ComStock Measure Documentation: Electric Resistance Boilers

Marlena Praprost

National Renewable Energy Laboratory

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List of Acronyms

AFUE	annual fuel utilization efficiency
CBECS	Commercial Buildings Energy Consumption Survey
CO_2e	carbon emissions equivalent
DOAS	dedicated outdoor air system
EFFFPLR	efficiency function of part load ratio
EIA	U.S. Energy Information Administration
EIR	electric input ratio
HVAC	heating, ventilating, and air conditioning
Kg	kilogram
LRMER	Long-Run Marginal Emissions Rate
MMBtu	million British thermal units
MMT	million metric tons
MWh	megawatt-hour
PADD	Petroleum Administration for Defense District
PLR	part load ratio
PSC-AC	packaged single-zone air conditioner
PTAC	packaged terminal air conditioner
PVAV	packaged variable air volume
RE	renewable energy
TBtu	trillion British thermal units
URDB	Utility Rate Database
VAV	variable air volume

Executive Summary

Building on the three-year effort to calibrate and validate the U.S. Department of Energy's ResStock™ and ComStock™ models, this work produces national datasets that empower analysts working for federal, state, utility, city, and manufacturer stakeholders to answer a broad range of questions regarding their commercial building stock.

ComStock is a highly granular, bottom-up model that uses multiple data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual subhourly energy consumption of the commercial building stock across the United States. The baseline model intends to represent the U.S. commercial building stock as it existed in 2018. The methodology and results of the baseline model are discussed in the final technical report of the End-Use Load Profiles project.

The goal of this work is to develop energy efficiency and demand flexibility end-use load shapes that cover high-impact, market-ready (or nearly market-ready) measures. *Measures* refer to various "what-if" scenarios that can be applied to buildings.

An *end-use savings shape* is the difference in energy consumption between a baseline building (or collection of buildings) and a building with an energy efficiency or demand flexibility measure applied. It results in a time-series profile broken down by end use and fuel (electricity or on-site gas, propane, or fuel oil use) at each time step as well as annual aggregations.

This report describes the modeling methodology for a single end-use savings shape measure—electric resistance boilers—and briefly introduces key results. The full public dataset can be accessed on the ComStock data lake or via the Data Viewer at comstock.nrel.gov. The public dataset enables users to create custom aggregations of results for their use case (e.g., filter to a specific county).

Key modeling assumptions and technology details are summarized in Table ES-1. National annual results for site energy, utility bills, and carbon emissions equivalent (CO_2e) are summarized in Table ES-2, Table ES-3, and Table ES-4.

Table ES-1. Key Modeling Specifications

Measure Title	Electric Resistance Boilers
Technology description	This measure study investigates the impacts of replacing existing natural gas-fired boilers with electric resistance boilers. Data is provided for all geographical regions of the U.S. Electric boilers use electric resistance elements to heat water, which can be used for space heating in buildings. Compared to electric heat pumps, they are generally considered to have a relatively lower first cost but also lower performance.
Performance assumptions	This measure assumes a nominal thermal efficiency of 1.0 (100%) to represent electric resistance heating efficiency. This compares to traditional atmospheric gas-fired boilers, which operate at around 75%–85% efficiency. Performance curves from the MASControl database are implemented. The curve used is a linear curve, in which the electric input ratio scales linearly from 98% to 100% as a function of part load ratio.
Applicability	This measure is applicable to buildings served by hot water boiler systems, which represent 26% of the baseline stock floor area. It is not applicable to buildings served by district heating hot water.
Release	2025 Release 2: 2025/comstock_amy2018_release_2/

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

Fuel Type	Absolute Savings (TBtu)	Baseline Total, All Buildings (TBtu)	Percent Savings, All Buildings (%)	Baseline Total, Applicable Buildings Only (TBtu)	Percent Savings, Applicable Buildings Only (%)
Natural gas	542.0	1524.1	35.6%	670.4	80.8%
Electricity	-426.0	3173.4	-13.4%	754.5	-56.5%
Other fuel[a]	6.6	53.7	12.3%	6.7	98.0%
Total	122.6	4751.2	2.5%	1431.7	8.6%

[a] Combination of fuel oil and propane annual site energy results

Table ES-3. Key Results for Annual Bill Savings

Fuel Type	Absolute Savings (Billion USD, 2022)	Baseline Total, All Buildings (Billion USD, 2022)	Percent Savings, All Buildings (%)	Baseline Total, Applicable Buildings Only (Billion USD, 2022)	Percent Savings, Applicable Buildings Only (%)
Natural gas	6.2	17.4	35.5%	7.7	79.7%
Electricity	-13.3	107.7	-12.4%	26.0	-51.1%
Fuel oil	0.2	0.7	33.4%	0.2	98.0%
Propane	0.0	1.0	0.0%	0.0	0.0%
Total	-6.9	126.8	-5.4%	34.0	-20.3%

Electricity bill savings in this table are calculated using the mean electricity rate available for each building. Other electricity rate structures are available in this report and in the public dataset.

Table ES-4. Key Results for Annual Emissions Savings

Fuel Type	Absolute Savings (MMT CO_2e)	Baseline Total, All Buildings (MMT CO_2e)	Percent Savings, All Buildings (%)	Baseline Total, Applicable Buildings Only (MMT CO_2e)	Percent Savings, Applicable Buildings Only (%)
Natural gas	36.2	101.8	35.6%	44.8	80.8%
Electricity	-34.3	239.6	-14.3%	53.4	-64.2%
Fuel oil	0.6	1.7	33.5%	0.6	98.0%
Propane	0.0	2.7	0.0%	0.0	0.0%
Total	2.5	345.9	0.7%	98.8	2.5%

Electricity emissions avoided in this table are calculated using the Cambium Long-Run Marginal Emissions Rate (LRMER) High Renewable Energy (RE) Cost 15-Year grid scenario. Other grid scenarios are presented in this report and in the public dataset.

Acknowledgments

The author acknowledges the ComStock™ team, specifically Chris CaraDonna, for their expert guidance during development of this measure scenario. In addition, thank you to those who reviewed this measure scenario, Shanti Pless and Eric Bonnema.

Table of Contents

List of Figures

List of Tables

1 Technology Summary

Electric resistance boilers (often referred to as electric boilers) use electric resistance elements to heat water for space heating. They offer an electric alternative to traditional fuel-fired boilers and can accomplish fuel switching of the space heating load in buildings. Water is heated by the electric boiler and circulated through the building's heating system. The hot water is pumped into hydronic heating coils, which emit warm air to the space. After the heat has been released from the water, the colder water is then recirculated back to the boiler until it needs to be heated again. This process is illustrated in Figure 1 [1]. Compared to other electric options, such as heat pumps, electric boilers are generally considered to have a lower first cost with simpler operation, albeit with lower performance, which can reduce operational benefits.

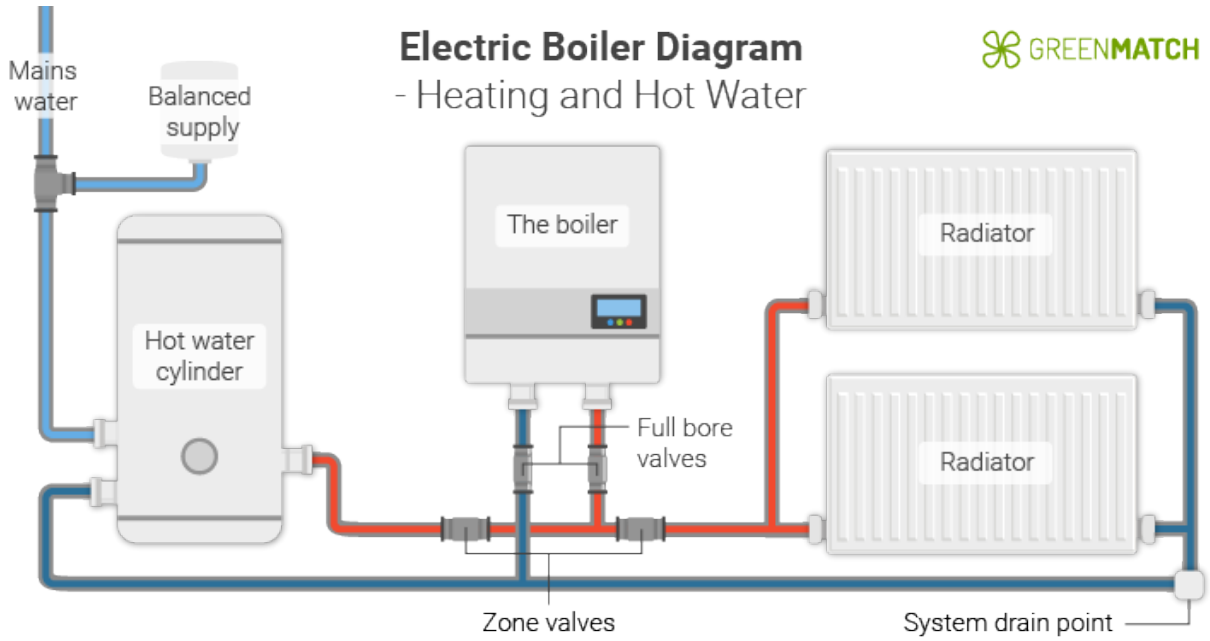

Figure 1. Electric boiler diagram [1]

Electric boilers can typically be easily retrofitted in buildings with existing fuel-fired boilers. Because no combustion occurs, a boiler heating surface and flue gas venting are not necessary [2], which simplifies the installation and space constraints. The only retrofit consideration is ensuring that the existing building has the proper electrical infrastructure to support the new electric heating system as well as capping old flue gas vents. Electric boilers can produce the same supply temperatures as gas boilers, so existing coil sizes with different supply temperatures are generally not a concern with this retrofit concept.

