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ComStock Measure Scenario Documentation:

Reduced Thermostat Setbacks for Heat Pumps

Amy Allen

National Renewable Energy Laboratory

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List of Acronyms

AHU	air handling unit
CBECS	Commercial Buildings Energy Consumption Survey
CO_2e	carbon emissions equivalent
COP	coefficient of performance
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
HP-RTU	heat pump rooftop unit
HVAC	heating, ventilating, and air conditioning
LRMER High RE	Long-Run Marginal Emissions Rate High Renewable Energy
MMT	million metric tons
RTU	rooftop unit
TBtu	trillion British thermal units
URDB	Utility Rate Database

Executive Summary

Building on the 3-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 represents 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" refers 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 measure scenario—Reduced Thermostat Setbacks for Heat Pumps—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.

Table ES-1. Summary of Key Modeling Specifications

Technology Description	• This measure scenario couples a 2°F unoccupied thermostat setback with the Heat Pump Rooftop Unit measure. • The intent is to implement more mild thermostat setbacks when using heat pumps, which is a common recommendation to avoid the use of supplemental heating and resulting demand spikes. Some buildings use much higher unoccupied thermostat setbacks of 10°F or more, while others may use no setback at all. This measure uses 2°F for all buildings applicable to either heat pump measure scenario.
Performance Assumptions	• Measure will be applied in conjunction with the Standard Performance Heat Pump Rooftop Unit measures • A setback of 2°F will be implemented during unoccupied periods, which is generally less than typical unoccupied setbacks
Applicability	• Applied to buildings eligible for the Standard Performance Heat Pump Rooftop Unit measure **(36%).**
Release	2025 Release 1: 2025/comstock_amy2018_release_1

National annual results for site energy, energy bills, and carbon emissions equivalent (CO_2e) are summarized in Table ES-2–Table ES-4.

Table ES-2. Summary of 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	320.0	1524.1	20.1%	627.4	51.0%
Electricity	-0.3	3173.4	0.0%	1219.9	-1.7%

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

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

End Use / 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)
Electricity	0.3	107.7	0.0%	41.5	0.0%
Natural Gas	3.4	17.4	19.6%	7.0	48.6%
Fuel Oil	0.3	0.7	50.8%	0.4	87.6%
Propane	0.6	1.0	56.1%	0.9	62.0%
Total	4.6	126.8	3.7%	49.8	8.6%

Table ES-4. Summary of Key Results for Annual CO_2e Savings

Electricity emissions avoided in this table are calculated using 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.

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	21.4	101.8	20.1%	41.9	51.0%
Electricity	-4.4	239.6	-1.9%	97.8	-4.7%
Fuel Oil	0.9	1.7	50.1%	1.0	87.7%
Propane	1.6	2.7	57.0%	2.5	62.9%
Total	19.5	345.9	5.9%	143.2	16.3%

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1 Introduction

Thermostat adjustments (also known as “setbacks”) during periods when a building is unoccupied, with heating setpoints reduced and cooling setpoints increased, are a commonly recommended energy efficiency strategy. Setbacks save energy during unoccupied periods both through reduced heating, ventilating, and air-conditioning (HVAC) system operation and reduced envelope losses. The prescriptive compliance path of ASHRAE 90.1 2022 requires that control systems in commercial buildings be configured for a setback of at least 10°F from the occupied heating setpoint during unoccupied periods (with an exception for radiant heating systems) [1]. However, in heating mode for buildings with typical daytime occupancy, “morning warm-up” in the hours right before the building is occupied imposes a large load on the system as it tries to recover to the occupied setpoints because outdoor air temperatures are generally cooler overnight than in the daytime [2]. Different strategies, including “optimum start” approaches, have been developed to try to mitigate this load. For heat pump systems, the high electrical demand required for morning warm-up, especially if supplemental/backup heating is required, and the additional cost associated with higher demand charges could outweigh the energy cost savings associated with the setback itself.[1] This measure will focus on reducing heating setbacks during unoccupied periods for packaged rooftop air-to-air heat pumps. It may be extended to air-to-water heat pump boilers in the future.

Much of the research focused on unoccupied setbacks and conventional optimum start approaches is old and is based on analysis of buildings with poor envelopes and HVAC systems without modulating capacity control, which improves efficiency of operations at part-load conditions [2]. Additionally, incorporating the intention of minimal or no setbacks in the design stage can reduce peak heating loads and thus required equipment capacity, reducing capital costs and potentially improving the efficiency of equipment at its typical operating points [2].[2]

A study by Cheng, Raftery, and Wendler (2024) evaluated a modified optimum start approach at a community college building in Northern California. The modified approach gradually increased the heating setpoint from the unoccupied to occupied level over several hours. Over a several-day test period, the modified approach significantly reduced peak heating loads relative to the baseline, in which morning warm-up occurred over a 1.5-hour period [2]. Although this study did not address heat pumps specifically, the effect on heating loads is expected to be generally extensible to heat pump systems. The fact that air-to-air heat pumps are electrically driven and often incorporate electric resistance supplemental heat makes this sudden change in load problematic for distinct reasons.

The available heating capacity of air-source heat pumps generally reduces with outdoor air temperature, which usually corresponds to times of higher heating loads for the building. Heat pump compressors are often disabled (“locked out”) below a certain outdoor air temperature, which requires supplemental heating (often electric resistance) to be used exclusively [3]. Air-source heat pumps in cold climates are almost always equipped with a supplemental heat source,

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[1] Some heat pumps are configured to have supplemental heating operate if setpoints are not achieved within a certain amount of time or if temperatures drift out of a certain band.

[2] Equipment sizing in ComStock does not account for heating setbacks.

often electric resistance, to provide some or all of the heating requirement when the compressor's capacity is diminished or the compressor is disabled. (Supplemental heating from natural gas, such as from gas furnaces, is also an option.) Electric resistance heating operates with an effective coefficient of performance (COP) of 1, which is always no greater than, and sometimes significantly lower than, the COP of the heat pump under the given conditions.[3] In retrofit applications, air-to-water heat pumps can be supplemented with electric boilers or existing fossil-fuel-fired boilers. If the high heating load associated with morning warm-up after a significant setback causes electric supplemental heat or an electric boiler to operate when it would not have been required to otherwise, or to operate at a higher capacity, a significant penalty in electric demand can result [4].

Fewer measurement-driven studies of heat pump performance with setbacks have been performed in commercial buildings, but several studies have evaluated the influence of large setbacks on air-source heat pump performance in homes, and the general principles regarding the response of air-source heat pumps to setbacks are expected to be instructive. An evaluation of electric meter data from homes in the Pacific Northwest with air-to-air heat pumps by Douglass and Rushton (2024) found that, in homes with nighttime setbacks of at least 4°F, a ratio of 2:1 would typically exist between morning peak power demand to average nighttime power demand. An analysis of data from homes in California by Higa, Horowitz, Buendia, et al. (2024) found that the energy penalty resulting from use of electric supplemental heat during morning warm-up negated the energy savings from the setback. However, note that the focus of this measure is on reducing setbacks to control peak demand, not directly for energy savings. Peak demand is especially relevant in the context of commercial buildings. Demand charges can vary greatly with electricity tariffs, but an oft-cited range is that demand charges can account for 30%–70% of a commercial building's electricity costs [5]. With adoption of heat pumps, more areas of the country are likely to have electric demand profiles that are "winter-peaking"; thus, heat pump operation could contribute to setting overall system peaks that dictate sizing (and cost) of utility-owned electrical distribution infrastructure [6]. Appropriate control of heat pump systems can potentially mitigate these effects, for both utility-owned and building-owned electrical infrastructure.

A significant peak demand penalty resulting from heating setbacks has also been observed in very mild climates, demonstrated by a monitoring study on homes in the service territory of a utility in Central Florida with high heat pump penetration (58% of homes in the sample had air-source heat pumps). The utility's peak demand hour for the year occurred on a winter morning from 7 to 8 a.m. The study found that setbacks of 3°F or greater increased electricity demand for heating in individual buildings at the utility's peak demand hour by around 35% relative to homes with minimal or no setback. The study estimated that the use of "deep" thermostat setbacks of 3°F or more on residential heat pumps contributed to an increase of 300 MW in the utility's peak load [7].

