End-Use Savings Shapes Measure Documentation: Electric Cooking Equipment

Marlena Praprost

National Renewable Energy Laboratory

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Technical Report
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Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

List of Acronyms

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	British thermal units
CBECS	Commercial Buildings Energy Consumption Survey
CEUS	California Commercial End-Use Survey
CO_2e	carbon dioxide equivalent
DOE	U.S. Department of Energy
eGRID	Emissions & Generation Resource Integrated Database
FSTC	Food Service Technology Center
HVAC	heating, ventilating, and air conditioning
LRMER	Long-Run Marginal Emissions Rate
MMT	million metric tons
PG&E	Pacific Gas and Electric Company
RE	Renewable Energy
TBtu	trillion British thermal units
W	watts

Executive Summary

Building on the successfully completed effort to calibrate and validate the U.S. Department of Energy's ResStock™ and ComStock™ models over the past three years, the objective of this work is to produce national datasets that empower analysts working for federal, state, utility, city, and manufacturer stakeholders to answer a broad range of analysis questions.

The goal of this work is to develop energy efficiency, electrification, and demand flexibility end-use load shapes (electricity, gas, propane, or fuel oil) that cover most of the high-impact, market-ready (or nearly market-ready) measures. "Measures" refers to energy efficiency variables that can be applied to buildings during modeling.

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

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 sub-hourly 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.

This documentation focuses on a single end-use savings shape measure—Electric Cooking Equipment. This measure replaces gas-fired commercial cooking equipment with electric equipment where applicable. The cooking appliances modified in this measure include broilers, fryers, griddles, ovens, ranges, and steamers. The scope of this study does not include commercial dishwashing equipment. This measure only affects ComStock building types with kitchens. This includes hospitals, large hotels, schools, strip malls, and restaurants.

This measure was applicable to 37.5% of the ComStock floor area. This measure demonstrates 2.0% total site energy savings (86 TBtu) for the U.S. commercial building stock modeled in ComStock (Figure 10). The savings are primarily attributed to:

- **88.2%** stock **interior equipment, natural gas** savings (187.0 TBtu)
- **−14.1%** stock **interior equipment, electricity** savings (−104.1 TBtu)
- **−0.2%** stock **natural gas heating** savings (−1.7 TBtu)
- **0.6%** stock **cooling electricity** savings (4.1 TBtu).

Three electricity grid scenarios are presented to compare the emissions of the ComStock baseline and the Electric Cooking Equipment upgrade. 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 data set, and the last uses the Emissions & Generation Resource Integrated Database (eGRID) data set [1], [2]. Across the three electricity grid scenarios presented, electricity emissions increased by 2.6-3.5% (4–11 MMT CO_2e), while natural gas emissions dropped by 14.8% (12 MMT CO_2e), resulting in an overall greenhouse gas emissions reduction across all fuel types of 0.5-3.3% depending on grid scenarios.

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Electric Cooking Equipment

Accessing Results

This documentation covers the Electric Cooking Equipment upgrade methodology and briefly discusses key results. Results can be accessed via the ComStock™ Published Datasets page.

Measure Summary

Measure Title	Electric Cooking Equipment
Measure Definition	This measure replaces gas commercial cooking equipment with electric equipment where applicable. The specific equipment types modeled include broilers, fryers, griddles, ovens, ranges, and steamers.
Applicability	This measure is applicable to models with kitchen space types, which include hospitals, large hotels, primary schools, secondary schools, strip malls, quick service restaurants, and full-service restaurants. This measure is applicable to 37.5% of the ComStock floor area.
Not Applicable	This measure is not applicable to models that do not have kitchen space types or models that already have fully electric kitchens.
Release	2024 Release 1: 2024/comstock_amy2018_release_1/

1 Technology Summary

Cooking equipment in commercial buildings can consume high amounts of energy and contribute substantial heat gain to spaces. The California Commercial End-Use Survey (CEUS) estimates that cooking equipment consumes 23% of natural gas consumption and 4% of electricity consumption in commercial buildings [3]. The Commercial Buildings Energy Consumption Survey (CBECS) estimates that cooking equipment consumes 517 trillion British thermal units (TBtu) annually or 7% of total commercial building energy consumption [4].

Some of the most common types of primary commercial cooking equipment are broilers, fryers, griddles, ovens, ranges, and steamers. All these equipment types have gas-fired or electric options. Gas-fired cooking equipment has historically been more common in commercial kitchens due to cooking preferences, cost advantages, and availability of products. However, in recent years, electric cooking equipment has gained more interest, sparked by concerns over the health and safety of gas equipment, combined with a push toward electrification and decarbonization. Beyond safety and electrification benefits, electric cooking equipment keeps kitchens cooler and allows for more flexible layouts by eliminating gas lines [5].

This measure replaces existing gas-fired cooking equipment with electric equivalents. Each of the types of cooking equipment listed above are modeled separately in the model using a design level in Watts derived from several sources, primarily the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Fundamentals Handbook [6]. Gas equipment specifications, which are typically listed in British thermal units (Btu)/hour, are converted to watts (W) in the model. The baseline contains probability distributions of gas and electric cooking equipment, based on market share estimates for each type of the six types of modeled equipment [7]. In addition to the design level in Watts, equipment loads are defined by their fractions of radiant, latent, and lost energy. Gas and electric cooking equipment operate differently and have their own advantages and disadvantages in the way they heat food. Therefore, the amount of and type of excess heat produced will change when switching from gas to electric equipment. This measure will find all gas cooking equipment in the baseline and upgrade it to its electric counterpart in applicable kitchen space types. The change in power may impact internal gains, and therefore heating and cooling energy, in addition to the equipment end use.

1.1 Literature Review

A literature review was performed to determine the rated input power and fractions of radiant, latent, and lost energy for gas and electric models for each of the six types of cooking equipment. In addition, this section outlines the sources used to determine the prevalence of gas and electric equipment for each of the six appliances modeled.

1.1.1 Rated Input Power

The rated input power of a piece of equipment refers to the maximum power drawn from the appliance as specified by the manufacturer. This is different from the rated output, which is the maximum power delivered by the appliance after its efficiency is considered. Because gas-fired equipment has combustion losses, the efficiencies are lower and therefore typically require a larger input power to deliver the same output power as a similar electric model. A variety of sources were used to find typical rated input values for comparable gas and electric equipment. These values were then compared to actual equipment on the market to verify that the rated input assumptions were reasonable. Some ENERGY STAR® appliances list cooking efficiencies as part of their product specifications, so these were used as an additional check when available. The sections below walk through this process for each of the six types of cooking equipment.

1.1.1.1 Broilers

There are several types of commercial broilers, including underfired, overfired, and salamander. According to a U.S. Department of Energy (DOE) study, underfired broilers (pictured in Figure 1) are the most common and versatile type [8]; therefore, we will assume this type of broiler in our modeling.

Figure 1. Typical commercial underfired broiler [8]

Table 1 summarizes the rated input power for gas and electric broilers, as defined by four sources: a 2015 DOE study [8], 2002 Food Service Technology Center (FSTC) Appliance Technology Assessments [9], the 2017 ASHRAE Fundamentals Handbook [6], and results from a 1993 Pacific Gas and Electric Company (PG&E) production test kitchen [7]. It is important to note that the FSTC 2002 study and ASHRAE Fundamentals 2017 define these rated input values specifically for underfired broilers, while the other two sources do not specify the type of broiler. All rated input power values are shown in Btu/h so that the gas and electric values can be compared more easily.

Table 1. Comparison of Broiler Rated Input Power from Four Sources

Source	Gas (Btu/h)	Electric (Btu/h)
2015 DOE Report [8]	88,000	37,534
FSTC 2002 [9]	90,000–120,000	21,000–46,000
ASHRAE 2017 [6]	96,000	36,900
PG&E Production Test Kitchen [7]	105,000	37,500

As can be seen, all four sources generally align in their rated input power assumptions for gas and electric underfired broilers. To verify that these values were reasonable, an online search was done on a variety of commercial restaurant equipment websites. The image above, taken from the DOE study, was used as a baseline when searching for products, because there is a large range of sizes and models available. Table 2 summarizes several comparable gas and electric products available on the market, and their associated rated input power values.

Table 2. Specifications for Commercially Available Gas and Electric Broilers [10] [11]

Image [10]	 Vulcan VBB1BF-NAT Natural Gas Upright Ceramic Broiler	 Vulcan VBB1CF-NAT Natural Gas Upright Ceramic Broiler
Fuel	Gas	Gas
Rated Input (Btu/h)	100,500	132,500
Image [11]	 **Southbend E-170** 12 kW Freestanding Electric Single Deck Broiler	 **Southbend E-171** 12 kW Freestanding Electric Single Deck Broiler w/ Warming Oven
Fuel	Electric	Electric
Rated Input (kW)	12	12
Rated Input (Btu/h)	40,945	40,945

Again, the commercially available products aligned with the rated input power from the studies. The rated input values from ASHRAE 2017 were chosen for the model because it is a reputable source, is the most recent source from our comparison, and contained values specific for underfired broilers, all of which add credibility and consistency to the modeling approach. Therefore, the final rated input power values for gas and electric broilers are 96,000 and 36,900 Btu/h, respectively.