Electric resistance boilers operate at nearly 100% efficiency, whereas traditional atmospheric fuel-fired boilers operate at 75%–85% efficiency. Despite this improved efficiency, electric boilers have had low adoption due to the high electricity prices compared to natural gas, making them difficult to be cost-effective, especially in heating-dominated climates [3], [4]. Electric boilers also have slower recovery times than fuel-fired boilers because the electric resistance components are limited by the electrical power input available. Fuel-fired boilers can draw high

volumes of energy without the same infrastructure constraints, allowing them to achieve higher heating capacities and faster recovery times. However, electric boilers can be an option for buildings without natural gas service, or in locations where electricity prices are comparable to natural gas prices. Hybrid natural gas/electric boilers do exist—they alternate which fuel is being used based on electricity and gas prices throughout the day; however, this ComStock measure will focus on a fully electric boiler to enables analysis for scenarios where fuel switching is appropriate.

2 ComStock Baseline Approach

Of the buildings represented in ComStock™, approximately 26% are served by boiler heating systems; however, these systems represent more than 56% of the natural gas heating energy in the baseline stock. This measure will be applicable to the heating, ventilating, and air-conditioning (HVAC) system types shown in Table 1., along with the respective percentages of the ComStock floor area and natural gas heating energy that they represent.

Table 1. Boiler HVAC Systems in ComStock and Respective Percentages of Floor Area

HVAC System Type	Percentage of ComStock Floor Area	Percentage of ComStock Natural Gas Heating Energy
Packaged variable air volume (PVAV) with gas boiler reheat	9.7%	18.9%
Variable air volume (VAV) chiller with gas boiler reheat	6.5%	13.3%
VAV air-cooled chiller with gas boiler reheat	4.2%	11.9%
Packaged single-zone air conditioner (PSZ-AC) with gas boiler	1.8%	6.1%
Packaged terminal air conditioner (PTAC) with gas boiler	1.3%	2.0%
Dedicated outdoor air system (DOAS) with fan coil air-cooled chiller with boiler	1.1%	2.6%
DOAS with fan coil chiller with boiler	0.6%	0.9%
DOAS with water source heat pumps cooling tower with boiler	0.3%	0.5%
Total	**25.5%**	**56.2%**

The current version of boilers in ComStock are gas- or fuel oil-fired, noncondensing boilers, with efficiencies generally around 80% [5]. Their efficiencies were determined using the U.S. Department of Energy's reference building templates and capacities. The values are summarized in Table 2 [5]. Three different cubic performance curves based on the part load ratio (PLR) are used to adjust the boiler efficiency, as shown in Table 3, based on size and vintage. Figure 2 shows the variations of boiler efficiency multipliers with PLR based on the three performance curves, a graphical representation of the curves' output [6]. All ComStock boilers have a heating set point of 180°F and can modulate flow based on heating load.

Table 2. Boiler Efficiency and Performance Curve Assignment [5]

Template	Minimum Capacity (Btu/hr)	Maximum Capacity (Btu/hr)	Minimum Annual Fuel Utilization Efficiency (AFUE)	Minimum Thermal Efficiency (%)	Minimum Combustion Efficiency (%)	Efficiency function of part load ratio (EFFFPLR)	Notes
Pre-1980	-	299,999		0.73		Boiler constant efficiency curve	From U.S. Department of Energy Reference Buildings
Pre-1980	300,000	No max		0.74			
Pre-1980	250,000,000	249,999,999		0.76			
1980–2004	-	299,999	0.8				From 90.1-1989
1980–2004	300,000	249,999,999			0.8		
90.1-2004	-	299,999	0.8			Boiler with no minimum turndown	From 90.1-2004
90.1-2004	300,000	249,999,999		0.75			
90.1-2004	250,000,000	No max			0.8		
90.1-2007	-	299,999	0.8				From 90.1-2007
90.1-2007	300,000	249,999,999		0.8			
90.1-2007	250,000,000	No max			0.82		
90.1-2010	-	299,999	0.8				From 90.1-2010
90.1-2010	300,000	249,999,999		0.8			
90.1-2010	250,000,000	No max			0.82		
90.1-2013	-	299,999	0.82				From 90.1-2013
90.1-2013	300,000	999,999		0.8			
90.1-2013	1,000,000	249,999,999		0.8		Boiler with minimum turndown	
90.1-2013	250,000,000	No max			0.82		
90.1-2016	-	299,999	0.82			Boiler with no minimum turndown	From 90.1-2016
90.1-2016	300,000	999,999		0.8			
90.1-2016	1,000,000	249,999,999		0.8		Boiler with minimum turndown	
90.1-2016	250,000,000	No max			0.82		
90.1-2019	-	299,999	0.84			Boiler with no minimum turndown	From 90.1-2019
90.1-2019	300,000	999,999		0.8			
90.1-2019	1,000,000	249,999,999		0.8		Boiler with minimum turndown	
90.1-2019	250,000,000	No max			0.82		

Table 3. Boiler Performance Curves [5]

Name	Form	Dependent Variable	Independent Variable 1	coeff_1	coeff_2	coeff_3	coeff_4	Notes
Boiler constant efficiency curve	Cubic	Efficiency multiplier	PLR	1	0	0	0	From U.S. Department of Energy Reference Building
Boiler with minimum turndown				0.7791	1.4745	-2.5795	1.3467	From regression of prototype building Energy Management System
Boiler with no minimum turndown				0.7463	1.3196	-2.2154	1.1674	From regression of prototype building Energy Management System

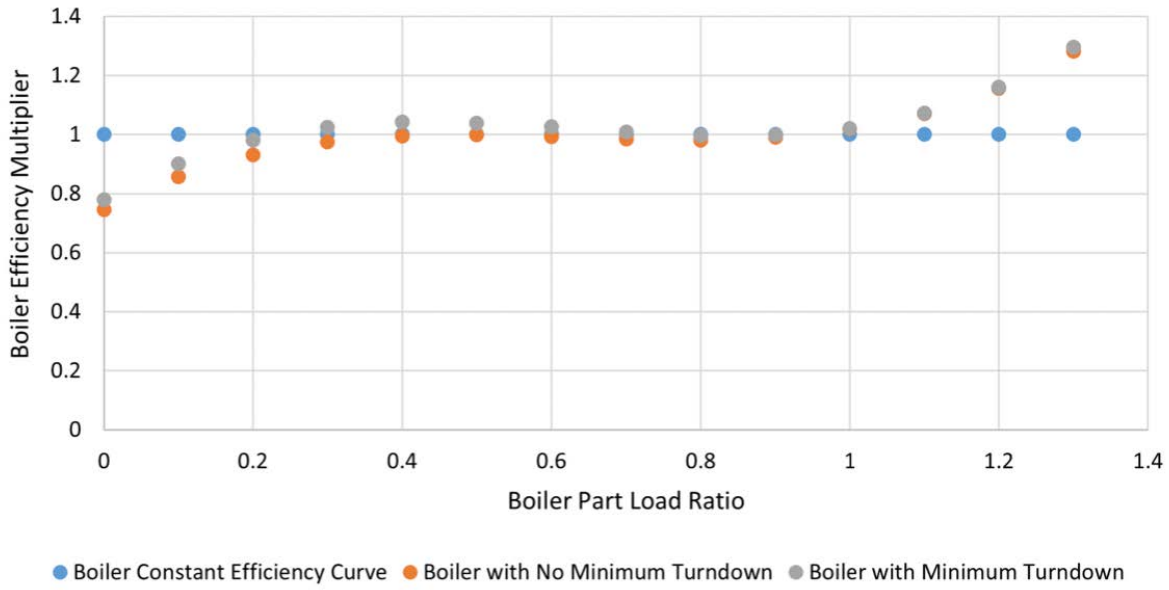

Figure 2. Boiler efficiency multiplier as a function of PLR [6]

3 Modeling Approach

This measure replaces existing natural gas and fuel oil boilers with electric resistance boilers. The implementation of this measure is rather simple—it converts the fuel type of existing boilers in the model from "Natural Gas" or "FuelOilNo2" to "Electricity." In addition, it modifies the nominal thermal efficiency from the original value (around 0.8 for natural gas boilers) to 1.0. The capacity, water flow rate, and all other settings of the boiler will remain the same as in the baseline.