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[3] For example, a two-stage Rheem Renaissance packaged rooftop air-source heat pump is reported to have a heating COP of 1.98 at outdoor air temperatures of 0°F. However, the unit has only about 40% of its nominal direct expansion heating capacity at this outdoor air temperature [3].

A modeling analysis of an office building in a cold climate designed to be highly efficient found that operating a system consisting of an air-to-water heat pump and supplemental electric resistance boiler increased peak demand by more than 15% and reduced heat pump operating hours by 32%, relative to operating the heat pump with a constant setpoint [8]. The magnitude of the setback was not stated.

Numerous sources recommend reducing or eliminating setbacks for air-source heat pumps or using refined optimum start approaches [9]. Heat pump manufacturers often recommend a setback of no more than 2°F during unoccupied periods in heating mode [10]. We implemented the approach of a 2°F setback in this measure. Note that, while modifications in cooling setbacks could also be beneficial for heat pump performance, cooling setbacks are not currently considered in the scope of this measure. This measure will be applied in conjunction with the Standard Performance Heat Pump Rooftop Unit (HP-RTU) with Electric Backup retrofit measure, since heat pumps (other than packaged terminal heat pumps) are not present in the ComStock baseline [11].

The Standard Performance HP-RTU measure applies a standard efficiency HP-RTU as a replacement for existing rooftop packaged units. The heat pump is sized to the design cooling load with electric supplemental heating used to address any remaining loads when the direct expansion heating capacity is unavailable due to compressor lockout or is insufficient. The Standard Performance HP-RTU measure configures a heat pump compressor lockout at 0°F [11]. For more details related to the HP-RTU measure (cited above), refer to its report.

2 ComStock Baseline Approach

In the ComStock baseline, thermostat setpoints are characterized with square-wave schedules, with one setpoint during occupied periods, and potentially a different setpoint during unoccupied periods, representing a thermostat setup/setback. Where setbacks are present, the occupied and unoccupied periods align with the building occupancy schedules. Building occupancy schedules in states other than California align with occupancy schedules in the U.S. Department of Energy (DOE) prototype buildings. Schedules from the DEER prototype models are used for buildings in California [12].

In the baseline, thermostat setpoint schedules (including occupied and unoccupied setpoints, where applicable) for many buildings (all building types except hospitals, outpatient healthcare facilities, storage areas in warehouses[4], and hotels) are characterized based on a distribution obtained from data from real building automation systems (BAS). The master BAS dataset includes time-series heating and cooling setpoints. Where sufficient samples are available, distributions are created by building type. (For building types with fewer than 25 samples, the entire dataset is used to generate the distribution.) The prevalence of thermostat setbacks in each building type is based on data from CBECS 2012, which reports automated and manual setbacks, with an adjustment to account for the expected lack of persistence of manual thermostat setbacks. The proportion of buildings in the baseline having a thermostat setback varies by building type, ranging from 46% for quick-service restaurants to 95% for secondary schools. For buildings represented in the BAS dataset and having thermostat setbacks, thermostat setback temperatures are populated from distributions in a similar manner to the occupied temperature setpoints.

For the storage areas of warehouse buildings, heating setpoints are adjusted from the DOE/DEER prototype building models to better calibrate warehouse energy consumption to data from CBECS 2018, as well as engineering judgement [12]. Setpoints from OpenStudio® standards, scaled to the individual building's hours of operation, are used for hospitals, outpatient healthcare facilities, and hotels.

Some air handling units (AHUs) in the ComStock baseline with airflow over 10,000 cfm have an optimum start control sequence enabled. The optimum start sequence seeks to adjust setpoints over a several-hour period before the building is occupied to ensure comfortable conditions once the building opens. The measure is applicable to these AHUs.

ComStock equipment sizing in general does not account for heating setbacks, so implementation of this measure is not expected to directly affect equipment sizing.

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[4] Office areas in warehouses have setpoint schedules characterized by the BAS dataset.

3 Modeling Approach

3.1 Applicability

This measure is generally applicable to all baseline system types to which the Standard Performance HP-RTU measure is applicable. The Standard Performance HP-RTU measure is applicable to packaged single-zone systems with gas or electric coils. ComStock HVAC distributions are informed by CBECS (the 2012 and 2018 results combined). The methodology for interpreting CBECS data to create HVAC probability distributions for ComStock is discussed in the ComStock Documentation report [2].

This measure will not be applied to spaces with 24/7 operation due to the nature of the building or space, such as data centers and spaces in hospitals requiring constant operation. This measure will also not be applied to hotel guest rooms. ComStock randomly assigns occupants to rooms to achieve a 65% occupancy rate across the building, in line with industry averages [12].

Figure 1 illustrates the prevalence of the available baseline HVAC system types in ComStock and those to which this measure is applicable.

Based on HVAC system type, this measure is expected to be applicable to 36% of the ComStock floor area, or about 22 billion square feet in weighted floor area.

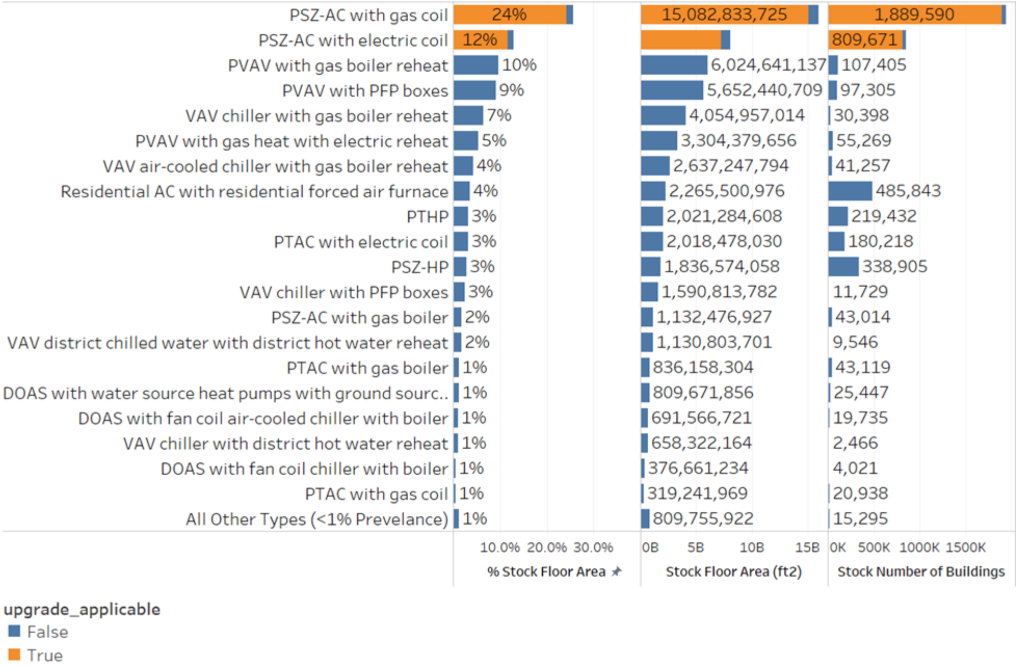


Figure 1. Measure applicability by baseline HVAC system type

3.2 Measure Scenario Modeling Methodology

This measure is applied in conjunction with the Standard Performance HP-RTU measure. As part of this measure, a thermostat schedule with a 2°F (1.1°C) setback during unoccupied periods is implemented in all applicable buildings. (A thermal zone is considered unoccupied for a given time period if its occupancy is less than 5% of its maximum occupancy value throughout the year.) The setback is determined relative to the occupied heating setpoint(i.e., by subtracting 2°F from it). The magnitude of the setback has been selected based on advice from HVAC manufacturers and engineering judgement [10]. Note that in some buildings this will result in an increased setback from the baseline, and in other buildings it will result in a decreased setback. (In buildings with 24/7 operation and occupancy, there is no opportunity for setbacks to be implemented.)

Special consideration is needed for buildings with AHUs that operate 24/7 due to a fault (i.e., they do not have fan or outdoor air setbacks but are not 24/7 buildings). If the air loop level HVAC operations schedule has an occupied and unoccupied period, setbacks will be implemented following that schedule. If the HVAC operations schedule does not have occupied and unoccupied periods, zone occupancy will be used to determine a schedule on which to implement setbacks, with 5% occupancy being used as a threshold for consideration of the space as “occupied.”

