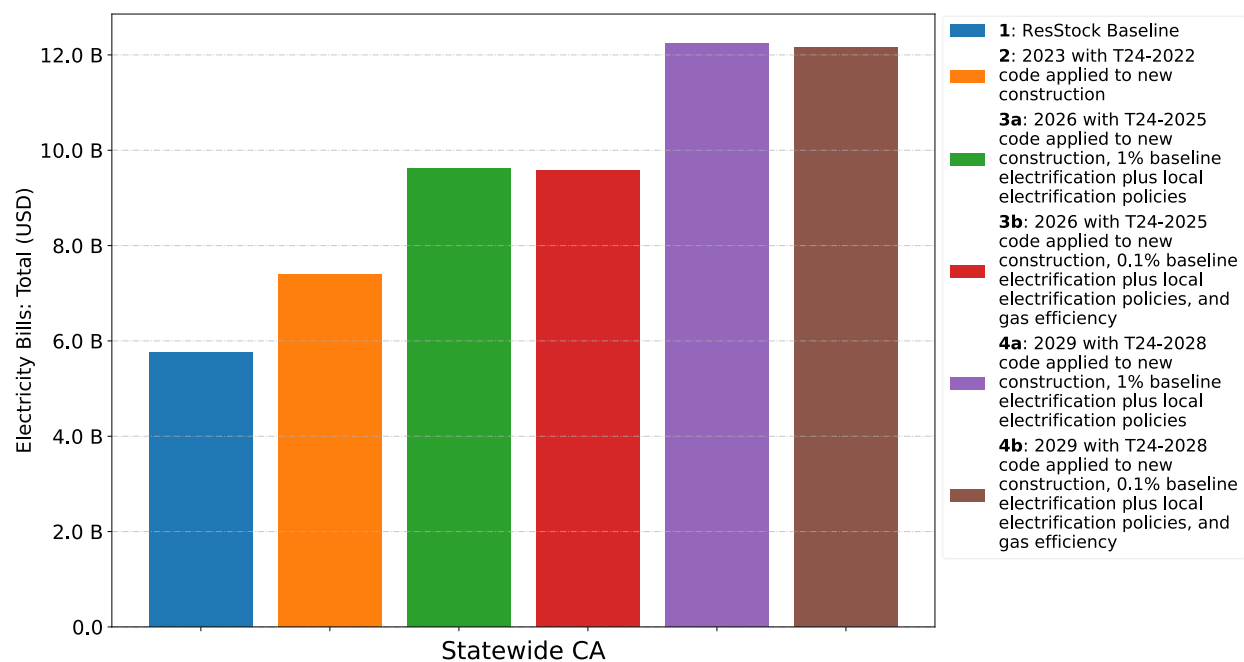
Figure 72: Total electricity bills across projection scenarios, across California.

Figure 73: Total (top) and per-unit average (bottom) electricity bills across projection scenarios, broken out by CEC climate zone.