Finally, the existing boiler efficiency performance curve is replaced. The new electric boiler curve is a linear function derived from the MASControl3 database maintained by the California Public Utilities Commission [7]. The new linear performance curve plots the electric input ratio (EIR) as a function of PLR using the following equation:

$$EIR = 0.02 * PLR + 0.98$$

This equation is shown in Figure 3. As shown, the electric input ratio always exceeds 0.98, or 98% efficiency, and reaches 100% efficiency when operating at maximum capacity; therefore, this curve suggests minimal cycling efficiency losses for electric boilers.

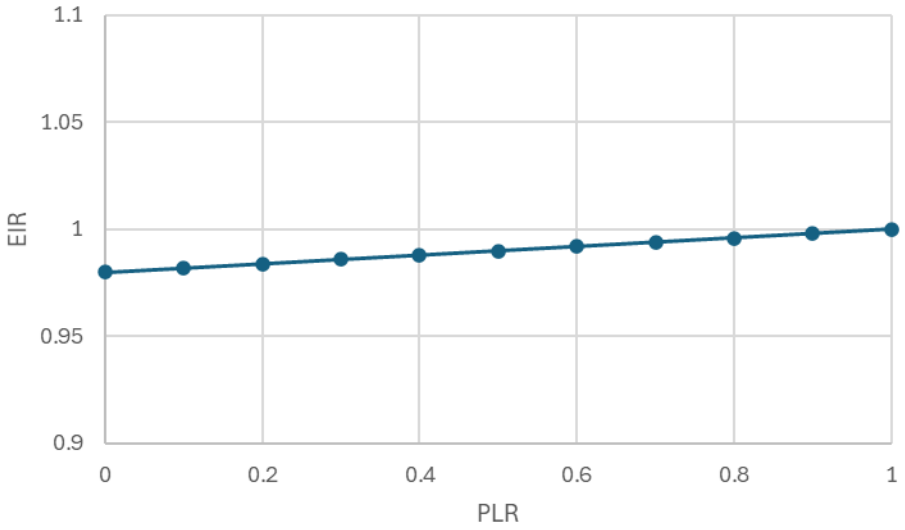

Figure 3. Electric boiler performance curve

3.1 Applicability

Figure 4 shows the heating type distribution among the ComStock buildings. This measure is applicable to buildings that use gas boilers as a heating source, which accounts for 25% of the ComStock baseline floor area. In addition, there is one HVAC system that is classified as "WSHP" as the heating type—"DOAS with water source heat pumps cooling tower with boiler"—which also uses a boiler for heating. This brings the total applicable floor area to approximately 26%.

Although buildings with boiler systems account for 26% of the floor area, they account for 56% of the natural gas heating consumption in ComStock. The breakdown of HVAC system types

that are applicable to this measure and their respective percentages of floor area was shown in Table 1.

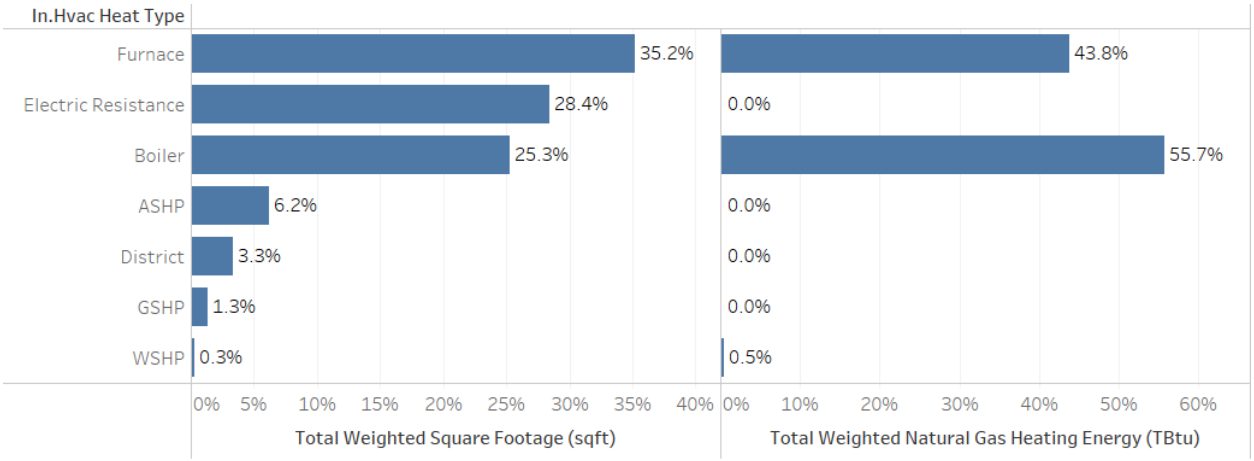

Figure 4. Breakdown of ComStock floor area and natural gas energy consumption by heating type

3.2 Utility Bills

ComStock provides utility bill estimates for several fuel types in buildings: electricity, natural gas, propane, and fuel oil. The current implementation represents utility bills circa 2022, which is the most current year of utility data available from the U.S. Energy Information Administration (EIA). This section provides a high-level overview of the methodology behind utility bills in ComStock, but more detailed information is available in the ComStock Reference Documentation [5]. Summary statistics from this implementation are shown in Table 4. Note that ComStock does not currently estimate utility bills for district heating and cooling.

Table 4. Summary Statistics of Utility Bill Implementation in ComStock by Fuel Type

Fuel Type	Minimum Price ($)	Average Price ($)	Maximum Price ($)
Natural gas	$0.007/kBtu	$0.012/KBtu	$0.048/kBtu
Propane	$0.022/kBtu	$0.032/kBtu	$0.052/kBtu
Fuel oil	$0.027/kBtu	$0.033/kBtu	$0.036/kBtu
Electricity	$0.003/kBtu	$0.035/kBtu	$3.530/kBtu

Natural gas bills are estimated using 2022 EIA averages by state. 2022 U.S. EIA Natural Gas Prices–Commercial Price and U.S. EIA Heat Content of Natural Gas Delivered to Consumers are used to create an energy price in dollars per kBtu [8].

Propane and fuel oil bills are estimated using 2022 EIA averages by state. Residential No. 2 Distillate Prices by Sales Type and U.S. EIA residential Weekly Heating Oil and Propane Prices (October–March) and EIA assumed heat content for these fuels are used to create an energy price in dollars per kBtu [9]. Residential prices are used because commercial prices are only available at the national resolution. Additionally, most commercial buildings using these fuels are assumed to be smaller buildings where a residential rate is likely realistic. For states where state-level pricing was available, these prices are used directly. For other states, Petroleum Administration

for Defense District (PADD) average pricing is used. For states where PADD-level pricing is not available, national average pricing is used.

The primary resource for ComStock electric utility rates is the Utility Rate Database (URDB) [10], which includes rate structures for approximately 85% of the buildings and 85% of the floor area in ComStock [5]. The URDB rates include detailed cost features, such as time-of-use pricing, demand charges, and ratchets. ComStock only uses URDB rates that were entered starting in 2013, and a cost adjustment factor is applied such that the rates reflect 2022 U.S. dollars.

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

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

For buildings with no URDB electric utility assigned, or for buildings where none of the stored rates are applicable, the annual bill is estimated using the 2022 EIA Form-861 average prices based on the state each model is in [11]. Although this method does not reflect the detailed rate structures and demand charges, it is a fallback for the 15% of buildings in ComStock with no utility assigned.

3.3 Carbon Emisions Equivalent

Three electricity grid scenarios are presented to compare the emissions of the ComStock baseline and the boiler replacement scenario. More are available in the full public dataset. The choice of grid scenario will impact the grid emissions factors used in the simulation, which determines the corresponding emissions produced per kilowatt-hour. Two scenarios—Long-Run Marginal Emissions Rate (LRMER) High Renewable Energy (RE) Cost 15-Year and LRMER Low RE Cost 15-Year—use the Cambium dataset, and the last uses the eGrid dataset [12] [13]. All three scenarios vary the emissions factors geospatially to reflect the variation in grid resources used to produce electricity across the United States. The Cambium datasets also vary emissions factors seasonally and by time of day. This study does not imply a preference for any particular grid emissions scenario, but other analysis suggests that the choice of grid emissions scenario can impact results [14]. Emissions due to the on-site combustion of fossil fuels use the emissions factors shown in Table 5, which are from Table 7.1.2(1) of the draft American National Standards Institute/Residential Energy Services Network/International Code Council 301 [15]. To compare the total emissions due to both on-site fossil fuel consumption and grid electricity generation, the emissions from a single electricity grid scenario should be combined with all three on-site fossil fuel emissions.