1.1.1.2 Fryers

There are several types of commercial fryers, namely floor-mounted (also called “open deep-fat”), countertop, and pressure fryers. Floor-mounted fryers are the most common type [12], in which baskets of food are submerged into a vat of hot oil. The oil can be heated by either fire tubes (gas-fired) or resistance heaters (electric), as pictured below.

Figure 2. Typical commercial open deep-fat fryer [8]

Table 3 details the rated input power for gas and electric fryers from four sources. Once again, only the FSTC and ASHRAE sources specifically refer to floor-mounted deep-fat fryers; the others do not specify the type of fryer.

Table 3. Comparison of Fryer Rated Input Power from Four Sources

Source	Gas (Btu/h)	Electric (Btu/h)
2015 DOE Report [8]	164,000	75,067
FSTC 2002* [9]	40,000–60,000	80,000–120,000
ASHRAE 2017 [6]	80,000	47,800
PG&E Production Test Kitchen [7]	80,000–85,000	58,000

*It is suspected that this study flipped the gas and electric rate input values, as the gas rated input being significantly lower than electric contradicts all other studies found and products available. Fryer data from this source will be disregarded for this reason.

There is some discrepancy in the rated input for fryers, with the DOE source reporting much higher numbers than ASHRAE and the PG&E study. We researched commercially available floor-mounted fryers to determine which data source to use for fryer rated input power. Some gas and electric fryers and their specifications are shown in Table 4.

Table 4. Specifications for Commercially Available Gas and Electric Fryers [13]

Image	 MoTak MGF3-N-C Gas Fryer - (1) 40 lb Vat, Floor Model, Natural Gas	 MoTak MGF4-N-C Gas Fryer - (1) 50 lb Vat, Floor Model, Natural Gas
Fuel	Gas	Gas
Rated Input (Btu/h)	90,000	120,000
Image	 Dean SR114E Electric Fryer - (1) 40 lb. Vat, Floor Model, 240v/1ph	 Imperial IFS-50-E Electric Fryer - (1) 50 lb Vat, Floor Model, 208v/3ph
Fuel	Electric	Electric
Rated Input (kW)	14	15.25
Rated Input (Btu/h)	47,800	52,000

Commercial fryer vats typically range from 15–80 pounds. The fryers shown above are for 40- and 50-pound vats. Without data to inform what size is most common, we will assume our model represents a 40-pound floor-mounted fryer. We once again selected the ASHRAE 2017 rated input power values for our model, as this source is credible, recent, and aligns with commercially available products. Therefore, the rated input power values we model for gas and electric fryers are 80,000 and 47,800 Btu/h, respectively.

The ENERGY STAR Product Finder [14] contains product specifications for commercial fryers that list cooking efficiency for various gas and electric fryers. Five products of each fuel type were selected, and the average cooking efficiencies were calculated. For gas fryers, the average efficiency was 59%, whereas for electric, the average efficiency was 86%. This means that electric fryers are about 45% more efficient on average than gas fryers. The rated input values we selected of 80,000 Btu/h for gas and 47,800 Btu/h for electric represent an electric fryer that is 40% more efficient than its gas counterpart. This efficiency difference aligns closely with the ENERGY STAR products, further validating that our rated power assumptions are reasonable.

1.1.1.3 Griddles

The two main types of griddles are standard griddles (flat, one-sided plate) and double-sided griddles (like a panini press). Standard griddles, as the name suggests, are more common and will be assumed for modeling.

Figure 3. Typical commercial one-sided standard griddle [8]

Table 5 shows the same four sources used previously and their assumptions for rated input power for gas and electric griddles. ASHRAE specifies that their values represent a flat, 3-foot griddle, but we can safely assume that all of them refer to standard, flat griddles.

Table 5. Comparison of Griddle Rated Input Power from Four Sources

Source	Gas (Btu/h)	Electric (Btu/h)
2015 DOE Report [8]	70,000	40,946
FSTC 2002 [9]	40,000–80,000	25,000–60,000
ASHRAE 2017 [6]	90,000	58,400
PG&E Production Test Kitchen [7]	60,000	42,000

All sources are generally in the same range for gas and electric power. To verify, Table 6 shows some commercially available standard griddles for comparison.

Table 6. Specifications of Commercially Available Gas and Electric Griddles [10]

Image		
Fuel	Gas	Gas
Rated Input (Btu/h)	90,000	120,000
Image		
Fuel	Electric	Electric
Rated Input (kW)	16.2	12
Rated Input (Btu/h)	55,200	41,000

The power levels of the griddles shown above align with our sources. The rated input values for the two 36-inch models match very closely to ASHRAE, so we can once again feel confident and use the rated input values from ASHRAE as our assumptions in the model. Therefore, our gas and electric griddles are modeled as 90,000 Btu/h and 58,400 Btu/h, respectively.

The ENERGY STAR Product Finder [14] does not report cooking efficiency for griddles, but it does give idle energy use per square foot. Three products for each fuel type were selected, and the average idle energy per square foot was calculated. For gas, the average was 2492 Btu/h/ft^2, and for electric, the average was 869 Btu/h/ft^2, meaning the idle conditions of the electric griddle are 65% more efficient than the gas griddle. The rated power values selected of 90,000 Btu/h and 58,400 Btu/h represent an electric griddle that is 35% more efficient than its gas counterpart, based on their rated conditions. This is a more conservative assumption than the ENERGY

STAR idle power/ft^2 values suggest, but the ENERGY STAR products do not report rated power conditions. Therefore, it is difficult to conclude whether the rated power and idle power efficiency differences can be extrapolated. Without additional data to compare, we will leave our rated power assumptions as is.

1.1.1.4 Ovens

Ovens are one of the most versatile types of cooking appliances, and therefore one of the most widely used. There are many types of ovens that utilize different types of heat transfer, including convection, deck, combination, rack/rotating rack, cook-and-hold, and conveyor ovens. For the sake of ComStock modeling, our modeling assumes full-size convection ovens (pictured below), which are common in commercial kitchens.

Figure 4. Typical commercial full-size convection oven [8]

Table 7 gives rated input power estimates for commercial ovens from four sources. Only the ASHRAE and FSTC sources specify that these numbers represent a convection oven.

Table 7. Comparison of Oven Rated Input Power from Four Sources

Source	Gas (Btu/h)	Electric (Btu/h)
2015 DOE Report [8]	56,000	51,182
FSTC 2002 [9]	20,000–100,000	20,000–136,000
ASHRAE 2017 [6]	44,000	41,300
PG&E Production Test Kitchen [7]	34,500	33,800

Once again, these numbers were compared to several commercially available models of full-size convection ovens, both gas and electric.

Table 8. Specifications of Commercially Available Gas and Electric Ovens [13]

Image	 Blodgett DFG-100 Single Full Size Natural Gas Convection Oven - Base Oven, No Legs, 55,000 BTU	 Southbend BGS/12SC Bronze Single Full Size Natural Gas Convection Oven - 54,000 BTU
Fuel	Gas	Gas
Rated Input (Btu/h)	55,000	54,000
Image	 Vulcan VC4ED Single Full Size Electric Convection Oven - 12.5 kW, 208v/3ph	 Blodgett ZEPH-100-E SGL Zephaire Single Full Size Electric Convection Oven - 11kW, 208v/3ph
Fuel	Electric	Electric
Rated Input (kW)	12.5	11
Rated Input (Btu/h)	42,600	37,500

The power magnitudes of the products available align with the four sources we have. We once again elected to use the ASHRAE values as our final assumptions; therefore, the gas and electric power values used are 44,000 Btu/h and 41,300 Btu/h, respectively.

Five gas and electric convection ovens from the ENERGY STAR Product Finder [14] were selected, and the average cooking efficiencies were calculated. For gas ovens, the average efficiency was 55%, whereas for electric, the average efficiency was 78%. The rated power values we selected based on ASHRAE were closer together than this (only 6% efficiency improvement); however, we felt more comfortable assuming a more conservative efficiency improvement when swapping out gas ovens with electric. In addition, the four sources from Table 7 suggest that there is not a significant difference in the rated power of gas and electric ovens; therefore, we kept our assumptions as is to avoid overestimation of modeled savings.

1.1.1.5 Ranges

Ranges are a standard appliance in most commercial kitchens. Commercial ranges typically have six burners, as shown below. Most ranges also contain an oven or warming shelf below the cooktop, which also contributes to the energy consumption of the appliance.

Figure 5. Typical commercial range [8]

Historically, gas ranges have been the standard if gas service is available to the building. However, innovations in electric-powered ranges have resulted in increased adoption of electric alternatives. Induction ranges are a fairly new technology that increase efficiency, safety, and heat gains in a kitchen space. Induction ranges use copper coils that create a magnetic current when a ferrous metal pot or pan is placed on the cooktop, heating the cookware directly and reducing losses. [15] This also means that the range is only drawing power and emitting heat when a metal pot or pan is on the cooktop, which reduces unnecessary energy consumption and lowers the risk of fires. For this measure, we intend to model induction cooktops as the electric option for ranges. We believe that if commercial kitchens are going to invest money in electrifying their appliances, they would elect for an induction range for the reasons listed above, as opposed to a standard electric range.