In air loops in which an optimum start sequence is implemented, this measure will apply the setback change to the “unoccupied” setpoint conditions and will not modify the optimum start sequence to isolate the effects of the setback change. The unoccupied conditions are determined based on the schedule’s minimum setpoint value, which is an accurate inference based on how thermostat setpoint schedules are structured in ComStock.

3.3 Utility Costs

ComStock provides utility cost estimates for several fuel types in buildings: electricity, natural gas, propane, and fuel oil. The current implementation represents utility rates 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 rates in ComStock, but more detailed information is available in the ComStock Reference Documentation [22]. Summary statistics from this implementation are shown in Table 1. Note that ComStock does not currently estimate utility costs for district heating and cooling.

Table 1. Summary Statistics of Utility Bill Implementation in ComStock by Fuel Type

Fuel Type	Minimum Price ($)	Average Price ($)	Maximum Price ($)
Natural gas	$0.007/kBtu ($0.70/therm)	$0.012/kBtu ($1.20/therm)	$0.048/kBtu ($4.80/therm)
Propane	$0.022/kBtu ($2.20/therm)	$0.032/kBtu ($3.20/therm)	$0.052/kBtu ($5.20/therm)
Fuel oil	$0.027/kBtu ($2.70/therm)	$0.033/kBtu ($3.30/therm)	$0.036/kBtu ($3.60/therm)
Electricity	$0.003/kBtu ($0.01/kWh)	$0.035/kBtu ($0.12/kWh)	$3.530/kBtu ($12.04/kWh)

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 [18].

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 [19]. 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), which includes rate structures for about 85% of the buildings and 85% of the floor area in ComStock [20]. The URDB rates include detailed cost features such as time-of-use pricing, demand charges, ratchets, etc. 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 non-building-load keywords (e.g. Security Light,, Irrigation, Snow, Cotton Gin), rates where the load profile does not follow any potential min/max demand or energy consumption qualifiers, and rates that cause unrealistically 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 unrealistic bills.

For buildings with no URDB electric utility assigned, or for buildings where none of the stored rates are applicable, the annual bill is estimated using the 2022 EIA Form-861 average prices based on the state each model is located [21]. While this method does not reflect the detailed rate structures and demand charges, it is a fallback for the 15% of buildings in ComStock with no utility assigned.

3.4 Carbon Emissions Equivalent

Three electricity grid scenarios are presented to compare the emissions of the ComStock baseline and the window 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 third scenario uses the eGrid dataset [15], [14]. 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 [16]. Emissions due to on-site combustion of fossil fuels use the emissions factors shown in Table 2, which are from Table 7.1.2(1) of draft American National Standards Institute/Residential Energy Services Network/International Code Council 301 [17]. To compare 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 2. On-Site Fossil Fuel Emissions Factors

Natural gas	147.3 lb/MMBtu (228.0 kg/MWh)[a]
Propane	177.8 lb/MMBtu (182.3 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

3.5 Limitations and Concerns

Due to the stochastic method by which thermostat setpoint schedules are set in the ComStock baseline, it is possible that in some cases, the 2°F setback will result in an increase of the setback from the baseline. The primary focus of this study is to analyze the effects of reduced setbacks on heat pump performance.

The same limitations and concerns that apply to the Standard Performance Heat Pump RTU measures are applicable to this measure, including limitations in representing variable-speed air-to-water heat pumps and limitations in availability of heat pump performance maps.

4 Output Variables

Table 3 includes a list of relevant output variables that are calculated in ComStock. These variables are important in terms of understanding the differences between buildings with and without the Reduced Thermostat Setbacks for Heat Pumps measure applied.

Table 3. Output Variables Calculated From the Measure Application

Variable Name	Description
build_existing_model.add_hvac_nighttime_operation_variability_rtu_night_mode	Nighttime operation mode for AHUs (to determine if a fault resulting in 24/7 operation is present).
in.tstat_clg_delta_f	Cooling thermostat unoccupied setpoint temperature delta from primary occupied cooling set point.
in.tstat_htg_delta_f	Heating thermostat unoccupied setpoint temperature delta from primary occupied cooling set point.
opt_start	Flag set if an optimum start sequence is implemented in the building.

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 carbon emissions equivalent (CO_2e) savings. This is especially important when a measure impacts multiple fuel types or causes decreased consumption of one fuel type and increased consumption of another. Many factors should be considered when analyzing the impact of an energy efficiency strategy, depending on the use case.

5.1 Single-Building Measure Tests

This section reviews the application of the Reduced Thermostat Setbacks for Heat Pumps measure to two models in different climate zones to demonstrate the functionality of the measure. The HP-RTU with reduced setbacks measure was applied to two retail buildings with packaged single-zone RTUs in two different locations (Cody, Wyoming, in climate zone 6B and Phoenix, Arizona, in climate zone 2B). In both cases, the measure was applied to implement a 2°F thermostat setback.

In the Wyoming location, with cold outdoor air temperatures during the winter, supplemental heating power draw is substantial but is lower in magnitude during the warm-up period with the reduced setbacks, as shown for the heating “peak week” (the week of the lowest hourly outdoor air temperature) in Figure 2 (a and b). The lowest hourly outdoor air temperature during the simulation is -24.2°F and occurs the week of January 29. The reduction in setback reduces the overall supplemental heating peak for the year (which occurs during this week, in both cases) by about 13% and shifts the time when the peak occurs. At the time when the lowest temperature of the year occurs, the reduced setbacks lower the contemporaneous supplemental heating power draw, which is the daily peak, by about 45%. Additionally, the reduced setbacks reduce the peak supplemental heating power draw by a similar fraction on several other days during the peak week.