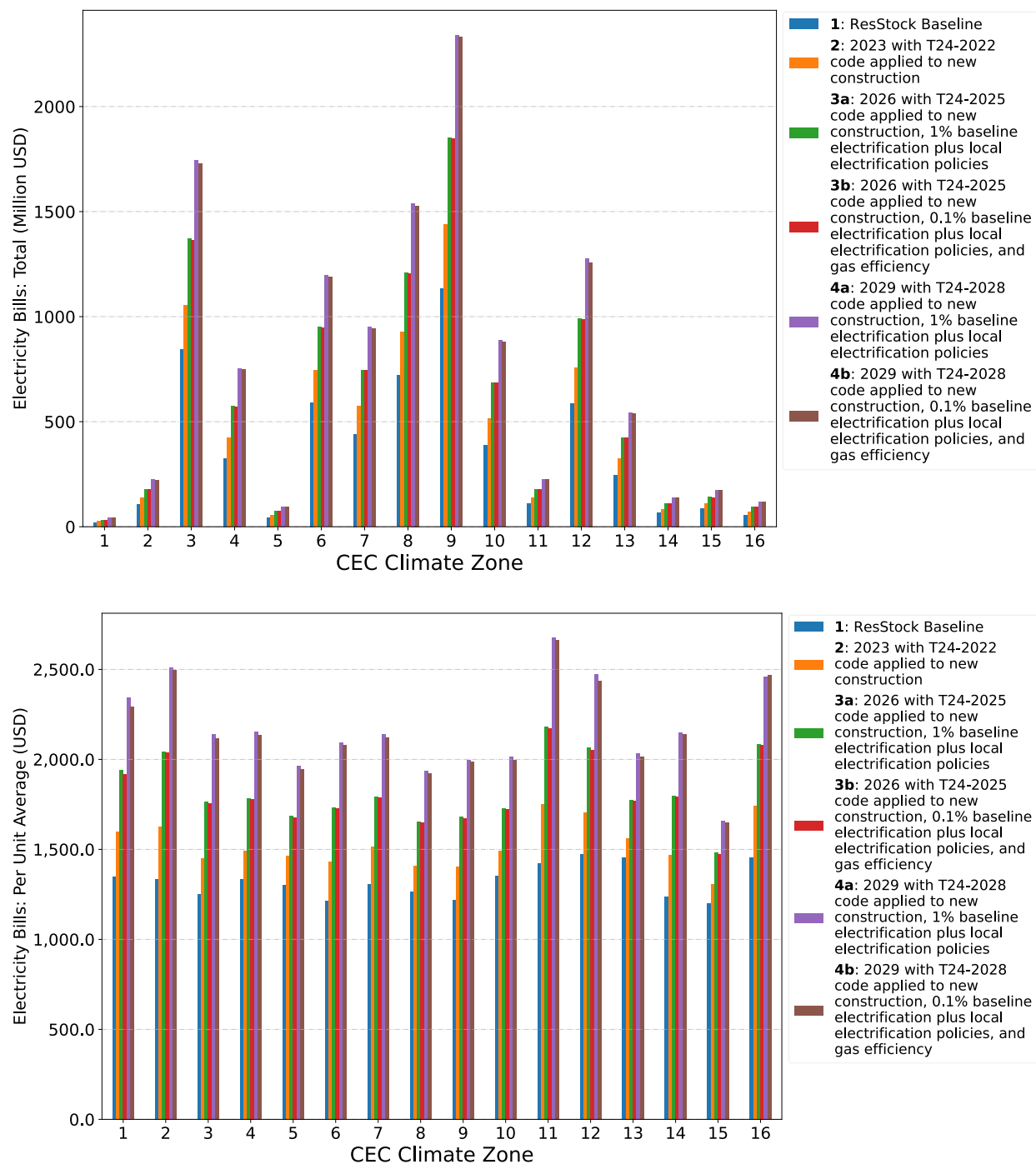


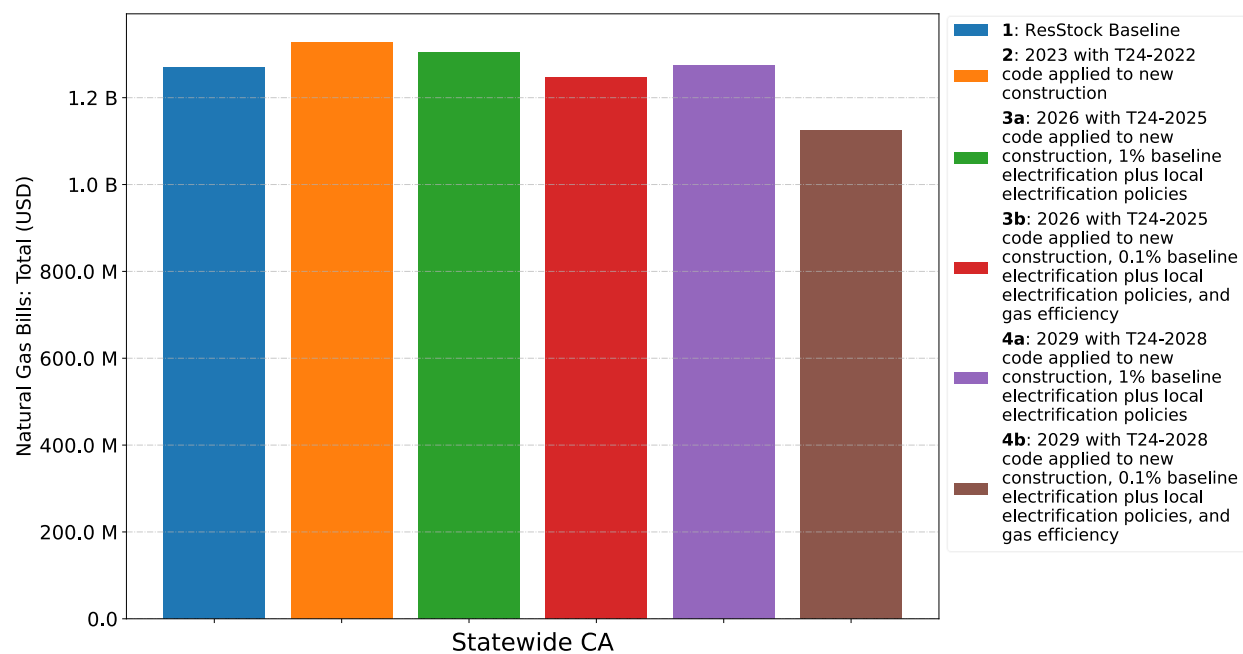