Table 5. On-Site Fossil Fuel Emissions Factors

Natural gas	147.3 lb/MMBtu (228.0 kg/MWh)[a]
Propane	177.8 lb/MMBtu (275.7 kg/MWh)
Fuel oil	195.9 lb/MMBtu (303.2 kg/MWh)

[a] lb = pound; MMBtu = million British thermal units; kg = kilogram; MWh = megawatt-hour

3.4 Limitations and Concerns

The HVAC distributions in ComStock are derived from the EIA Commercial Buildings Energy Consumption Survey (CBECS) dataset, and they are a function of building type, census region, and space heating fuel. Although CBECS is the best available dataset for national HVAC distributions, there are still some uncertainties given that it is a survey of a representative subset of building owners and operators. The uncertainties in HVAC system distribution affect the baseline prevalence of boilers, which, in turn, affects the measure applicability and impact potential of the technology.

Another minor limitation of ComStock's boiler modeling is that in all buildings, even very large buildings, a single boiler is modeled. In reality, multiple boilers can be used in a single building, which allows for higher efficiency and better load management. This modeling discrepancy can affect cycling operation and performance curves, but the energy impacts are minimal. This could have a nontrivial effect on utility bills for rates with peak demand charges. ComStock reports out annual utility bills for all applicable rates; therefore, it might be better to use the statistical utility bill metrics (minimum, mean, maximum) when analyzing utility bill results for this measure.

4 Output Variables

Table 6 includes a list of output variables that are calculated in ComStock. These variables are important in terms of understanding the differences between buildings with and without the electric resistance boiler measure applied. These output variables can also be used for understanding the economics of the upgrade (e.g., return on investment) if cost information (i.e., material, labor, and maintenance costs for technology implementation) is available.

Table 6. Output Variables Calculated From the Measure Application

Variable Name	Description
out.params.boiler_average_efficiency	Load weighted average thermal efficiency
out.params.boiler_cap_weight_efficiency	Capacity weighted nominal thermal efficiency
out.params.boiler_load_weight_efficiency	Load weighted nominal thermal efficiency
out.params.boiler_capacity..kbtu_per_hr	Sum of boiler capacity
out.params.boiler_load..j	Total boiler heating load served
out.params.boiler_electric..j	Total boiler electric use
out.params.boiler_gas..j	Total boiler gas use
out.params.boiler_other_fuel..j	Total boiler other fuel use
out.params.hot_water_loop_load..j	Heating load provided by boilers and heat pumps
out.params.hot_water_loop_boiler_fraction	Heating load provided by boilers divided by total hot water loop heating load
out.params.hvac_count_boilers	Count of boilers
out.params.hvac_count_boilers_0_to_300_kbtuh	Count of boilers in size range 0–300 kBTUh
out.params.hvac_count_boilers_300_to_2500_kbtuh	Count of boilers in size range 300–2,500 kBTUh
out.params.hvac_count_boilers_2500_plus_kbtuh	Count of boilers in size range >2,500 kBTUh

5 Results

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

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

5.1 Single-Building Measure Tests

This section demonstrates the electric boiler measure application on a 300,000-ft^2 large office test model in Boise, Idaho. The building has a "VAV chiller with gas boiler reheat" HVAC system. The measure replaced the model's central 80% efficient natural gas boiler with a 100% efficient electric resistance boiler. In addition to the efficiency improvement and heating fuel switch, the boiler performance curve was updated to the curve in Figure 3. A summary of the energy use intensity, annual site energy, and heating site energy impacts are shown in Table 7.

Table 7. Energy Impacts of Electric Boiler Measure Scenario for Single-Building Example

	Baseline Scenario	Electric Boiler Measure Scenario	Percent Savings
Energy use intensity (kBtu per square foot)	58.8	52.1	11.4%
Annual site energy consumption (MBtu)	17,636	15,635	11.3%
Heating site energy consumption/fuel	Natural gas—8,391 MBtu (2.5 GWh)	Electric—1.9 GWh	24.0% overall heating savings

This 24% savings in heating site energy is consistent with what we would expect for a 20% improvement in boiler efficiency, combined with an updated boiler performance curve. Note that these are site energy savings, which might not translate to source energy savings or bill savings due to fuel switching of the heating load. Although the annual site energy for this building was reduced by 11%, the switch to electric heating is likely to result in utility bill increases due to the price differences between natural gas and electricity. The building's exact natural gas and electricity pricing structures would be required to calculate the change in annual utility bills.

Figure 5 shows the breakdown of energy consumption by month and end use before and after the electric boiler measure scenario was applied. In the figure, the hashed bars represent natural gas

end uses, and solid fill bars represent electricity. As shown, the natural gas heating load in the baseline is replaced with electric heating in the electric boiler measure scenario.

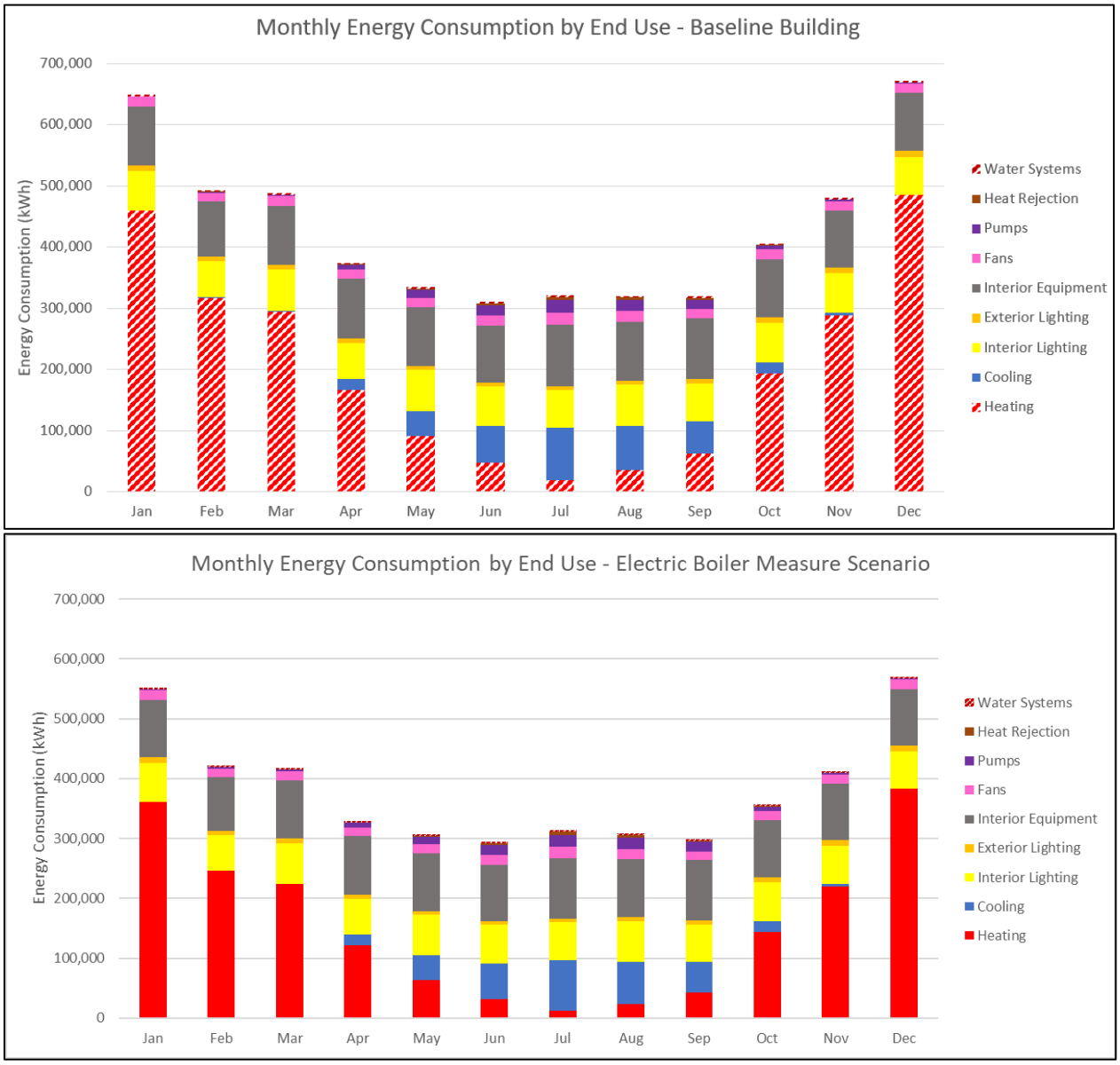

Figure 5. Single-building example—monthly energy consumption by end use for baseline scenario (top) vs. electric boiler measure scenario (bottom).

Hashed colored bars indicate natural gas energy, and solid colored bars indicate electricity.

5.2 Stock Energy Impacts

The electric boiler measure demonstrates 2.5% total site energy savings (123 trillion British thermal units [TBtu]) for the U.S. commercial building stock modeled in ComStock. The savings contributions by end use and fuel type are summarized in Table 8 and illustrated in Figure 6.