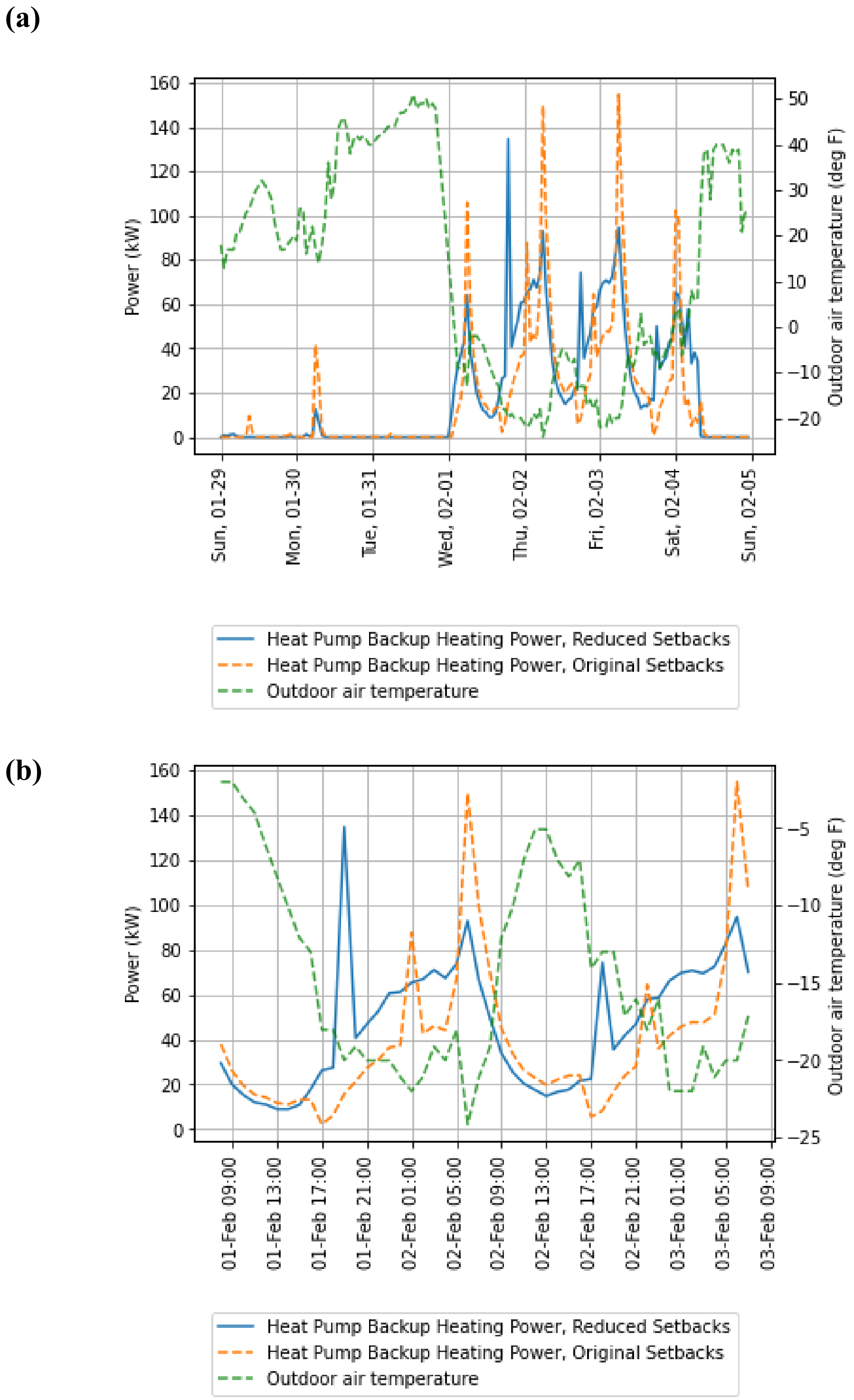


Figure 2. (a) Supplemental heating power, during the heating "peak week," with original (8°F) and reduced (2°F) unoccupied setbacks, Cody, Wyoming. (b) The same results for a subset of the heating peak week.

As expected, the reduction in setbacks also changes the time when high supplemental heating power draw occurs. In the case with the reduced setbacks, peaks in supplemental heating power draw tend to occur in the evening, around 6 p.m. This is explained by the reduction in internal loads at that time, increasing the heating load, while the heating setpoint remains close to the occupied value. In the case with standard setbacks, peak supplemental heating power draw tends to occur around 6 a.m., when the setpoint returns to the occupied value for the day.

To illustrate the effects of the setback on supplemental heating power draw, Figure 3 (a and b) shows supplemental heating power draw along with heating setpoint and outdoor air temperature for the same week, for the cases with the original and modified setbacks, respectively. At the beginning of the week, outdoor air temperatures are comparatively moderate. On January 30, the low temperature is just below 20°F. On that day, the reduced setbacks lowered the peak supplemental heating power draw by about 75%. The compressor lockout temperature is configured for 0°F. Supplemental heating is required during morning warm-up with the standard setbacks because the compressor's heating capacity is insufficient to meet the large load to bring the spaces from unoccupied to occupied setpoints. This is largely mitigated with the reduced setbacks.

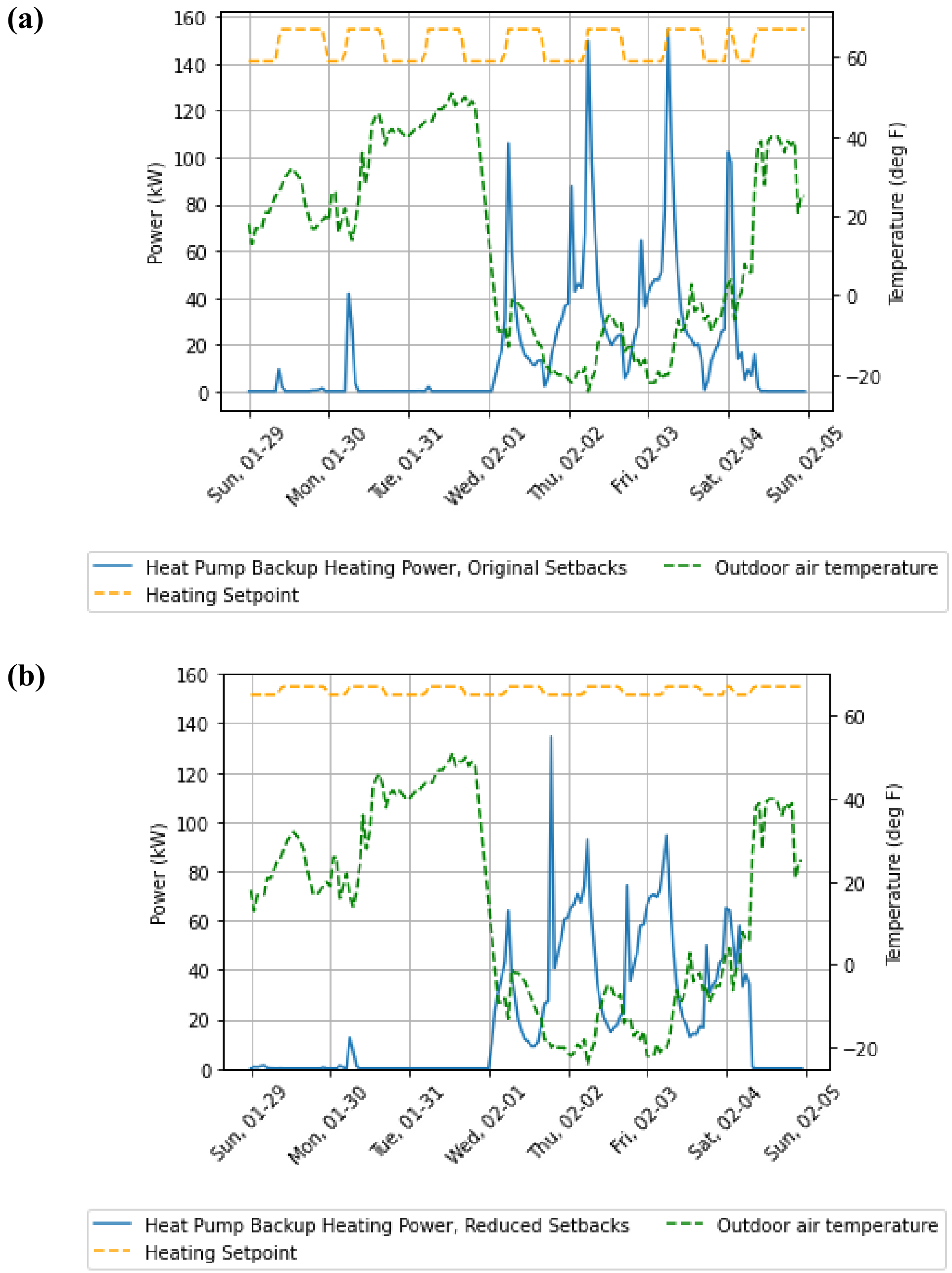
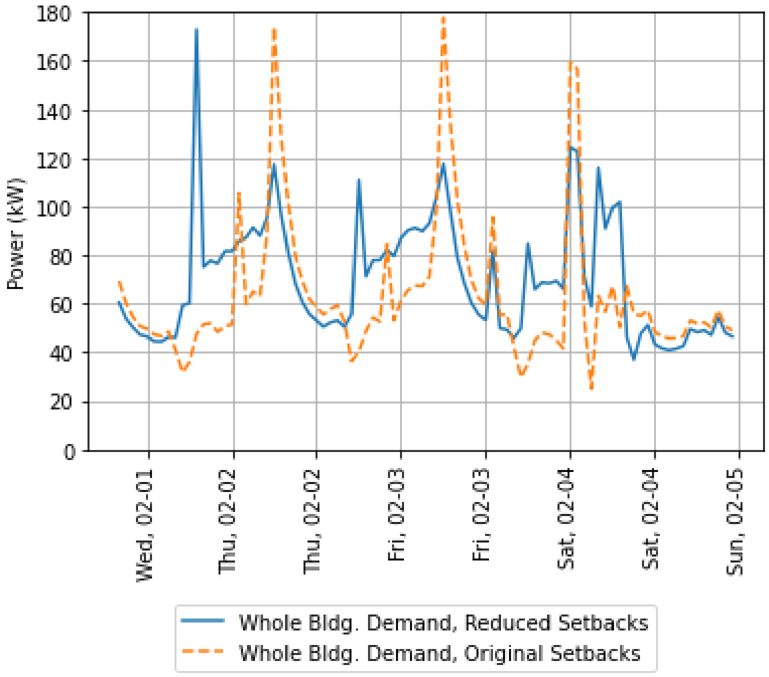


Figure 3. (a) Supplemental heating power, with setpoints and outdoor air temperatures, without setback modification, Cody, Wyoming, for the heating "peak week." (b) Supplemental heating power, with setpoints and outdoor air temperatures, with setback modification, Cody, Wyoming, during the heating "peak week."