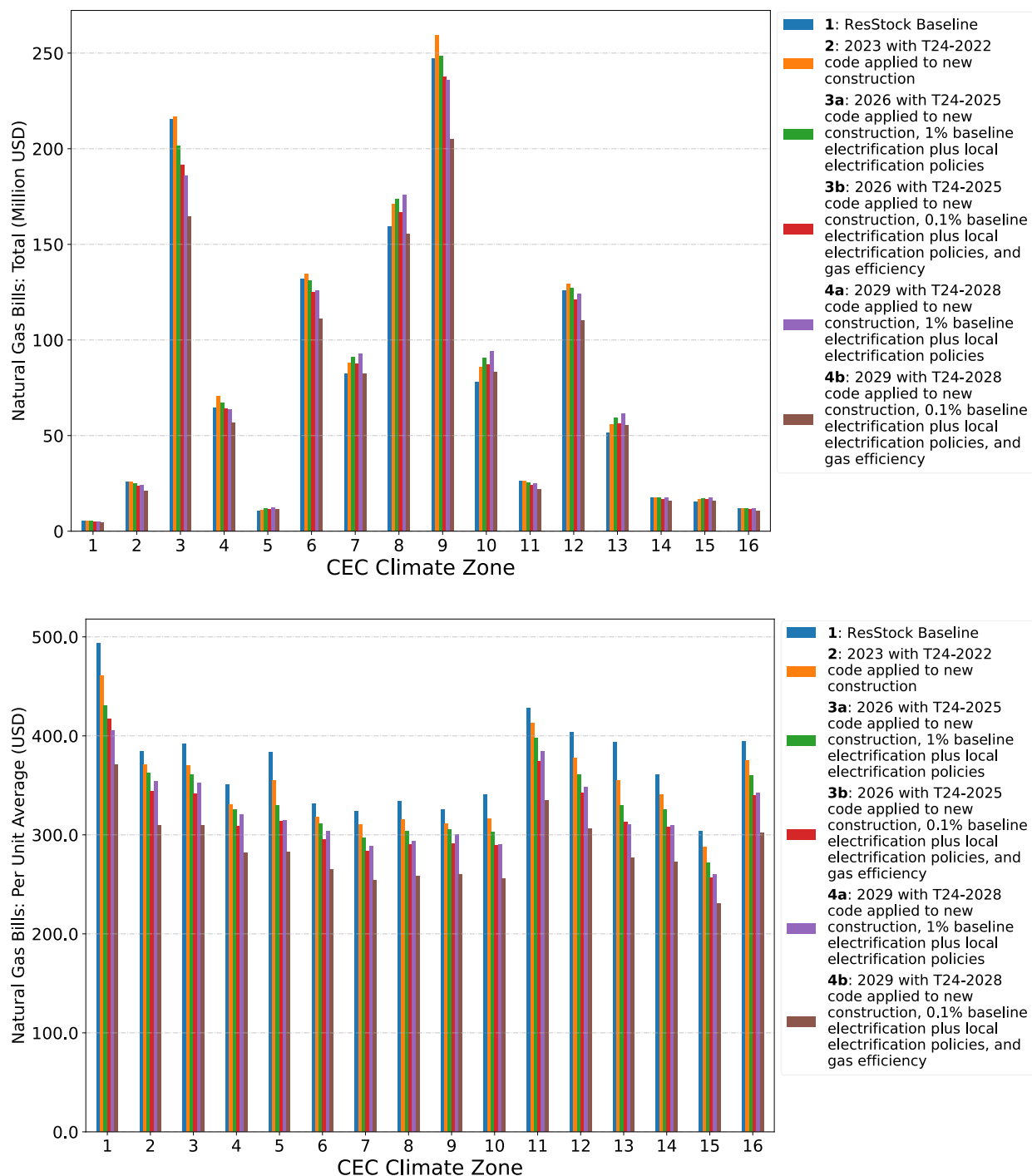
Figure 74: Total natural gas bills across projection scenarios, across California.