Table 9 shows the same four sources and their estimates for rated input power for gas and electric ranges. For the gas equipment, ASHRAE has several different options for rated input, defined by how many of the burners are on at one time and whether the oven is on. We have opted to use the power value corresponding to “six burners on, oven on,” as this represents the maximum potential operation of the range.

Table 9. Comparison of Range Rated Input Power from Four Sources

Source	Gas (Btu/h)	Electric (Btu/h)
2015 DOE Report [8]	179,000	40,946
FSTC 2002 [9]	120,000–150,000	40,800
ASHRAE 2017 [6]	145,000	71,700*
PG&E Production Test Kitchen [7]	155,000	63,800

*ASHRAE is the only source in this table that differentiates between induction and electric resistance ranges, and the induction range rated power was used above. The other sources are assumed to be electric resistance ranges.

ASHRAE is the only source that provides values for induction ranges specifically. For this reason, we are inclined to use ASHRAE values, but have again done our due diligence by checking the specifications for commercially available products.

Table 10. Specifications of Commercially Availably Gas and Electric Induction Ranges

Image [10]		
Fuel	Gas	Gas
Rated Input (Btu/h)	180,000	180,000
Image [16]		
Fuel	Electric Induction	Electric Induction
Rated Input (kW)	21	21.6
Rated Input (Btu/h)	71,700	73,700

We have decided to use the ASHRAE values for our assumptions, as ASHRAE is the only source with values for induction ranges, and the values match very closely to the products on the market. Therefore, the gas and electric range rated input power values used in the model are 145,000 Btu/h and 71,700 Btu/h, respectively.

1.1.1.6 Steamers

The last type of cooking equipment modeled in ComStock is commercial steamers. There are two main types of steamers: atmospheric (pressure-less) steamers and pressure steamers.

Atmospheric steamers can cook larger volumes of food and therefore may be more suitable for commercial kitchens, so this is what our model assumes.

Figure 6. Typical commercial atmospheric steamer [8]

Table 11 shows the rated input assumptions from the four sources. Notably, the ASHRAE values are substantially lower than the other three sources, which has not been the case with any other appliances.

Table 11. Comparison of Steamer Rated Input Power from Four Sources

Source	Gas (Btu/h)	Electric (Btu/h)
2015 DOE Report [8]	210,000	81,891
FSTC 2002 [9]	170,000–250,000	61,000–123,000
ASHRAE 2017 [6]	26,000	33,400
PG&E Production Test Kitchen [7]	200,000	92,000

We researched commercial atmospheric steamers to determine if the power values were more aligned with ASHRAE or the other three sources.

Table 12. Specifications of Commercially Available Gas and Electric Steamers [10]

Image		
Fuel	Gas	Gas
Rated Input (Btu/h)	200,000	240,000
Image		
Fuel	Electric	Electric
Rated Input (kW)	24	32
Rated Input (Btu/h)	81,900	109,000

Based on the commercially available products we found, the rated input power values align much more closely with the DOE, FSTC, and PG&E sources than with ASHRAE. We concluded that the ASHRAE Fundamentals source must be assuming a much smaller steamer model or a different type of steamer product, because the values are several times lower than the other three sources. Therefore, we have chosen for this appliance to use the PG&E source as the basis for our rated power assumptions. While the DOE and PG&E values were close in magnitude, the PG&E values assumed a more conservative efficiency improvement from gas to electric, so we selected this one to avoid overestimating savings in our results. Therefore, the gas and electric steamer rated input power values are assumed to be 200,000 Btu/h and 92,000 Btu/h, respectively.

The ENERGY STAR Product Finder [14] contains product specifications for commercial steamers that list cooking efficiency for various gas and electric steamers. Five products of each fuel type were selected, and the average cooking efficiencies were calculated. For gas steamers, the average efficiency was 46%, whereas for electric, the average efficiency was 68%. This means that electric steamers are about 54% more efficient on average compared to gas steamers. The rated input values we selected—200,000 Btu/h for gas and 92,000 Btu/h for electric—represent an electric steamer that is 48% more efficient than its gas counterpart. This efficiency difference aligns closely with the ENERGY STAR products, further validating that our rated power assumptions are reasonable. Once again, we feel comfortable using the slightly more conservative efficiency assumption to avoid overestimating savings.

1.1.2 Gas and Electric Prevalence

We assume that the baseline model already has some prevalence of electric cooking equipment. To determine the breakdown, we used percentages from a 2015 DOE study [8]. This study used data from a 1993 study called "Characterization of Commercial Appliances," which estimated market saturation of gas and electric cooking equipment. These numbers were then extrapolated to the present day using scaling factors based on CBECS and other sources. While these numbers may not be perfect, in the absence of a more recent study on the prevalence of gas and electric cooking equipment, we use the assumptions from Table 13.

Table 13. Prevalence of Gas and Electric Equipment by Appliance [8]

Appliance	Total Installed Base (thousands)	Gas Installed Base (thousands)	Electric Installed Base (thousands)	Gas Percentage	Electric Percentage
Broilers	380	346	34	91	9
Fryers	1,857	1,077	780	58	42
Griddles	893	447	447	50	50
Ovens	1,604	882	722	55	45
Ranges	725	660	65	91	9
Steamers	272	90	182	33	67

The percentages of gas and electric equipment from Table 13 were incorporated into the ComStock baseline model through ComStock's sampling processes [17]. For each type of equipment, a building is assigned either the gas or electric version of the appliance, and the rated input power and heat gain fractions are assigned in the model. Buildings in the baseline can have a mixture of gas and electric appliances.

In addition to the fuel type, the sampling process also determines the quantity of each appliance, which is based on the building type and kitchen square footage. Section 2 describes how this was done in more detail, and the ComStock Reference Documentation provides the full explanation of this methodology [17].

1.1.3 Fraction Latent, Radiant, and Lost

Gas and electric equipment release heat differently, which affects zone heating and cooling loads. This heat is divided into four fractions that must add up to one: fraction convective, fraction latent, fraction radiant, and fraction lost. As defined by the EnergyPlus® Input Output Reference Documentation [18]:

- Fraction latent: the amount of latent heat given off by electric equipment in a zone
- Fraction radiant: the amount of long-wave radiant heat being given off by electric equipment in a zone
- Fraction lost: the amount of "lost" heat being given off by electric equipment in a zone (in this case, this refers to heat that is vented to the atmosphere through the hood)
- Fraction convective: the amount of heat from electric equipment transferred by convection to the zone air.

The user defines the fractions latent, radiant, and lost in the model, and then the fraction convective can be calculated as follows:

$$FractionConvective = 1 - (FractionLatent + FractionRadiant + FractionLost) \quad (1)$$

ASHRAE Fundamentals defines the fraction radiant, latent, and convective for unhooded equipment, and the fraction radiant for hooded equipment at idle (ready to cook) conditions. The fractions for gas and electric equipment differ and are based on a 2009 study on heat gain rates for commercial kitchen appliances [19]. Latent and convective fractions are not defined by ASHRAE for hooded equipment: "where appliances are installed under an effective hood, only radiant gain adds to the cooling load; convective and latent heat from cooking and combustion products are exhausted and do not enter the kitchen." This may be an optimistic assumption, as it seems unrealistic for the ventilation hood to remove exactly 100% of the latent and convective heat from the space in practice.

ASHRAE categorizes all six types of cooking equipment modeled in ComStock as hooded [6]; therefore, only the radiant fraction is defined. To be conservative, we assume that the latent and convective fractions are 0.1 each, because we do not want to assume perfect removal through the ventilation hood. In addition, an actual kitchen may not have hoods located directly above the heat source for every piece of primary cooking equipment, leading to less-than-optimal performance of the ventilation hood.

With the latent, radiant, and convective fractions determined, we can then calculate the fraction lost, which is a required model input. Table 14 shows the final fractions used for each type of gas and electric equipment.

Table 14. Fraction Latent, Radiant, Convective, and Lost by Appliance

Appliance	Fraction Latent		Fraction Radiant		Fraction Convective		Fraction Lost	
Appliance	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric
Broiler	0.1	0.1	0.12	0.35	0.10	0.10	0.68	0.45
Griddle	0.1	0.1	0.18	0.39	0.10	0.10	0.62	0.41
Fryer	0.1	0.1	0.23	0.36	0.10	0.10	0.57	0.44
Oven	0.1	0.1	0.08	0.22	0.10	0.10	0.72	0.58
Range	0.1	0.1	0.11	0.10	0.10	0.10	0.69	0.7
Steamer	0.1	0.1	0.10	0.10	0.10	0.10	0.7	0.7

Although the radiant fraction for electric equipment is higher than gas, the absolute heat gain to the space when switching to electric is often still lower. This is because the magnitude of the load for the gas equipment is much higher than the electric counterpart. Therefore, when multiplying the power by the fractions of latent, radiant, and convective energy to the space, the gas equipment will still result in more total heat gain to the space in most cases. The fraction lost is the fraction of heat removed from the space, and therefore does not impact zone loads.

2 ComStock Baseline Approach

This measure replaces existing gas-fired cooking equipment in kitchen space types with comparable electric equipment. The measure only applies to building types in ComStock that already have kitchens:

- Hospital
- Large hotel
- Primary school
- Secondary school
- Strip mall
- Quick service restaurant
- Full-service restaurant.