However, the effect of the reduced setbacks on overall building peak demand is more complex. Figure 4a shows whole-building level power demand for the heating peak week for the cases with standard setbacks and the setback reduction. The reduction in setbacks shifts the supplemental heating peak, and the overall building-level peak power demand for the week, from the morning of February 3rd to the evening of February 1st. The net reduction in peak power demand for the week is only 3%, compared to the 13% reduction in peak supplemental heating power draw. This disparity is explained by the fact that the supplemental heating peak now coincides with a time when lighting loads are significantly higher, resulting in a smaller reduction in the overall peak than in the supplemental heating peak. Figure 4b shows a comparison of daily energy use (total and for heating only) under the scenarios with standard and reduced setbacks. The differences in total energy consumption for the two scenarios are attributable to the differences in heating energy use. The reduced setbacks scenario results in higher heating energy use due to the longer periods of operation of the heat pump at higher setpoint values. Over the period from February 2nd to February 4th, the proportionate increase in overall daily building energy use with the reduced setbacks is relatively small, between 3.9% and 7.5%. (These annual energy use increase associated with the reduced setbacks is 4.6%. It is expected that days during the heating "peak week" would see increases in energy use higher than this value.) On February 1st, the reduced setbacks result in an increase in building energy use of 30.8%. This corresponds with a day of low temperatures, and a peak in backup heating power draw under the reduced setbacks scenario.

(a)



(b)

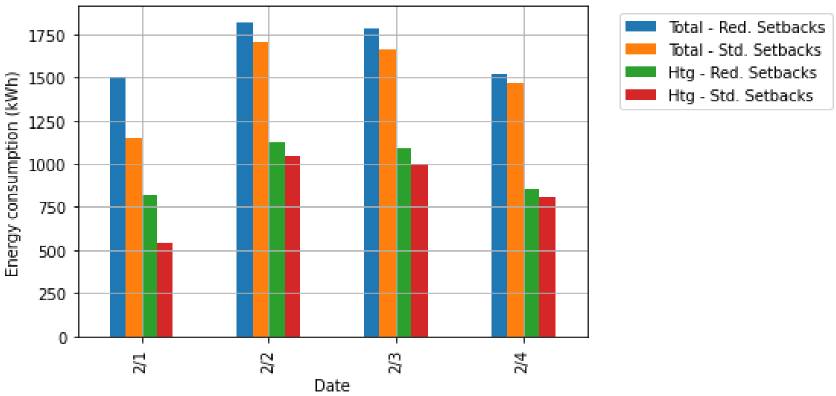
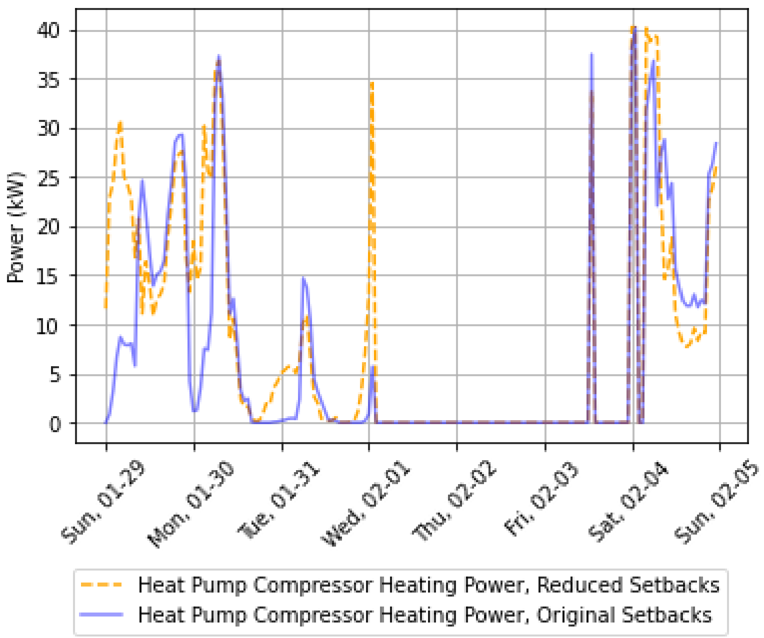


Figure 4. (a) Total building-level demand, with and without the setback reduction, for the heating "peak week." (b) Daily energy consumption (total and for heating only) for the two scenarios.

Figure 5a shows compressor heating power draw for the cases with and without the setback reduction during the heating peak week. During this week, the magnitudes of the peaks in compressor power draw are similar for the two cases, but their timing is different. Cumulatively over the year, compressor heating energy use is 28% higher in the case with reduced setbacks than in the case with standard setbacks. This reflects the greater number of hours of heating operation in the case with reduced setbacks, since the heat pump is now operating to meet a higher setpoint during unoccupied periods. During the heating peak week, outdoor air temperatures remain below 0°F (the compressor lockout temperature) for February 1 through February 3, and there is thus no compressor heating operation during that period. The greater number of hours of compressor heating operation is illustrated in Figure 5b for a winter week with milder conditions.

(a)



(b)

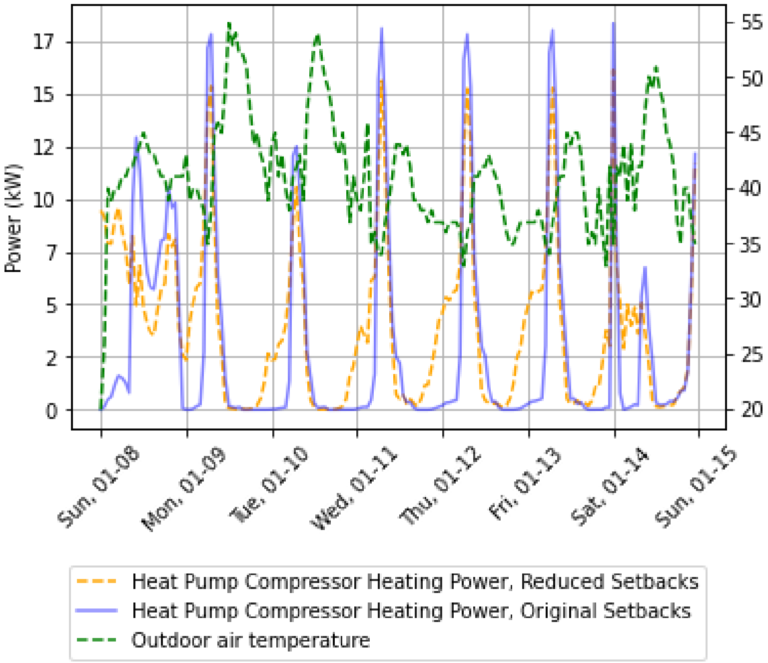


Figure 5. (a) Compressor heating power with original setbacks and with reduced setbacks, Cody, Wyoming, for the heating "peak week." (b) Compressor heating power with original setbacks and with reduced setbacks, Cody, Wyoming, for a week with milder outdoor air temperatures.

Figure 6 shows distributions of compressor heating power draw (for time steps when compressor heating power draw is nonzero) for the cases with standard and reduced setbacks. Figure 7 shows distributions of supplemental heating power draw for the two cases, for time steps when supplemental heating power draw is non-negligible, and less than 100 kW. (Note that there are a small number of time steps with higher supplemental heating power draw). The cumulative sums of supplemental heating power energy use between the two cases are almost identical.