Table 8. Summary of Site Energy Savings From the Electric Boiler Measure Application vs. the ComStock Baseline

End Use/ Fuel Type	Absolute Savings (TBtu)	Baseline Total, All Buildings (TBtu)	Percent Savings, All Buildings (%)	Baseline Total, Applicable Buildings Only (TBtu)	Percent Savings, Applicable Buildings Only (%)
Total natural gas	533.0	1524.1	35.0%	418.2	76.5%
Total electricity	-425.0	3173.4	-13.4%	754.0	-56.6%
Total heating	122.6	1309.0	9.4%	548.6	22.3%
Gas heating	542.0	965.2	56.2%	542.0	100.0%
Other fuel heating	6.6	42.7	15.5%	6.6	100.0%
Electric heating	-426.0	260.1	-163.8%	0	NA
Total	122.6	4865.4	2.5%	1431.8	8.6%

As shown in Figure 6, most of the annual site energy savings for the electric boiler measure are seen in natural gas heating. Much of the stock's natural gas space heating load is converted to electric space heating when replacing traditional natural gas boilers with electric boilers. The baseline also contains a small amount of fuel oil boilers, so we also see savings in "other fuel heating." The electric boiler in the measure scenario is more efficient than the baseline combustion fuel boiler; therefore, we see overall stock site energy savings of 2.5%, and total heating savings of 9.4%. But site energy savings does not directly translate to emissions or utility bill savings because this measure involves fuel switching of a major end use (this will be discussed in subsequent sections). The stock electric heating load nearly triples due to the new electric heating load in buildings that received the electric boiler measure. All other end uses are unaffected by the measure, as expected.

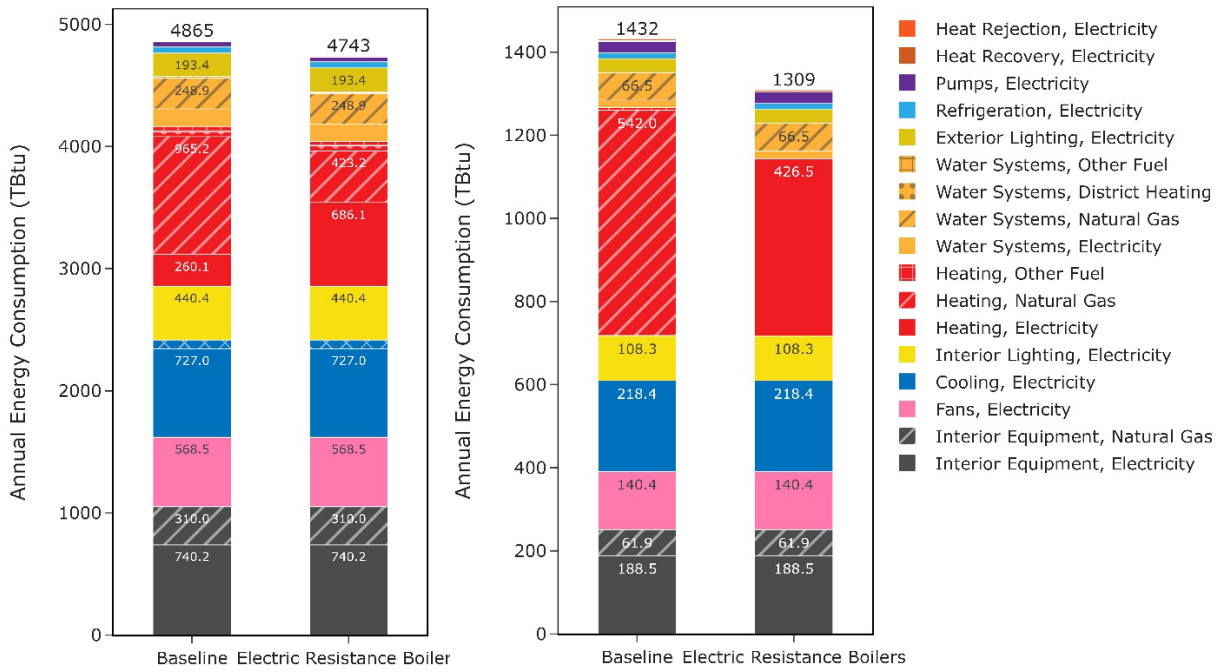

Figure 6. Comparison of annual site energy consumption between the ComStock baseline and the electric boiler measure scenario for the full stock (left) and applicable buildings only (right).

Energy consumption is categorized both by fuel type and end use.

5.3 Stock Utility Bill Impacts

This section includes a comparison of national-level annual utility bills of the stock across different fuel sources (i.e., electricity, natural gas, propane, fuel oil). ComStock uses utility region mapping to determine all associated electricity rates that can be used by a building in that region; therefore, the results can include many annual utility rates per building. The comparison in this section highlights three statistics (i.e., maximum, mean, and minimum) across all possible electric utility rates in a location. For more information about the utility bill methodology in ComStock, see the ComStock Reference Documentation [5].

When combining all fuels, the electric boiler measure scenario resulted in a $4–$9 billion total utility bill *increase* (4%–6% increase) nationally depending on the electricity rate used (Figure 7). Natural gas bills are reduced by $6 billion (35% savings) nationally as a result of converting much of the heating end use to electricity. The natural gas rates used are fixed by state and therefore remain constant across all three scenarios shown.

Electricity rates are determined based on the utility region of each building in the dataset. Some utilities can have multiple rates; therefore, only the minimum, mean, and maximum rates are shown in the figure. For the electric boiler measure, the mean electricity rate showed a $13 billion increase in electricity bills nationally. In many locations, electricity is currently more expensive than natural gas; therefore, switching from gas heating to electricity with simple electric resistance heating can result in an increase in the total utility bill of a building. In addition, the electric resistance heating can contribute to higher peak demand charges with

certain utility rates. But future modifications to rate structures or to the composition of the electric grid could change this.

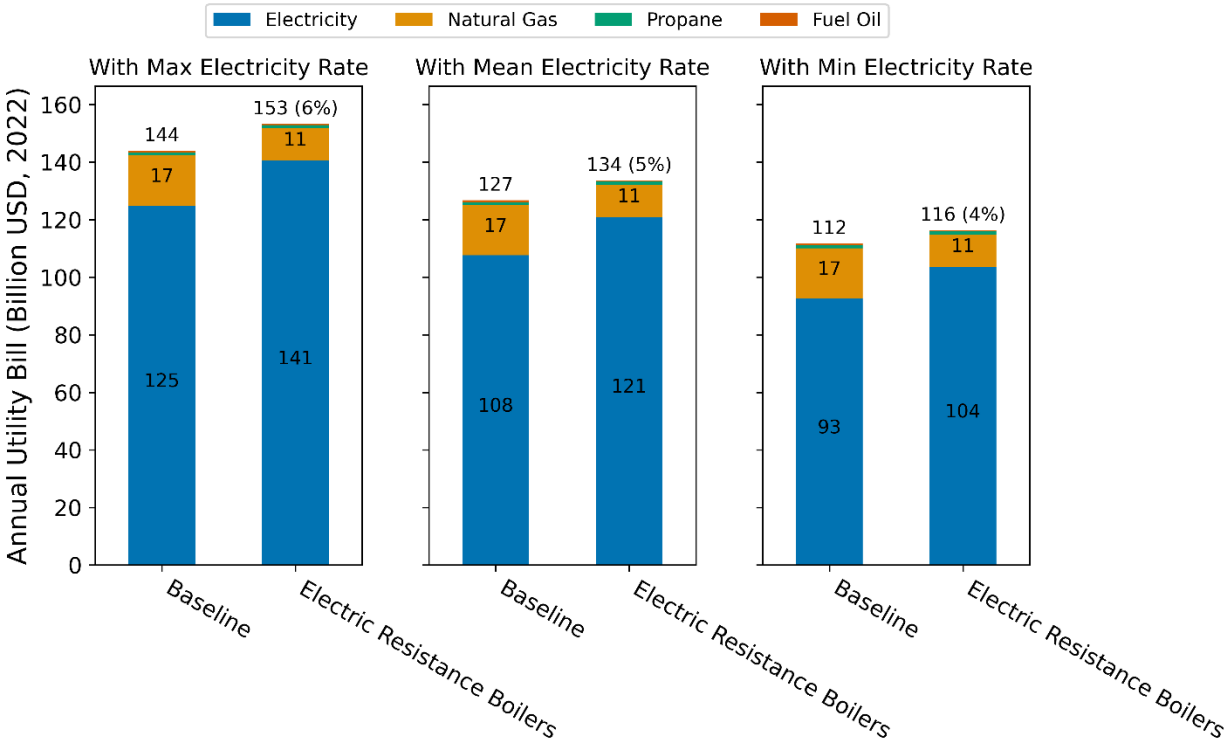

Figure 7. National annual utility bills comparison of the ComStock baseline vs. electric boiler measure scenario

5.4 Stock Emissions Impact

ComStock simulation results show carbon emissions equivalent (CO_2e) avoided across two of the three electricity grid scenarios (Figure 8). When combining all fuel types in the eGRID 2021 scenario, the electric boiler measure *increases* the total emissions by 11 million metric tons (MMT) of carbon dioxide equivalent (CO_2e) (2% increase). In the two Cambium LRMER scenarios shown, we see a 3–12 MMT CO_2e reduction (1%–5% savings) in total emissions across all fuels.