Figure 7 shows the fraction of buildings by type that include various food service types according to CBECS 2012 [4]. This data suggests that medium/large offices and outpatient buildings may have some prevalence of cooking equipment; however, these models do not currently contain "kitchen" space types and are therefore not modeled with cooking equipment. Cooking equipment may be added to these building types in future ComStock work. Note that food service building types in CBECS do not use these metrics, so they show 0%, when in reality they are 100%.

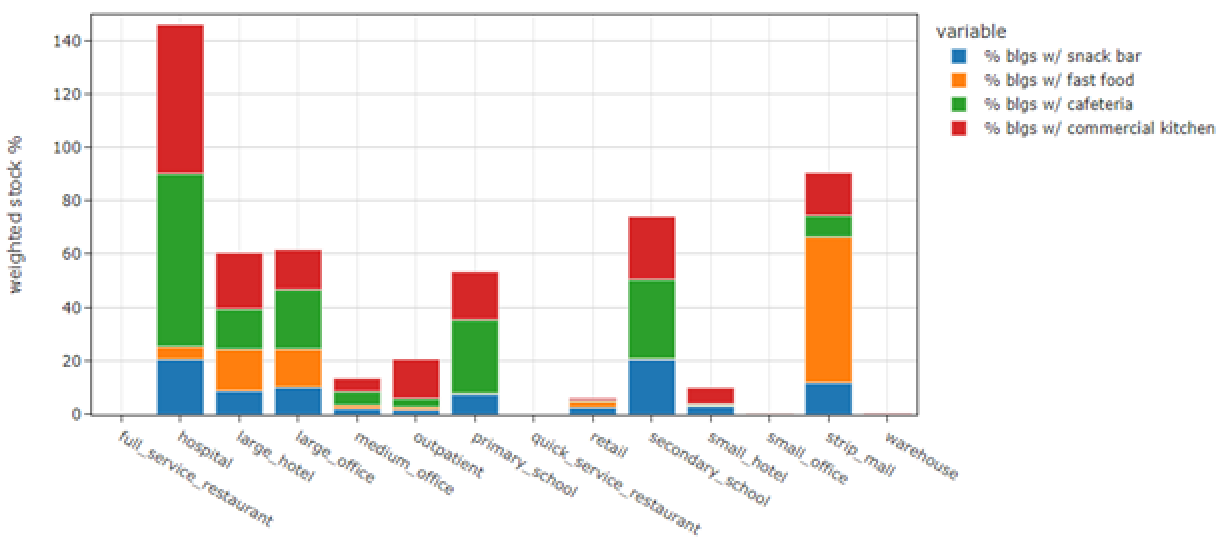

Figure 7. Weighted fraction of stock floor area with food service by building type. Data is from CBECS 2012 [4]. CBECS samples can include more than one food service type, so total stock percentage may exceed 100%.

The ComStock baseline uses building-type-specific probability distributions of commercial cooking equipment. Multiple data sources were used to derive these distributions, which include both gas and electric equipment. The prevalence of gas versus electric fuel types for each equipment type and the rated power for each gas and electric appliance are shown in Table 15, and the derivation of these values was described in Section 1.

Table 15. Gas Versus Electric Prevalence and Rated Power for Each Cooking Appliance

Appliance	% Gas	% Electric	Rated Power - Gas (Btu/h)	Rated Power - Electricity (kW)
Broiler	0.91	0.09	96,000	10.8
Griddles	0.58	0.42	90,000	17.1
Fryers	0.5	0.5	80,000	14.0
Ovens	0.55	0.45	44,000	12.1
Ranges	0.91	0.09	145,000	21.0
Steamers	0.33	0.67	200,000	27.0

The breakdown of equipment types and quantities for each ComStock building type was done using a dataset of equipment counts per restaurant type [7]. While this data source is from 1996, there is limited literature on this topic, and it is not expected that the breakdown of equipment types in a restaurant would have changed drastically over the past few decades. The restaurant types were mapped to ComStock building types, and probability distributions and equipment quantities for each restaurant type were generated for sampling. In addition, the breakdowns of gas versus electric equipment were also added via the sampling process based on the percentages in Table 1.

Figure 8 shows the final sampled breakdowns of equipment type fractions for each restaurant type. Note that the percentages shown in the breakdown represent the percentage of the total *count* of equipment, not the percentage of energy consumed. As can be seen, some restaurant types assume vastly different breakdowns of equipment than others based on what type of food is served in each establishment. In addition, not every restaurant type has all six types of cooking equipment. This methodology adds realistic and data-driven diversity to kitchen space types in ComStock modeling, as opposed to modeling all kitchens in all building types the same way. Scaling factors are added in the ComStock workflow to scale equipment counts based on kitchen floor area. The specific methods and probability distributions used to generate the cooking equipment quantities for each building type are discussed in the ComStock Reference Documentation [17].

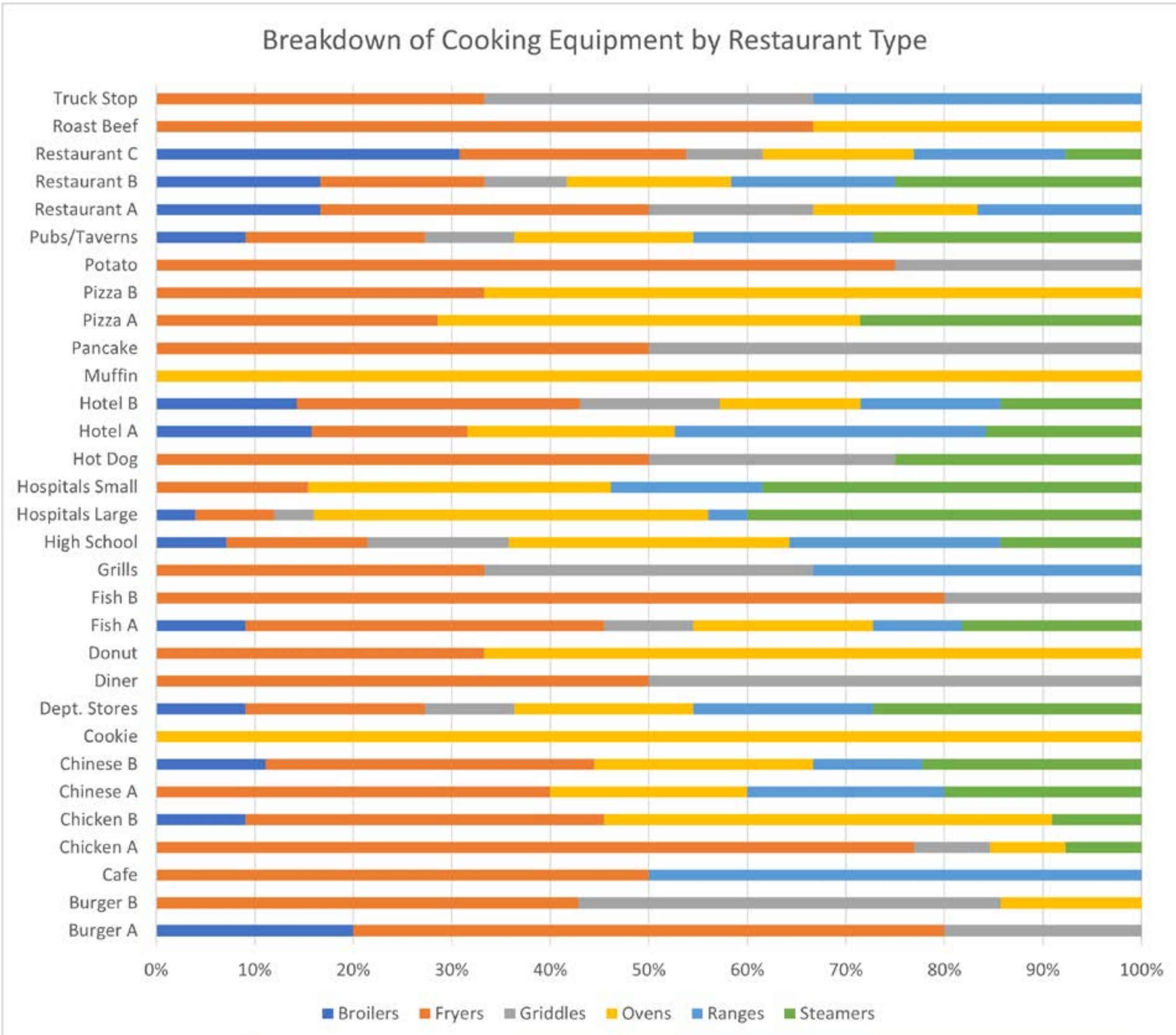

Figure 8. Fraction (by equipment count) of cooking equipment types by restaurant type

The ComStock workflow then uses the equipment quantities and equipment fuels from the sample, and the rated power values from Table 15, to generate equipment objects in the model. Each type of equipment is modeled as its own object using a design level value in watts (gas equipment Btu/h values are converted to W). Note that there are separate object types for gas and electric equipment, but the inputs are the same. The quantity of equipment is included in the name of the object, and the design level is calculated by multiplying the quantity by the rated input power for that appliance from Table 15.