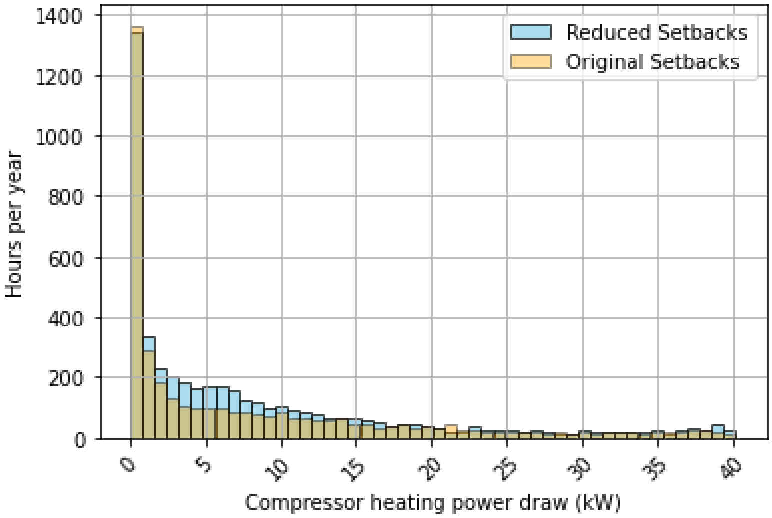


Figure 6. Distributions of compressor heating power draw for the cases with original and reduced heating setbacks, Cody, Wyoming

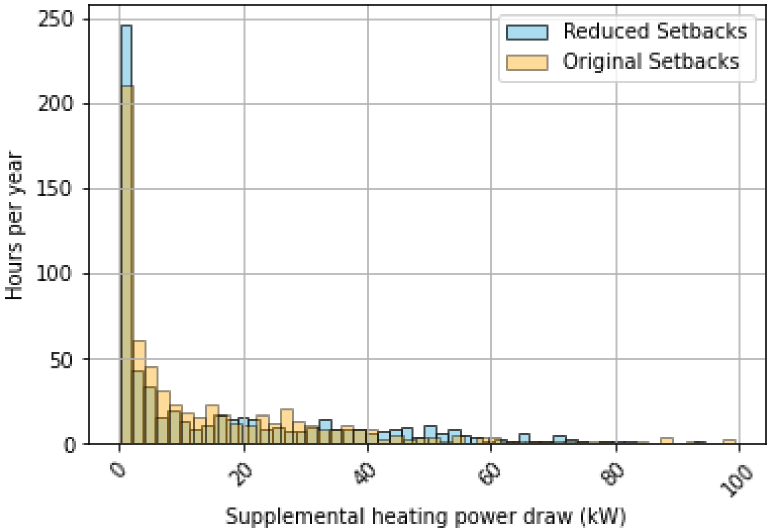


Figure 7. Distributions of supplemental heating power draw for the cases with original and reduced heating setbacks, Cody, Wyoming

Figure 8 and Table 4 show monthly peak demand for the two scenarios (with and without setback reduction) for the Cody, Wyoming building, and the monthly percent reduction in peak demand through the reduced setbacks. The reduced setbacks lower monthly peak demand during most of the simulated year (and by over 20% in October, November, and March). The reduction in setbacks causes a negligible increase (less than 1%) in monthly peak demand in June through September. Table 4 also shows a comparison of overall electricity use between the two scenarios. The setback reduction results in an overall 4.6% penalty (increase) in electricity use in this location, due to the longer operating hours at high heating setpoints.

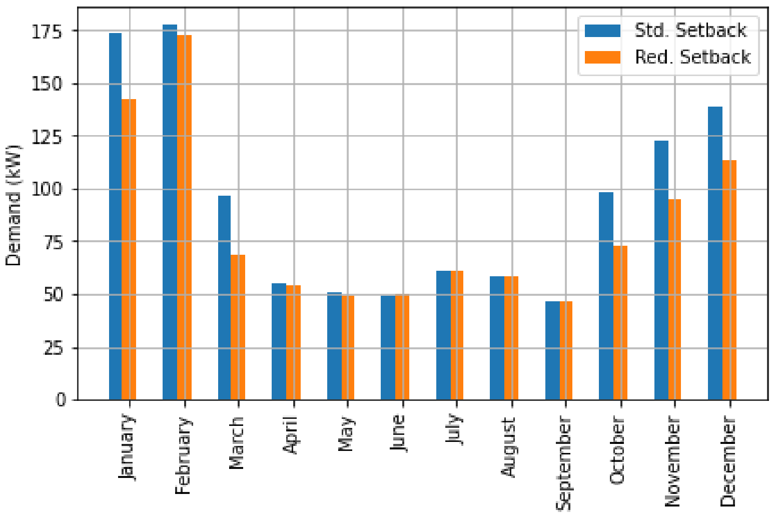


Figure 8. Building-level peak demand by month for cases with standard (std.) and reduced (red.) setbacks, Cody, Wyoming

Table 4. Monthly Peak Demand Comparison for Cody, Wyoming, Model With and Without Heating Setback Reduction

Month	Standard Setbacks	Reduced Setbacks	Reduction (%)
	Peak Demand (kW)		
Jan	173	142	18%
Feb	178	173	2.7%
Mar	96.9	68.5	29%
Apr	55.2	54.2	1.8%
May	51.0	49.4	3.1%
Jun	49.4	49.7	-0.6%
Jul	60.7	61.2	-0.9%
Aug	58.3	58.6	-0.5%
Sep	46.5	46.6	-0.3%
Oct	98.4	73.1	26%
Nov	123	95.0	23%
Dec	139	114	18%
Total electricity use (kWh)	243,377	254,628	-4.6%

Figure 9 shows the effects of the setpoint adjustment for the Phoenix model for the heating "peak week" with lowest outdoor air temperature (36°F). Application of the measure successfully reduces the setback from the 8°F unoccupied setback originally in the "baseline" model to 2°F.

In this warm climate, the effects of the setback modification on heating power draw by both the heat pump compressors and supplemental heating coils are minimal. Figure 10 shows the compressor and supplemental heating power draw for application of the measure without setback modification, for the Phoenix location, along with outdoor air temperature, for the same week. As shown in Figure 10, supplemental heating power draw in this warm climate is small. The power drawn by the supplemental heating coil and heat pump compressor with the setback adjustment is almost identical and is not shown on the plot for clarity. For most hours in the year, the outdoor air temperature in this location is above 50°F, virtually eliminating the need for supplemental heating. This measure is being applied in all climate zones, but the impacts from it in cooling-dominated climates such as Phoenix are expected to be minimal. Confirming this, Figure 11 shows peak demand by month with and without the setback reduction in the retail building in Phoenix. The values with and without the setback reduction are almost identical.

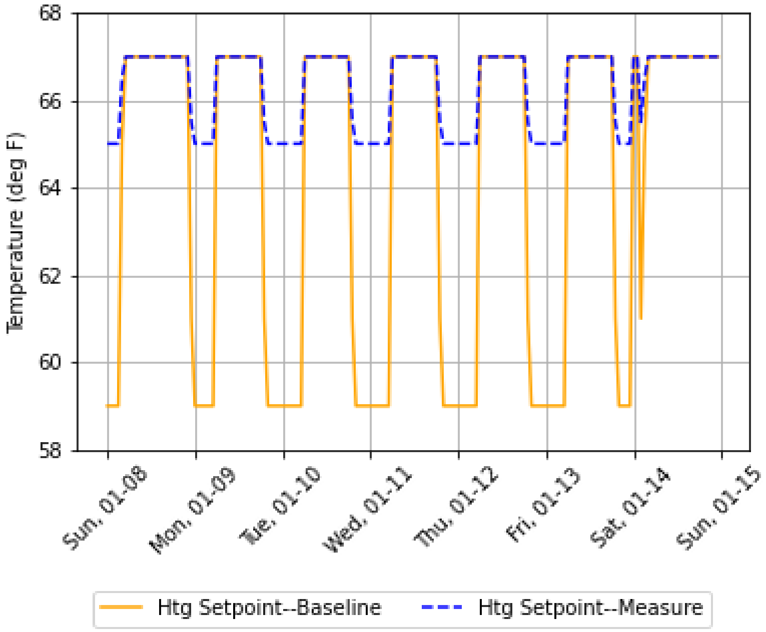


Figure 9. Implementation of 2°F unoccupied setbacks through measure application compared to baseline model for Phoenix, during week of coldest outdoor air temperature