Figure 75: Total (top) and per-unit average (bottom) natural gas bills across projection scenarios, broken out by CEC climate zone.



Glossary

Term	Definition
ResStock buildstock CSV file	The result of sampling from ResStock's parameter space (and optionally updating) for a given scenario. Rows of the file correspond to individual models, columns are parameters, and fields contain sampled or updated options.
baseline electrification	In the context of this project, this is the rate at which sampled options are "fuel-switching" to their electric equivalents.
existing stock	This portion of the entire housing stock represents only those homes that have been directly sampled from the ResStock parameter space. Each projection scenario contains the same set of existing stock samples, but weights may vary from year to year based on projected changes to vacancy and demolition rates.
local electrification	In the context of this project, this term refers to the same basic function as "baseline electrification." However, this only applies to specific locations that have policies encouraging electrification.
new construction stock	This portion of the entire housing stock represents the newly added homes that are calculated and generated using the BuildStock Projections tool.
ResStock parameter/option	The set of pairs that constitute the high-level properties of a given building model.
ResStock-sampled option	When options are sampled from ResStock's parameter space, they constitute the existing housing stock.
ResStock updated option	These are options that have been changed or upgraded from the sampled value.
ResStock scenario	For this project, a scenario is defined as the combination of (year basis, efficiency level, rate of baseline electrification, new construction local electrification policies, and adopted of gas-fired heat pump) that is translated to input files.
ResStock sample weight	The number of actual dwelling units that a single ResStock datapoint represents.

References

- California Energy Commission. *Appliance Efficiency Regulations (Title 20)*.
<https://www.energy.ca.gov/rules-and-regulations/appliance-efficiency-regulations-title-20>
- California Energy Commission. (2022). *2022 Building Energy Efficiency Standards (Title 24)*.
<https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency>
- California Energy Commission. (2025). *2025 Building Energy Efficiency Standards (Title 24)*.
<https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2025-building-energy-efficiency>
- Guada, Alejandro, Lee Van Dixhorn, Alex Fridlyand, and Ari Katz. 2024. *Robur GAHP A Performance Mapping*. GTI Energy. <https://ca-etp.com/sites/default/files/reports/ET23SWG0015%20%28MSO6a%29%20Final%20Report%20%282024-09-18%29.pdf>
- NREL. (2023, January). *Cambium 2022 Scenario Descriptions and Documentation*.
<https://www.nrel.gov/docs/fy23osti/84916.pdf>
- NREL. (2023, August). *OpenStudio-HPXML documentation*. https://openstudio-hpxml.readthedocs.io/en/v1.8.1/workflow_inputs.html
- NREL. (2023, August). *ResStock Documentation*. <https://resstock.readthedocs.io/en/v3.3.0/>
- NREL. (2023, August). *BuildStock Batch*.
<https://buildstockbatch.readthedocs.io/en/v2023.10.0/>
- NREL. (2023, August). *BuildStock Projections Documentation*.
<https://nrel.github.io/buildstock-projections-docs/readme.html>
- The Public Advocates Office. *Q2 2024 Electric Rates Report*. The Public Advocates Office at the California Public Utilities Commission, 2024. <https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/press-room/reports-and-analyses/240722-public-advocates-office-q2-2024-electric-rates-report.pdf>
- Sierra Club. (2023, February). *California's Cities Lead the Way on Pollution-Free Homes and Buildings*. <https://www.sierraclub.org/articles/2021/07/californias-cities-lead-way-pollution-free-homes-and-buildings>
- U.S. Energy Information Administration. (2024, December). *State Energy Data System (SEDS): 2023 Updates by energy source*. <https://www.eia.gov/state/seds/seds-data-fuel.php?sid=US#DataFiles>