In addition, a "Miscellaneous Electric Kitchen Equipment" object is included in each kitchen space type to account for non-major electrical appliances found in kitchens, such as microwaves, heating lamps, toasters, coffee machines, electric kettles, etc. This miscellaneous load is calculated such that it represents 10% of the total kitchen electric load.

An example screenshot of a gas equipment object from a model is shown in Figure 9. As can be seen, the quantity of the equipment is found in the object name. The design level field represents the rated input power of the appliance multiplied by the quantity. Note that the quantities in the models can be fractional, which is a result of the equipment quantity calculations based on kitchen size.

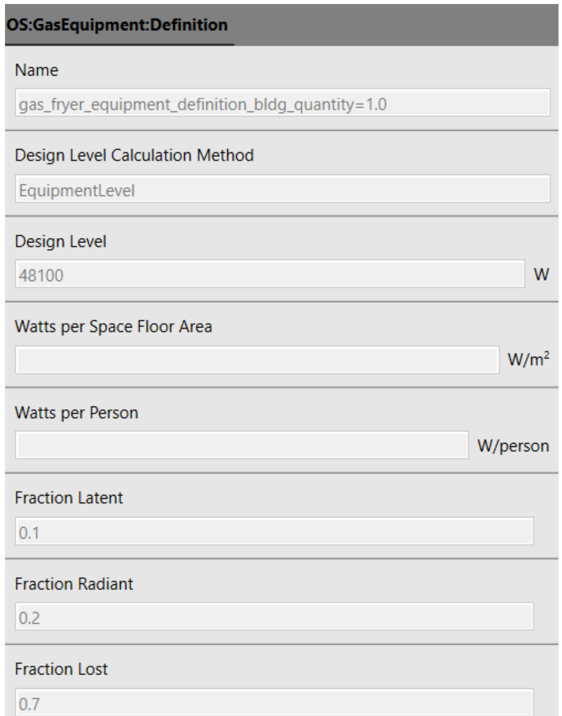

Figure 9. Example of gas equipment object from OpenStudio®

3 Modeling Approach

This measure replaces gas commercial cooking equipment with electric equipment where applicable.

3.1 Applicability

This measure is applicable to models that contain kitchen space types. This includes the following building types:

- Hospital
- Large hotel
- Primary school
- Secondary school
- Strip mall
- Quick service restaurant
- Full-service restaurant.

Buildings with kitchens represent approximately 32% of ComStock by building count and 37% by floor area. A very small fraction (<0.1%) of kitchen space types in ComStock are already all-electric; therefore, the measure will not be applicable to this small subset of buildings. Most kitchens have at least one type of gas-fired cooking equipment in the model.

3.2 Methodology

This measure replaces gas commercial cooking equipment with electric equipment where applicable. More specifically, the measure loops through the space types in the model to find any kitchen space types. If a building does not have a kitchen space type, the measure is deemed not applicable. Next, the measure loops through the equipment objects in the kitchen space types to find gas equipment objects. If none are found, this means the kitchen is already all electric, and the model is deemed not applicable.

There may be up to six gas equipment objects, each representing one of the six types of modeled cooking equipment (broilers, fryers, griddles, ovens, ranges, and steamers). The gas equipment object will contain the quantity of that type of equipment, the total design level (in watts), and fractions of latent, radiant, and lost heat. All gas equipment objects found in the model are replaced with the comparable electric equipment using the rated power values in the rightmost column of Table 16.

Table 16. Equipment Power of Existing Gas Equipment Converted to kW, Compared With Equipment Power of New Electric Equipment

Appliance	Existing Gas Equipment Power		New Electric Equipment Power
	Rated Power (Btu/h)	Rated Power (kW)	Rated Power (kW)
Broiler	96,000	28.1	10.8
Griddles	90,000	26.4	17.1
Fryers	80,000	23.4	14.0
Ovens	44,000	12.9	12.1
Ranges	145,000	42.5	21.0
Steamers	200,000	58.6	27.0

The measure will extract the equipment quantity from the original gas equipment object and use this to calculate the design level for the new electric equipment object. For example, if the original model had a quantity of two fryers, the new object would have a design level of 26,400 * 2 = 52.800 watts (equivalent to two electric fryers). This same methodology is repeated for each of the gas cooking appliances in the baseline model.

In addition to changing the design level, the measure will replace the fractions of latent, radiant, and lost heat with the electric equipment fractions from Table 14. The schedules for the kitchen equipment will not be altered, as we want to represent a direct replacement of equipment with no change to operation. Hence, minor differences in standby operation of gas versus electric equipment are not captured by this measure as schedules remain the same before and after the swap out.

One important note is that this measure does not touch water heating equipment in kitchens. For this reason, the measure is called "Electric Cooking Equipment" as opposed to "All-Electric Kitchens" (or something that implies that the entire kitchen is electricity-powered). There could still be gas-powered water heating equipment in the building after the measure is applied. "All-Electric Kitchens" could be a future measure developed in a later cycle.

In addition, a "Miscellaneous Electric Kitchen Equipment" object is included in each kitchen space type to account for non-major electrical appliances found in kitchens, such as microwaves, heating lamps, toasters, coffee machines, electric kettles, etc. This miscellaneous load is calculated in the baseline such that it represents 10% of the total kitchen electric load. This miscellaneous electric load object in kitchens is not altered by the Electric Cooking Equipment measure. However, because the total kitchen load changes from applying the measure, the miscellaneous load will no longer represent 10% of the total kitchen electric load in the final model. The kitchen's electric load increases substantially because of the Electric Cooking Equipment measure, therefore the miscellaneous electric kitchen equipment object will represent less than 10% of the kitchen's electric load in the final model.

4 Output Variables

Table 17 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 Cooking Equipment measure applied. Additionally, these output variables can be used for understanding the economics (e.g., return on investment) of the upgrade if cost information (i.e., material, labor, and maintenance costs for technology implementation) is available.

Table 17. Output Variables Calculated from the Measure Application

Variable Name	Description
Broiler Quantity	Number of broilers in the building to be replaced with electric broilers (if existing fuel is gas)
Existing Broiler Fuel	
Fryer Quantity	Number of fryers in the building to be replaced with electric fryers (if existing fuel is gas)
Existing Fryer Fuel	
Griddle Quantity	Number of griddles in the building to be replaced with electric griddles (if existing fuel is gas)
Existing Griddle Fuel	
Oven Quantity	Number of ovens in the building to be replaced with electric ovens (if existing fuel is gas)
Existing Oven Fuel	
Range Quantity	Number of ranges in the building to be replaced with electric induction ranges (if existing fuel is gas)
Existing Range Fuel	
Steamer Quantity	Number of steamers in the building to be replaced with electric steamers (if existing fuel is gas)
Existing Steamer Fuel	
Initial Electric Interior Equipment Energy Consumption*	Annual energy consumption of electric interior equipment in baseline (kWh)
Initial Natural Gas Interior Equipment Energy Consumption*	Annual energy consumption of electric interior equipment in baseline (therm)
Final Electric Interior Equipment Energy Consumption*	Annual energy consumption of electric interior equipment after upgrade is applied (kWh)
Final Natural Gas Interior Equipment Energy Consumption*	Annual energy consumption of electric interior equipment after upgrade is applied (therm)

* Note that annual energy consumption fields for electric and natural gas interior equipment are for the entire building. Energy consumption attributed to kitchen space types is not broken out in the published output variables.

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 upgrade. 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 Electric Cooking Equipment upgrade.

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 greenhouse gas savings. This is especially important when an upgrade 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 or electrification strategy, depending on the use case.

5.1 Single Building Example

This section demonstrates the measure application on a 3,000-ft^2 full-service restaurant test model in Detroit, Michigan. The measure installed replaced 1 broiler, 2 griddles, 1 fryer, 3 ovens, and 2 ranges with electric appliances in the kitchen space type. Steamers in the existing building were already electric, so they were not affected by the measure. In addition to swapping fuels and adjusting the design levels, the measure also replaced the fractions of radiant, latent, and lost heat in the equipment objects with the corresponding electric equipment fractions.

The kitchen space type started with 228,019 W of gas cooking equipment and 26,964 W of electric cooking equipment for a total of 254,983 W. The model ended with 164,360 W of all-electric cooking equipment, a 36% reduction in installed power of cooking equipment. The electric equipment load increased by 3.6x, while the gas equipment load was eliminated. Other end uses that saw changes were cooling (13% reduction) and heating (3% increase) because of the changes in internal gains given off by the new electric cooking equipment. The total site energy of the existing building was 628 MWh, and the upgraded building had total site energy of 517 MWh, an 18% reduction.

Table 18. Cooking Equipment Count, Fuel, and Power Before and After Upgrade Was Applied

Cooking Appliance	Initial			Final		
	Count	Fuel	Design Level (W)	Count	Fuel	Design Level (W)
Broilers	1.0	Gas	28,136	1.0	Electric	10,815
Griddles	2.0	Gas	52,754	2.0	Electric	34,232
Fryers	1.0	Gas	23,447	1.0	Electric	14,009
Ovens	3.0	Gas	38,688	3.0	Electric	36,312
Ranges	2.0	Gas	84,994	2.0	Electric	42,028
Steamers	1.0	Electric	26,964	1.0	Electric	26,964

5.2 Stock Energy Impacts

This measure was applicable to 37.5% of the ComStock floor area. This measure demonstrates 2.0% total site energy savings (86 TBtu) for the U.S. commercial building stock modeled in ComStock (Figure 10). The savings are primarily attributed to:

- **88.2%** stock **interior equipment, natural gas** savings (187.0 TBtu)
- **−14.1%** stock **interior equipment, electricity** savings (−104.1 TBtu)
- **−0.2%** stock **natural gas heating** savings (−1.7 TBtu)
- **0.6%** stock **cooling electricity** savings (4.1 TBtu).