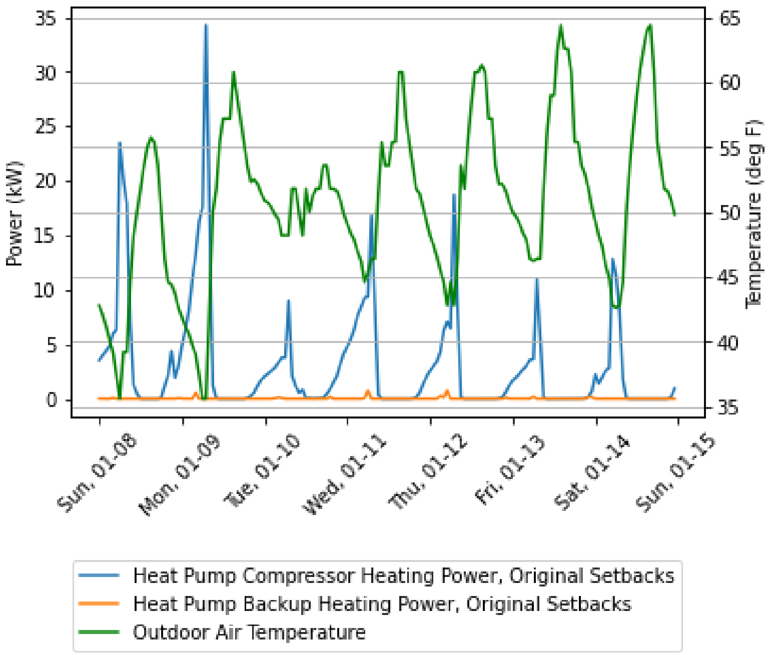


Figure 10. Heat pump compressor and supplemental heating power, with original setbacks approach, during week of coldest outdoor air temperature, Phoenix

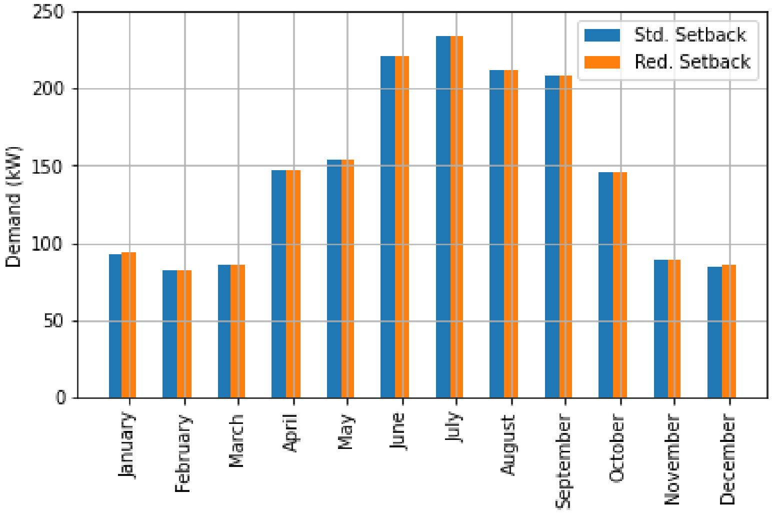


Figure 11. Building-level peak demand by month for cases with and without setback reductions, Phoenix

5.2 Stock Energy Impacts

The HP-RTU with reduced setbacks measure demonstrates 6.7% total site energy savings (328 trillion British thermal units [TBtu]) relative to the baseline for the U.S. commercial building stock modeled in ComStock (Figure 12 and Figure 13 show disaggregation of site energy use for all buildings and only those to which the upgrade was applicable, respectively). The savings of the reduced setback measure relative to the baseline are primarily attributed to:

- 33.2% stock heating natural gas savings (320.0 TBtu)
- -44.1 % stock heating electricity savings (-114.7 TBtu)
- 12.0% stock fan electricity savings (68.0 TBtu).

The reduction in heating natural gas use and increase in heating electricity use results from replacement of natural gas-fired heating systems with electrical ones. See the documentation for the Standard Performance HP-RTU measure for more detail [11]. The HP-RTU with reduced setbacks measure demonstrates a minimal increase in energy use (21 TBtu), relative to the HP-RTU measure with standard setbacks (as they exist in the stock today). The HP-RTU measure with standard setbacks is an important comparison point to isolate the effects of the setback reduction.

The small energy penalty relative to the measure with standard setbacks is primarily attributable to a 5% increase in heating electricity use (17.9 TBtu) and a small (less than 1%) increase in fan energy use (2.5 TBtu). This is because the intent of the measure is to implement a recommended 2°F thermostat setback for buildings with heat pumps, which in many cases results in a higher heating setpoint during unoccupied periods compared to the original building. This generally increases the heating load, with the intended benefit of potentially reducing peak demand and the correlated utility bills. In other words, it is expected that many buildings would experience increased annual heating load and energy use as a result of this change. This may not be the case with all buildings, however, as the measure scenario also adds a 2°F unoccupied setback to buildings that previously had none. The primary benefit of the reduction in setbacks is expected to lie in peak demand reduction and utility cost savings, as well as the improved thermal comfort of a faster morning warm-up.

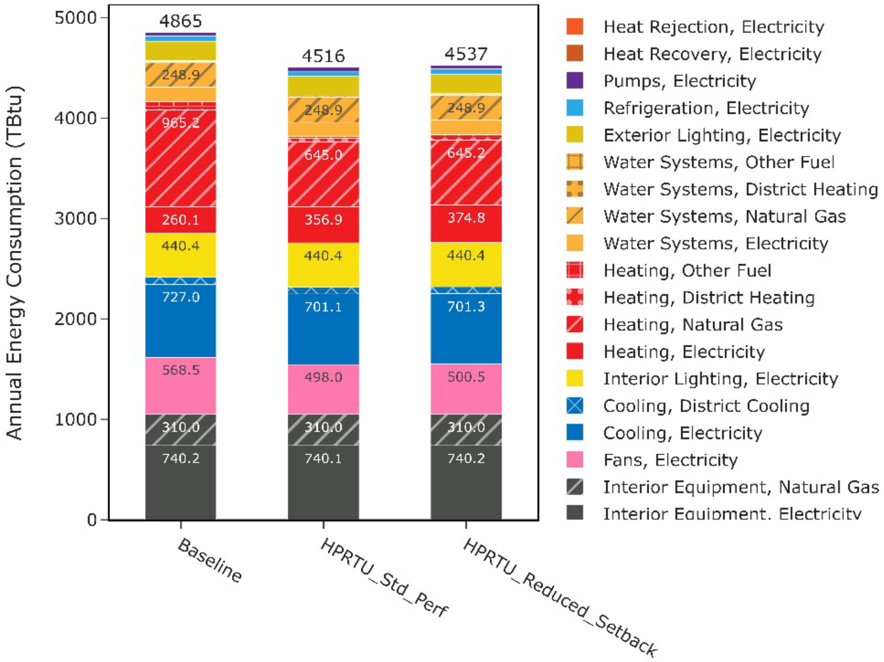


Figure 12. Comparison of annual site energy consumption between the ComStock baseline and the HP-RTU reduced setbacks measure scenario for the total building stock, including buildings not applicable to the measure scenarios. (The HP-RTU upgrade with standard setbacks is shown for comparative purposes.) Energy consumption is categorized both by fuel type and end use.

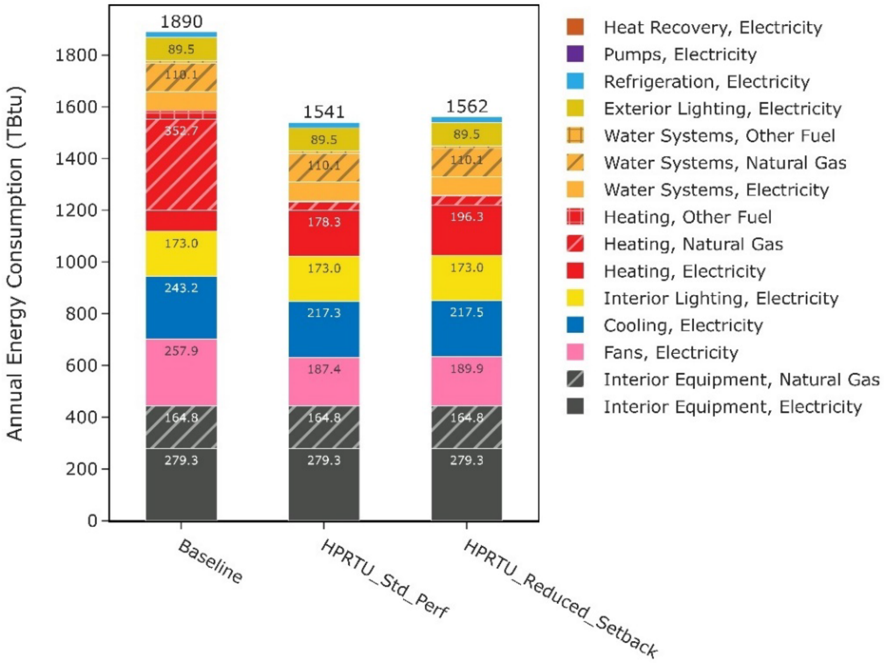


Figure 13. Comparison of annual site energy consumption between the ComStock baseline and the HP-RTU reduced setbacks measure scenario for applicable buildings only. (The HP-RTU upgrade with standard setbacks is shown for comparative purposes.) Energy consumption is categorized both by fuel type and end use.