The increase in total emissions in the eGRID scenario is because the current electricity emissions factors in some regions are higher than those of natural gas. This means that large-scale fuel switching to electricity can result in higher emissions at the national scale, despite the higher heating efficiency of electric boilers compared to natural gas. In the LRMER future projection scenarios, it is assumed that the electricity emissions factors are reduced due to the higher penetration of renewable energy on the grid; therefore, in those scenarios, measures that fuel switch from combustion fuels to electricity can result in emissions reductions at the national level.

The emissions from natural gas are reduced by 36 MMT CO_2e (35% savings) as a result of converting much of the heating end use to electricity. The natural gas emissions remain

consistent across all three grid scenarios, as these scenarios exclusively pertain to modifications within the electricity grid, without affecting natural gas outcomes.

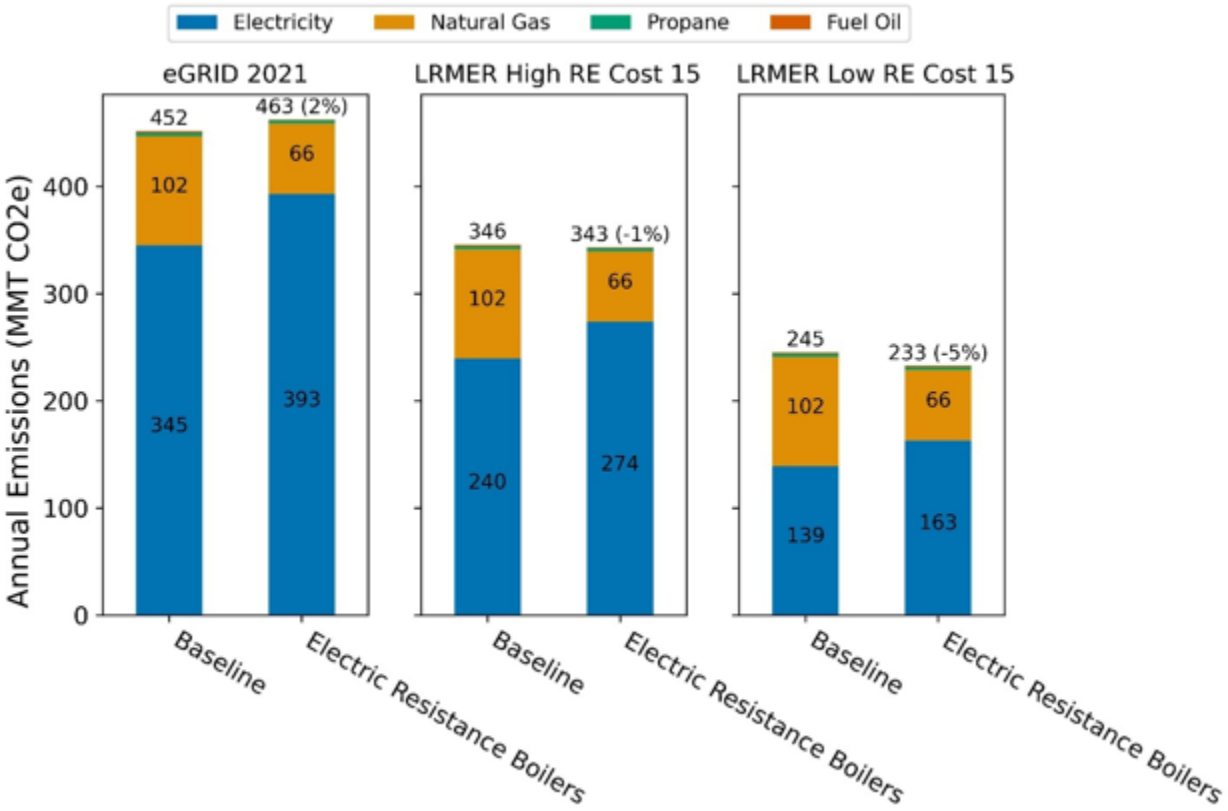

Figure 8. Emissions comparison of the ComStock baseline and the electric boiler scenario.

Three electricity grid scenarios are presented: Cambium LRMER High RE Cost 15-Year, Cambium LRMER Low RE Cost 15-Year, and eGRID. MMT stands for million metric tons.

5.5 Site Energy Savings Distributions

This section discusses site energy consumption for quality assurance/quality control purposes. Site energy savings can be useful for these purposes, but other factors should be considered when drawing conclusions, as they do not necessarily translate proportionally to source energy savings, CO_2e avoided, or energy costs.

Figure 9 shows the percent savings distributions of the baseline ComStock models versus the electric boiler measure by end use and fuel type for applicable models. In other words, each data point in the distribution represents the percent energy savings between a baseline ComStock model and the corresponding model with measures applied.

As expected, the only end uses and fuel type combinations that see a substantial percent change in energy use are other fuel heating, natural gas heating, and electricity heating. Both natural gas heating and other fuel heating show 100% savings in applicable buildings, indicating that the full space heating load in applicable buildings was converted to electricity. As a result, applicable buildings see a large increase in electric heating, anywhere from 10%–70% in the middle 50% of buildings. Note that the only buildings that are shown on this plot with changes to electricity

heating are ones that started out with some electric heating in the baseline. Some building types have multiple types of heating in the baseline—for example, an office can be primarily heated by a boiler system, but the vestibule space has electric baseboard heaters. Buildings that started out with no electric heating would have an infinite increase in electric heating and therefore cannot be displayed on this plot.

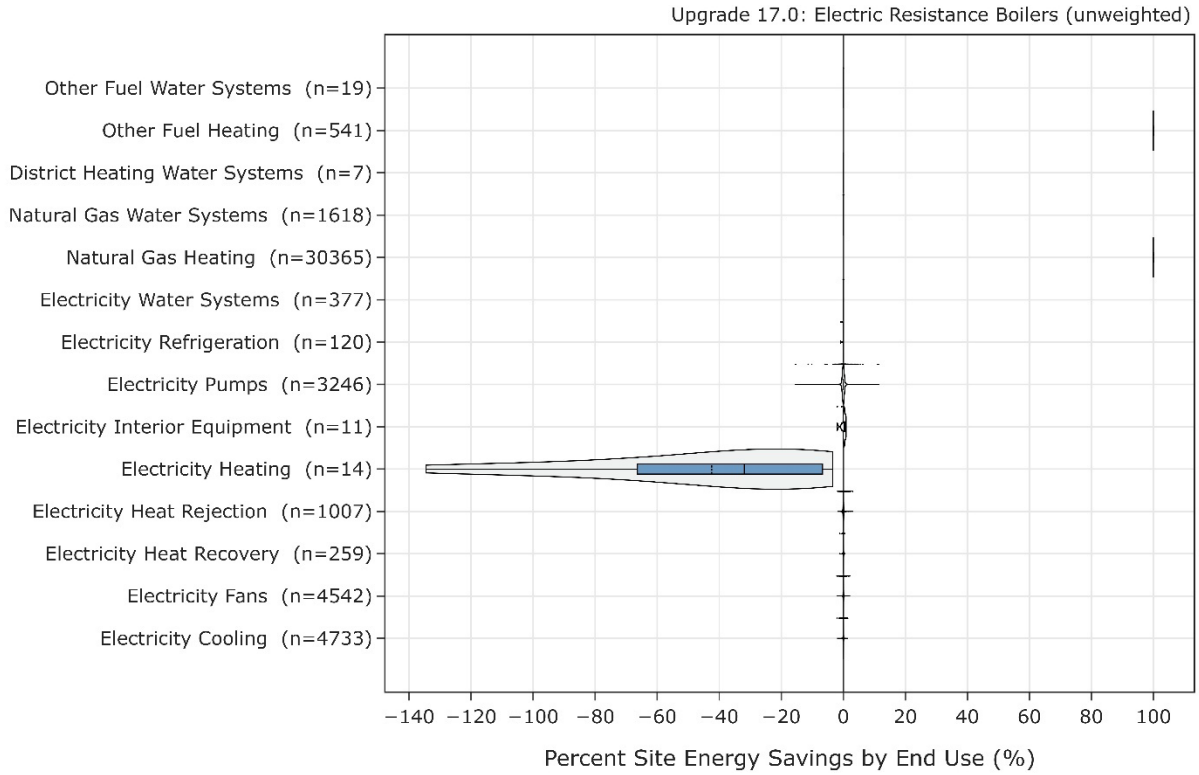

Figure 9. Percent site energy savings distribution for ComStock models with applied measure scenario by end use and fuel type.

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

5.6 Utility Bill Savings Distributions

Figure 9 and Figure 11 show the percent utility bill savings distributions of the baseline ComStock models versus the electric boiler measure by fuel type and climate zone, respectively, for applicable models. In other words, each data point in the distribution represents the percent utility bill savings between a baseline ComStock model and the corresponding model with measures applied.