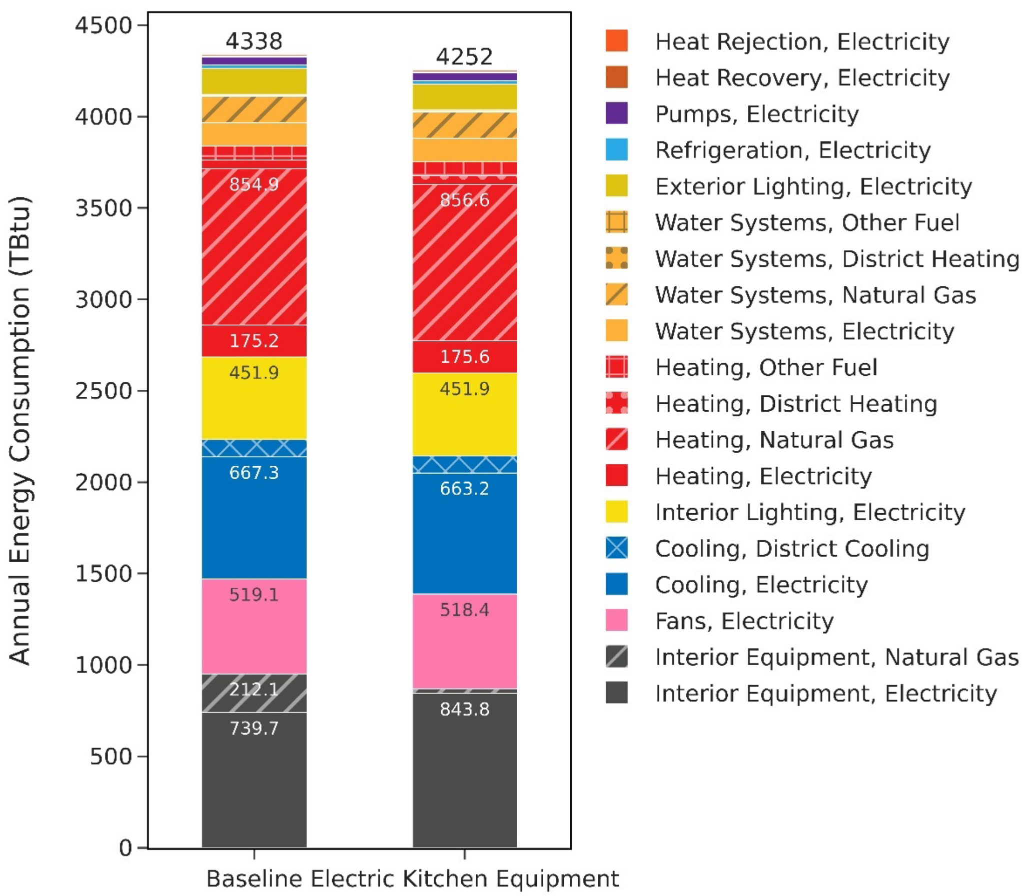

Figure 10. Comparison of annual site energy consumption between the ComStock baseline and the Electric Cooking Equipment upgrade scenario.

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

The largest savings are seen in natural gas interior equipment, as most of this end use is electrified when replacing gas-fired cooking equipment with electric. As such, there is a large increase in the electricity interior equipment end use. The total energy consumption due to all interior equipment is reduced from the baseline to the upgrade, a result of the efficiency improvements of the new electric cooking equipment compared to the gas equivalents. A small portion of natural gas interior equipment remains after the upgrade is applied. This is because the ComStock model includes a small portion of other natural gas equipment that was not upgraded by this measure, including commercial gas clothes dryers in hotels and gas-fired medical equipment in outpatient buildings.

In addition to interior equipment end uses, this measure had minor effects on heating and cooling. There was a 0.6% decrease in cooling energy and a 0.2% increase in all heating end uses. This is due to the change in internal gains given off by the new kitchen equipment. The new electric equipment is more efficient and gives off less heat to the space, meaning some cooling energy is saved in the summer but some additional heating energy is required in the winter. Because kitchens only make up a small fraction of the total stock floor area, the impact is minimal. However, the impact on heating and cooling loads in just kitchen spaces will be much more substantial.

Overall, the measure resulted in 2.0% total site energy savings. There was an overall decrease in natural gas energy and an increase in electricity, which is to be expected when electrifying all gas-fired cooking equipment. At a stock level, the total electricity consumption increased by 99 TBtu (3.4%), and natural gas consumption decreased by 186 TBtu (15.4%).

5.3 Stock Greenhouse Gas Emissions Impact

ComStock models three electricity grid scenarios to show potential avoided greenhouse gas emissions: Cambium Long-Run Marginal Emissions Rate (LRMER) High Renewable Energy (RE) Cost 15-Year, Cambium LRMER Low RE Cost 15-Year, and Emissions & Generation Resource Integrated Database (eGRID) [1], [2]. The overall emissions across all fuels saw a decrease of 0.5%–3.3% (2–8 MMT CO_2e) between the three scenarios. Electricity greenhouse gas emissions increased across all scenarios by approximately 2.6-3.5% (4–11 MMT CO_2e), while natural gas emissions dropped by 14.8% (12 MMT CO_2e). This is driven by transitioning natural gas cooking equipment to electric, but also includes the efficiency improvements of the electric appliances compared to gas-fired.

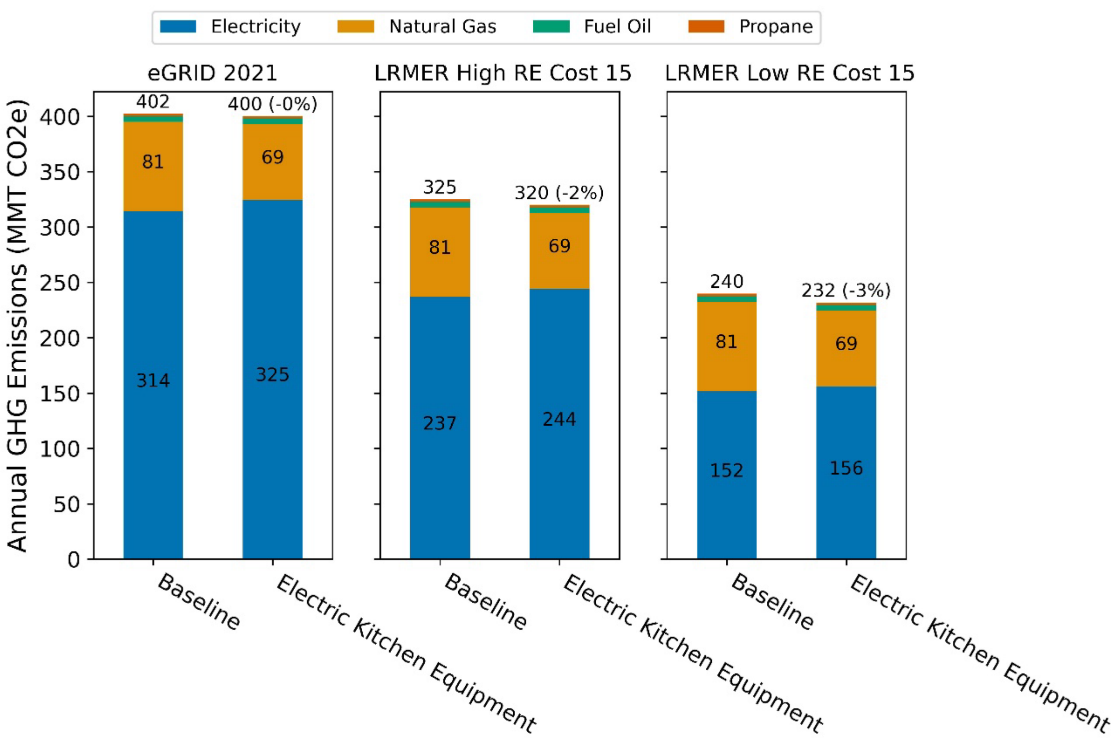

Figure 11. Greenhouse gas emissions comparison of the ComStock baseline and the Electric Cooking Equipment upgrade scenario.

Three electricity grid scenarios are presented: Cambium Long-Run Marginal Emissions Rate (LRMER) High Renewable Energy (RE) Cost 15-Year, Cambium LRMER Low RE Cost 15-Year, and eGRID. MMT stands for million metric tons.

5.4 Site Energy Savings Distributions

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

Figure 12 shows the percent savings distributions of the baseline ComStock models versus the Electric Cooking Equipment upgrade scenario by end use and fuel type for applicable models. Interior equipment, which includes cooking equipment, had the most noticeable change, as expected. Natural gas interior equipment saw savings of nearly 100%. Buildings that do not show 100% savings in natural gas equipment have other types of natural gas equipment that were not upgraded in this measure (e.g., commercial gas clothes dryers in hotels and gas-fired medical equipment in outpatient buildings).

Electric interior equipment saw a large increase in energy consumption due to the nature of electrifying all cooking appliances. However, the change is not a 100% increase, because the building started out with other electric equipment loads in non-kitchen space types. In addition, the new electric cooking equipment is generally 2–3 times more efficient (by rated input power) compared to the existing gas equipment. Every building that received the upgrade showed a decrease in natural gas equipment energy and an increase in electric equipment energy, which is expected.

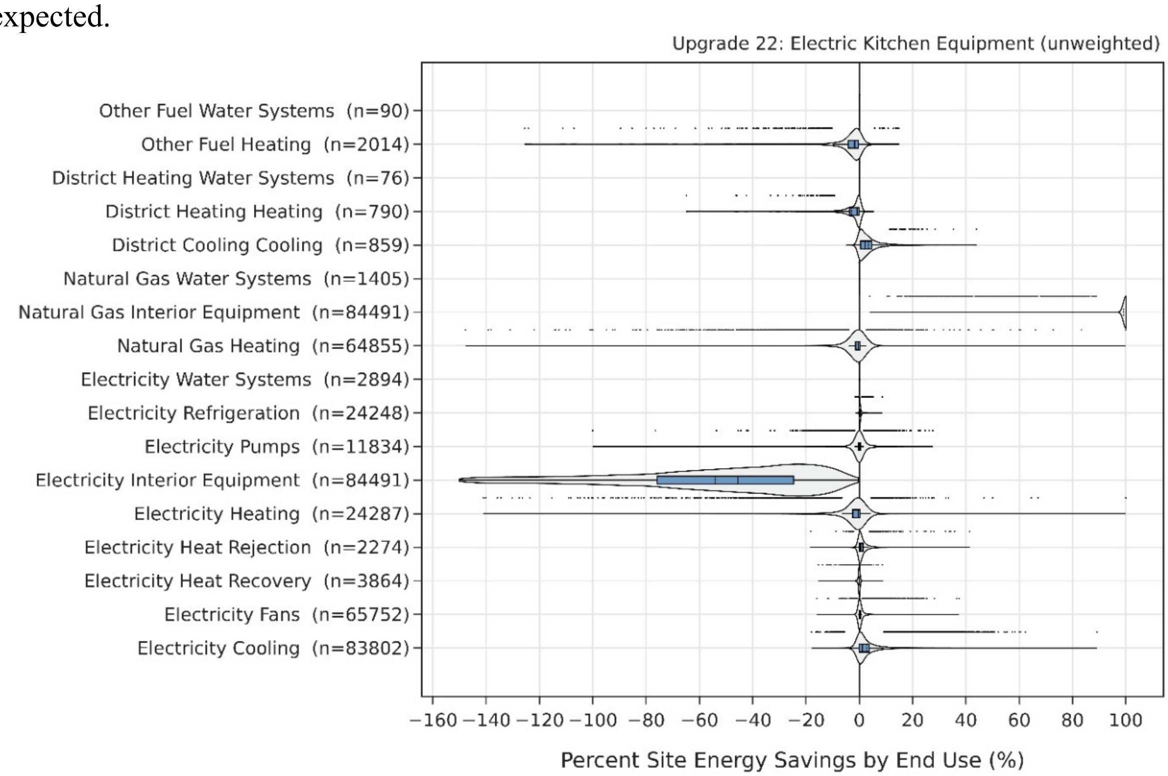

Figure 12. Percent site energy savings distribution for ComStock models with the Max Tech HVAC package applied by end use and fuel type

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.

Heating, ventilating, and air conditioning (HVAC) end uses had minor changes caused by the changes in internal gains when swapping out cooking equipment. In general, the new electric equipment has lower energy consumption and lower internal gains to the space, leading to some cooling savings and heating penalties in most cases. However, some buildings can show the opposite result based on the climate zone and the heating and cooling demands of the building. Upon investigation, the buildings showing cooling penalties or heating savings are in extreme climates that are either very heating dominated or very cooling dominated. Therefore, a small magnitude change in these end uses makes up a large percent change. For example, buildings showing large heating savings are mostly Florida and Arizona buildings, which have small heating loads to begin with.

This measure only touched kitchen space types, which make up a relatively small portion of floor area in most building types, so the impact on total HVAC load is usually minor. Buildings that show larger changes in HVAC loads are buildings where the kitchen space makes up a large portion of the floor area, such as restaurants or strip malls. Upon investigation, the buildings with high heating penalties and cooling savings (10% or more) are all quick service or full-service restaurants. In these buildings, kitchen space makes up a large portion of the building, and therefore drives the building’s load, so substantial changes to internal loads in the kitchen space can cause high percentage changes in HVAC loads.

Minimal or no differences are observed for water systems, refrigeration, lighting, and heat rejection/heat recovery, as these systems are not touched by the upgrade. Some buildings have very minimal changes due only to minor changes in ambient air temperature that affect the operation of these systems.

5.5 Peak Impacts

Figure 13 shows the impact of the Electric Cooking Equipment upgrade on seasonal peak hours. The seasonal peak times had very little change from the baseline to the upgrade, which is to be expected, as this measure only altered cooking equipment power, not schedules.

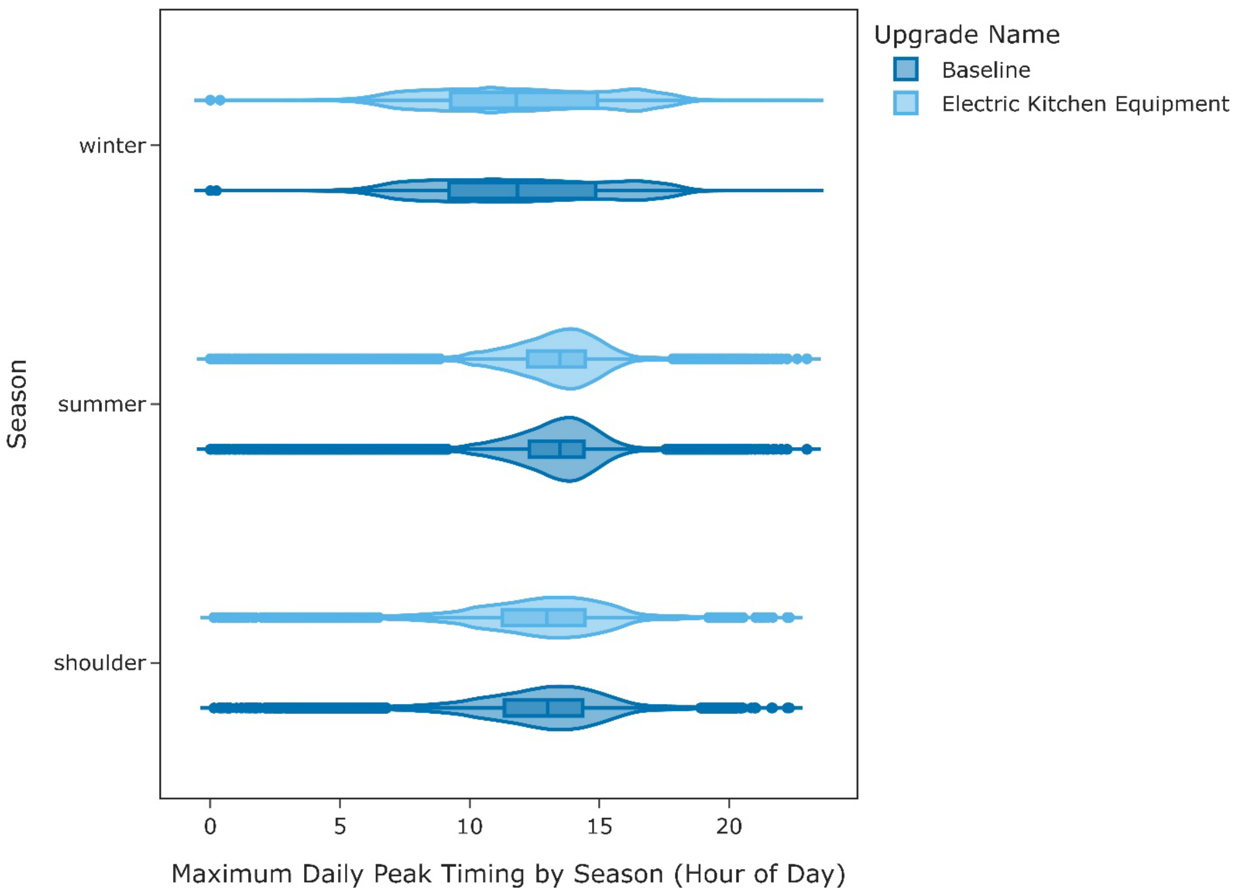

Figure 13. Maximum daily peak timing by season between the baseline and the Electric Cooking Equipment upgrade scenario

Figure 14 compares the noncoincident peak electricity demand intensity for the median building between the ComStock baseline and the Electric Cooking Equipment upgrade scenario. Results are presented by ComStock building type. All building types with kitchens (full-service restaurant, hospital, large hotel, primary school, quick service restaurant, retail strip mall, and secondary school) saw an increase in electric peak load intensity for all three seasons (summer, winter, and shoulder). The added electric equipment load in these building types caused the peak to increase. The magnitude of the change depends on the density of kitchen equipment in the building. The peak increases were rather uniform across seasons; however, the winter peaks had a slightly higher change because the new, more efficient equipment caused a small increase in heating loads during winter.