When evaluating utility bill savings by fuel type, we see that natural gas and fuel oil bills show 70%–100% bill savings in most buildings, a result of converting the space heating load in applicable buildings to electricity. Electricity bills increase by 1,570% in the middle 50% of buildings when using the mean electricity rate. The total utility bill also sees negative savings (increased bills) of up to 30% for the middle 50% of buildings. This indicates that the increase in

electricity bills outweighs the gas and fuel oil bill savings in most buildings. Approximately 25% of buildings (the right whisker) show total utility bill *savings*.

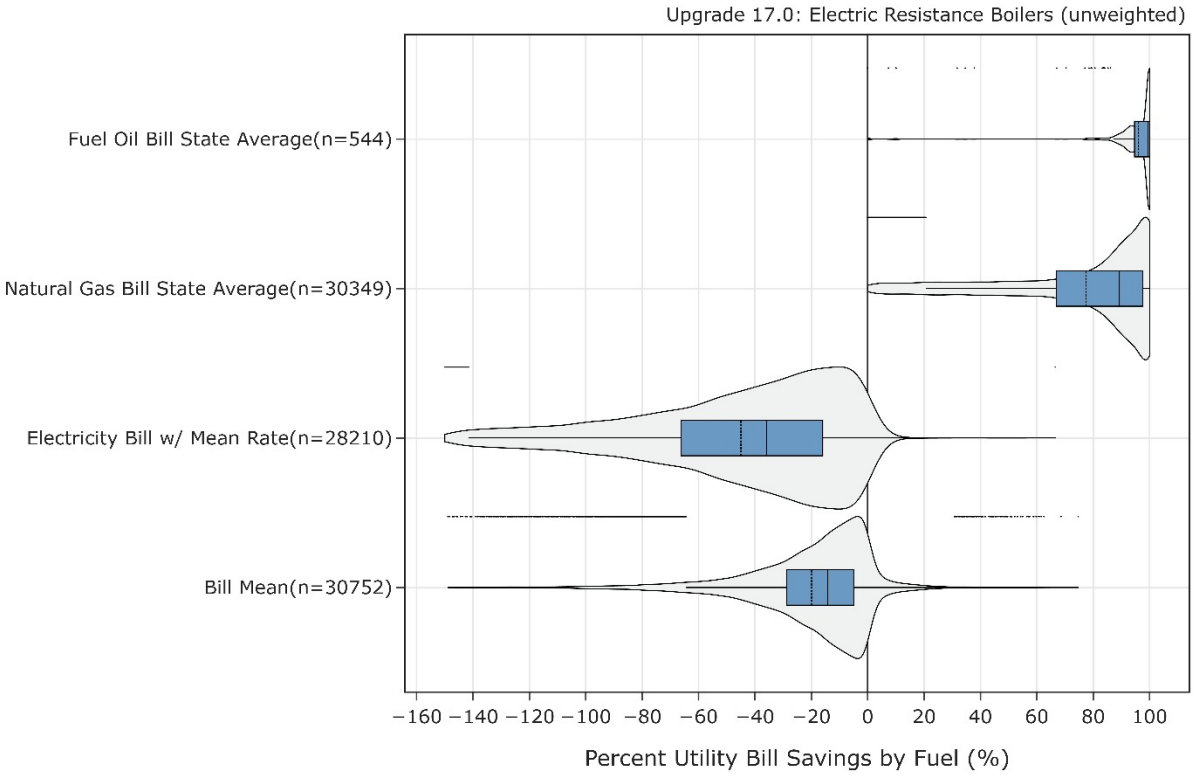

Figure 10. Percent utility bills savings distribution by fuel type for ComStock models with the electric boiler measure applied

When evaluating the utility bills savings distributions by climate zone, there is a clear correlation between the total utility bills savings and the climate zone. In most climate zones, most buildings will have negative utility bill savings (an increase in their total utility bill) by switching to electric boilers from natural gas or fuel oil. Again, this is a result of current electricity prices being more expensive than natural gas in many locations around the country. In addition, electric resistance heating can result in new demand charges for peak demand-based utility rates. These increases in both electricity energy and peak demand are more pronounced in heating-dominated climates. As we move from warmer climates to colder climates, the increase in utility bills gets larger because the new electric heating load represents a larger portion of a building's total utility bill. In the coldest climates (7 and 8), the median utility bill increases by 45%–65%. In the warmest climates (1 through 3), the median utility bill increases by 0–15%.

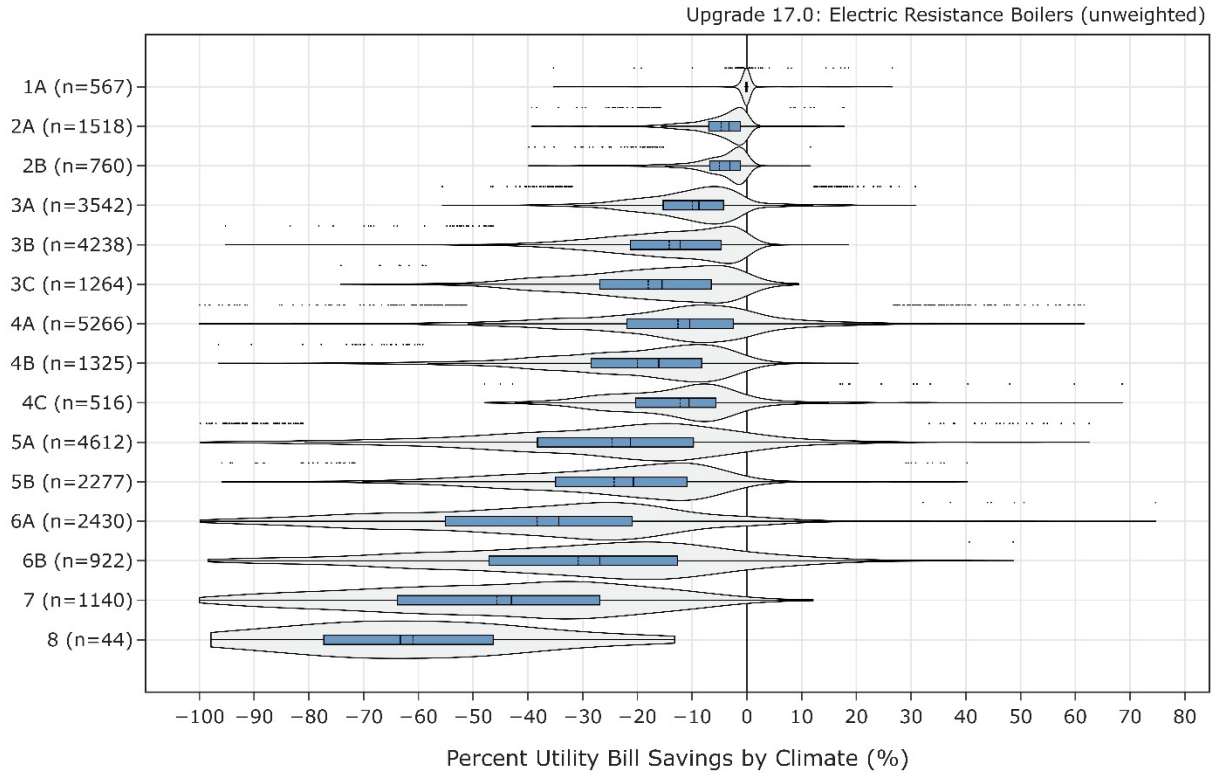

Figure 11. Percent utility bills savings distribution by climate zone for ComStock models with the electric boiler measure applied

5.7 Additional Figures—Electric Boiler vs. Heat Pump Boiler

This section compares some of the key results for the electric boiler measure and heat pump boiler measure. This will demonstrate how the electric boiler measure, a basic electric retrofit option for buildings with boilers, performs compared to a high-efficiency electric heat pump in terms of energy, utility bill, and emissions impacts. The heat pump boiler scenario chosen for comparison has electric backup heat, but there are other variations of this measure in the full dataset. Figure 12 shows the annual site energy by end use and fuel type for the full stock (left) and applicable buildings only (right) for the baseline, heat pump boiler scenario, and electric boiler scenario. The electric boiler measure shows 3% site energy savings for the full stock and 9% for buildings that received the measure. The heat pump boiler shows 8% site energy savings for the full stock and 24% for buildings that received the measure. Although results for individual buildings can vary, on aggregate, the heat pump boiler will show two to three times greater energy savings than the electric boiler. This is consistent with the difference in the coefficient of performance between a heat pump and electric resistance heating.

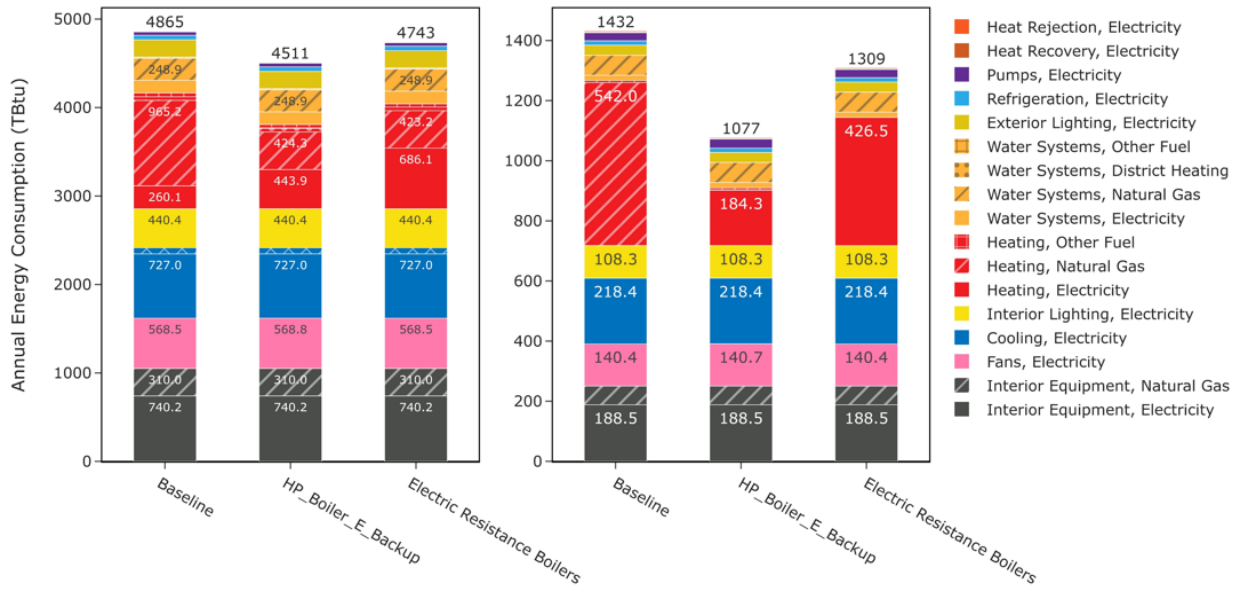

Figure 12. Comparison of annual site energy consumption between the ComStock baseline, heat pump boiler, and electric boiler measure scenarios for the full stock (left) and applicable buildings only (right).

Energy consumption is categorized both by fuel type and end use.

Figure 13 shows the stock-level annual utility bills by fuel type for the baseline, heat pump boiler, and electric boiler measure scenarios. The annual bills using the maximum, mean, and minimum electricity rates are shown. In all scenarios, the electric boiler measure increases the total utility bills across the stock by 4%–6%. The heat pump boiler results in less than 1% change in total utility bills. These results demonstrate that fuel switching from natural gas heating to electric resistance is likely to result in increased utility bills with the current rate structures; however, by switching to a heat pump boiler with higher efficiency heating, the utility bill impacts are minimal at the stock level.

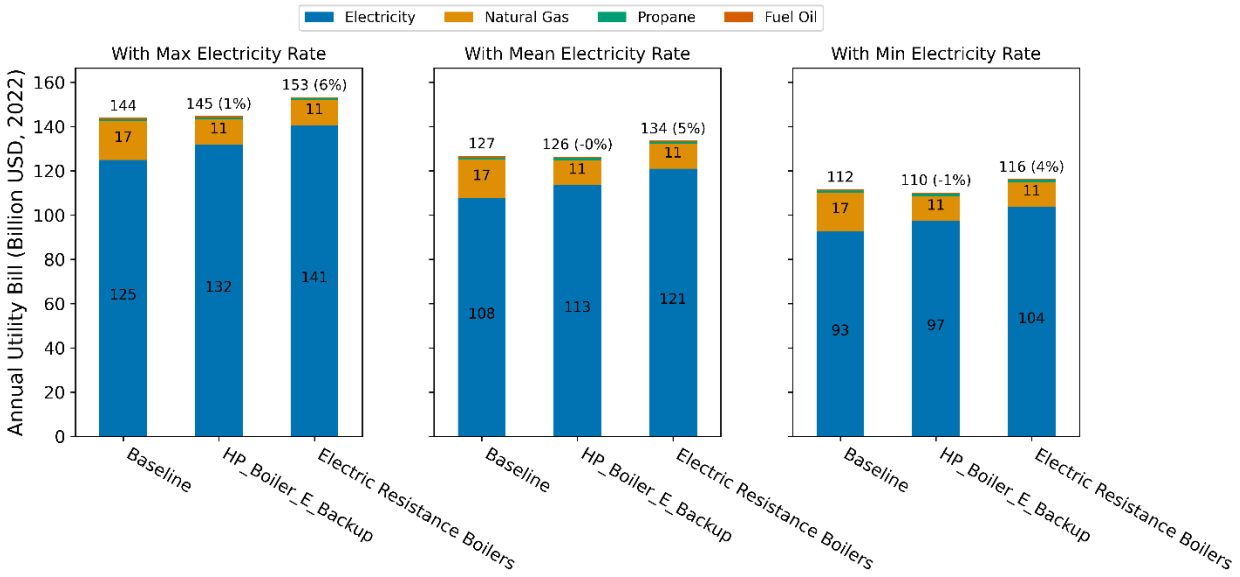

Figure 13. National annual utility bills comparison of the ComStock baseline, heat pump boiler, and electric boiler measure scenarios

Figure 14 shows the stock-level annual emissions by fuel type for the baseline, heat pump boiler scenario, and electric boiler scenario. In the eGRID 2021 scenario (the grid as of 2021), the electric boiler measure shows a 2% increase in total emissions, and the heat pump boiler shows a 3% reduction in emissions. In the LRMER scenarios (the projected grid in 15 years), the electric boiler measure shows a 1%–5% reduction in total emissions, and the heat pump boiler shows a 6%–10% reduction. Natural gas emissions are reduced by the same amount in both scenarios because both measures involve fuel switching of the full gas heating load in applicable buildings. Electricity emissions increase in both scenarios for this same reason; however, the heat pump boiler has a much higher efficiency heating, and therefore the increase in electricity emissions is lower than that of the electric boiler scenario.

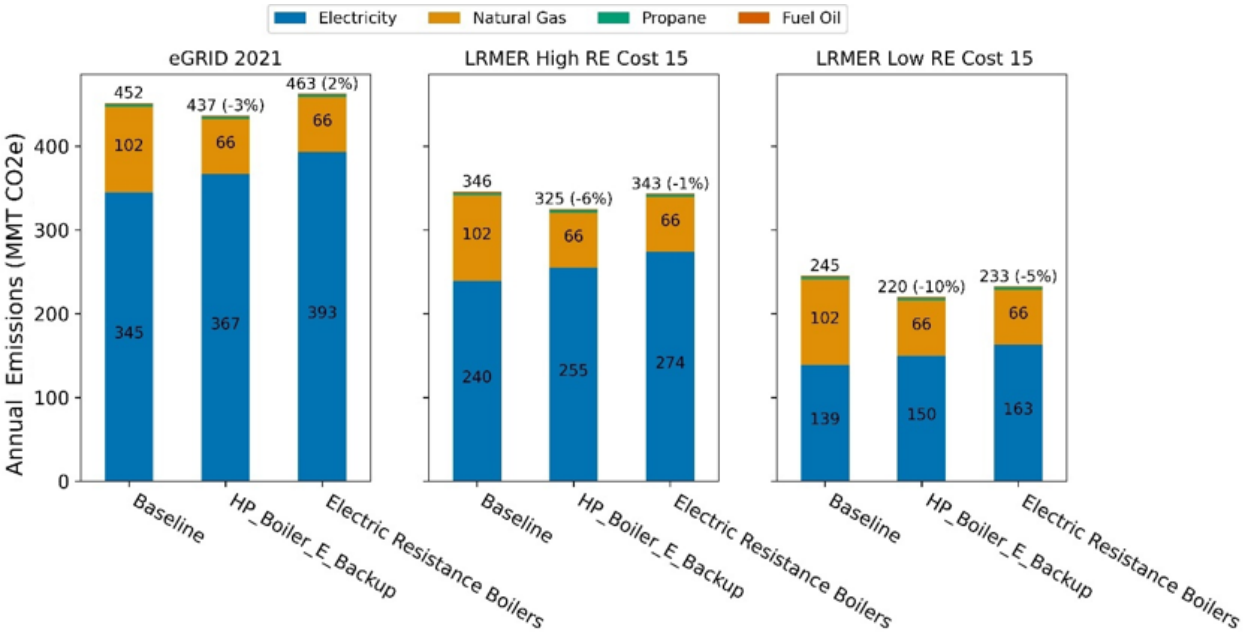

Figure 14. Emissions comparison of the ComStock baseline, heat pump boiler, and electric boiler measure scenarios.

Three electricity grid scenarios are presented: Cambium LRMER High RE Cost 15-Year, Cambium LRMER Low RE Cost 15-Year, and eGRID. MMT stands for million metric tons.

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