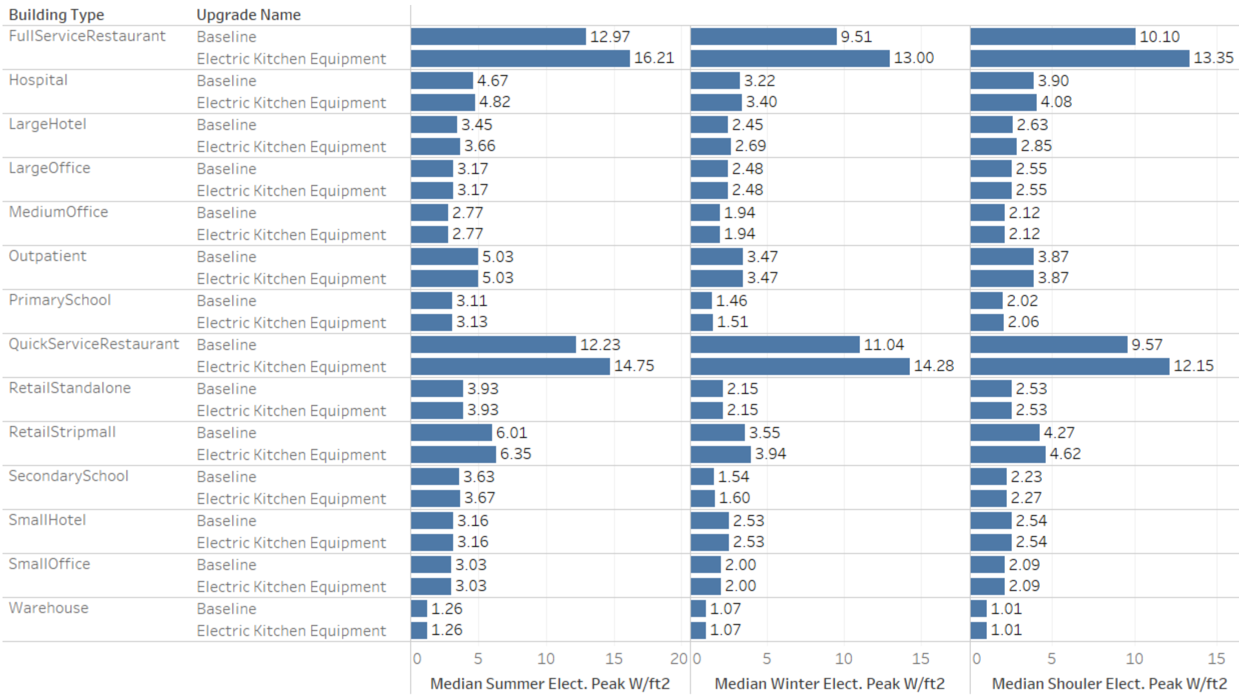

Figure 14. Maximum daily peak intensity by season and building type between the baseline and the Electric Cooking Equipment upgrade scenario

Restaurants see the largest change in peak intensity (21%–37%) because their load is dominated by cooking equipment. The other building types with kitchens see their peak intensity increase by up to 11% due to the addition of the new electric cooking loads. All remaining building types do not have kitchens and therefore have no change in peak loads from this measure.

5.6 Building Type Impacts

Figure 15 and Figure 16 show the impacts of the Electric Cooking Equipment upgrade on natural gas and electricity consumption across the building types in the stock. The largest changes occurred in restaurants and strip malls because of their high density of cooking equipment. Schools, hospitals, and large hotels also have some cooking equipment; however, the kitchen space is a relatively small portion of the building area, so the changes in energy consumption are lower. The remaining building types do not have kitchens; therefore, they were not affected by this measure and show no change in natural gas or electricity consumption.

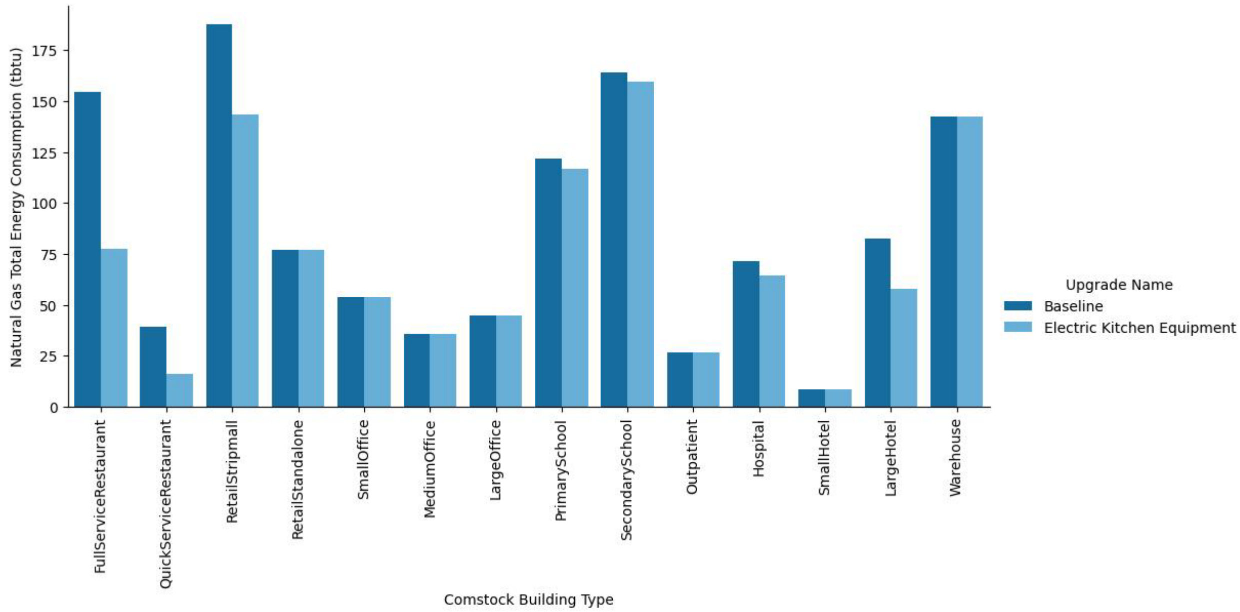

Figure 15. Annual stock natural gas consumption by building type before and after the Electric Cooking Equipment upgrade was applied

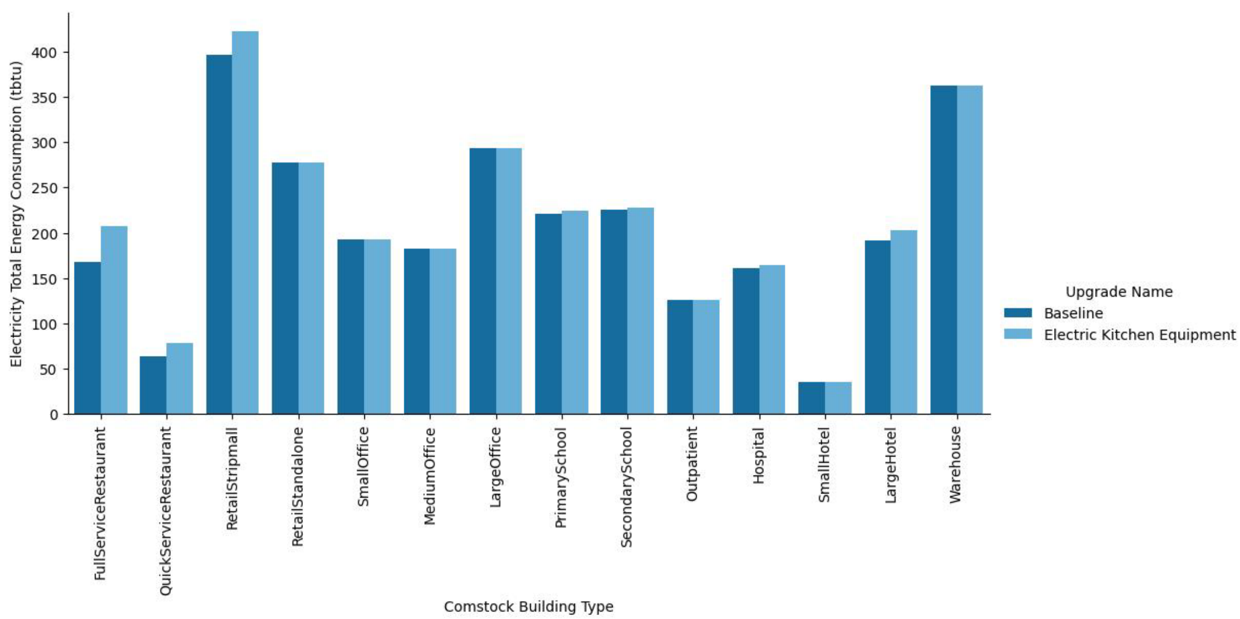

Figure 16. Annual stock electricity consumption by building type before and after the Electric Cooking Equipment upgrade was applied

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