5.3 Stock Utility Bill Impacts

This section includes a comparison of national-level annual utility bills that buildings are subject to across different energy sources (i.e., electricity, natural gas, propane, fuel oil). Because we apply many electricity utility rate structures that are available for a building located in a certain geographical location, our data include many annual utility bills per building model. The comparison in this section highlights three statistics (i.e., maximum, mean, and minimum) across all electric utility bill costs.

Figure 14 shows a comparison of total utility bill costs with minimum, mean, and maximum electricity rates for the HP-RTU with reduced setbacks measure, the ComStock baseline, and the HP-RTU measure with standard setbacks. Depending on the electric rate scenario considered, the measure with standard setbacks results in a 3%–4% reduction in annual utility bill costs relative to the ComStock baseline. The overall utility bill savings through this measure results from natural gas cost savings more than offsetting the increase in electricity costs due to increased electricity use for heating.

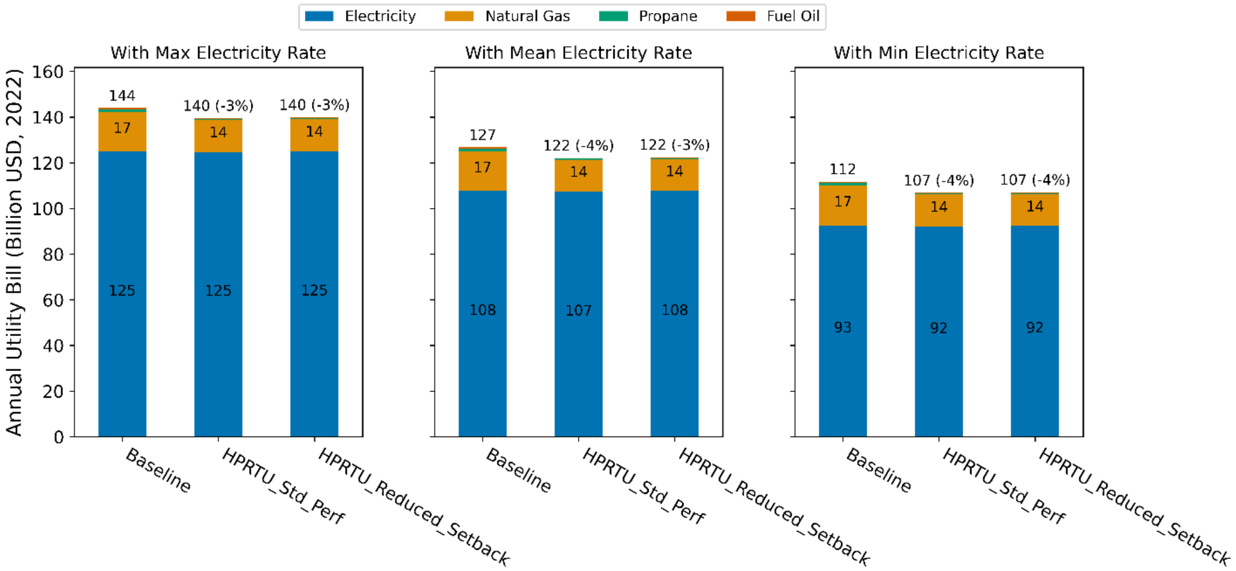


Figure 14. Utility bill comparison of the ComStock baseline and the HP-RTU with reduced setbacks scenario. (The HP-RTU scenario with standard setbacks is shown for comparative purposes.)

Electricity rates for commercial buildings generally have two main components: energy charges and demand charges. Application of the setback reduction is expected to result in a reduction in peak demand in months in which heating drives peak demand, with a small penalty in overall electricity consumption due to the longer periods of operation at higher heating setpoints. In buildings in which a peak demand reduction occurs due to the reduction in setbacks, a reduction in demand charges is expected, but the increased charges associated with an increase in electricity use may offset this, depending on the rate structure and the magnitude of the two changes.

Further analysis of utility bill effects was carried out considering only the sample of buildings to which the Heat Pump RTU measure was applicable. Among these buildings, in the aggregate, implementation of the reduced setbacks results in a very small (0.7%) increase in mean total utility bills relative to the standard setbacks. Many buildings (43.6%) see savings in utility bills through the setback reduction relative to standard setbacks. (45.2% of buildings see either savings in utility bills or no change through the setback reduction.) A very small fraction of buildings (1.9%) see a notable increase (10% or more) in utility bills through the setback reduction relative to standard setbacks. Figure 15 illustrates a histogram of utility cost savings with reduced setbacks relative to standard setbacks.

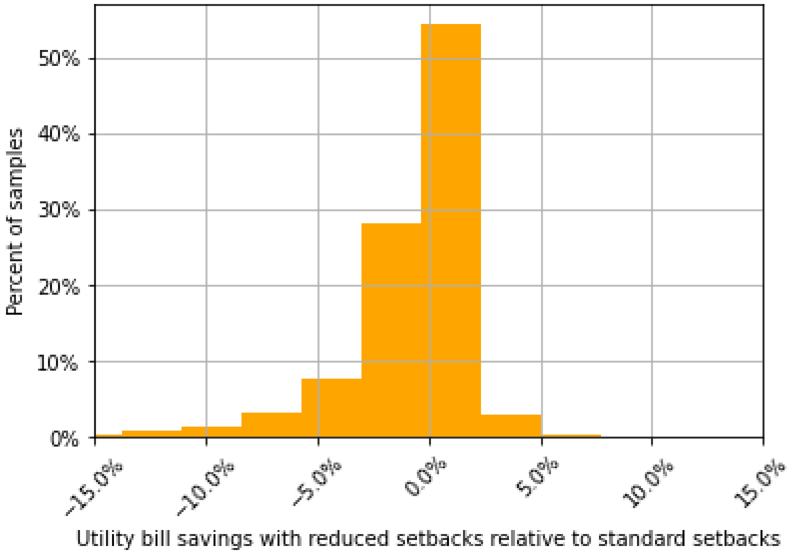


Figure 15. Distribution of utility bill savings with reduced setbacks, relative to standard setbacks, under mean electricity bill. Note that the upper and lower tails of the distribution are not shown for concision.

Focusing on buildings in which a non-negligible (greater than 1%) reduction in winter peak demand occurs through the reduced setbacks highlights the trade-offs between demand reduction and increases in electricity consumption. (This represents about 47% of those buildings receiving the heat pump RTU upgrade). Figure 16 shows a scatter of reduction in mean utility bills vs. reduction in winter peak demand, for those buildings with a non-negligible winter peak reduction. For concision, some outliers have been removed. Over this subset of data, there is a roughly linear relationship between utility bill savings and electricity savings, suggesting that electricity savings drives the utility bill impacts over this range. Either a small amount of electricity savings or a limited penalty allows the demand reduction to result in an overall reduction in utility bills. The coefficient of determination (R^2) value indicates that electricity savings explains about 53% of the variation in mean total utility bills. Note that utility bills encompass natural gas as well as electricity, and the reduction in natural gas energy use, and cost, is almost identical between the setback scenarios. About 17% of buildings in the sample experienced a non-negligible (greater than 1%) decrease in electricity use through the reduced setbacks. This is driven by a reduction in supplemental heating energy use.

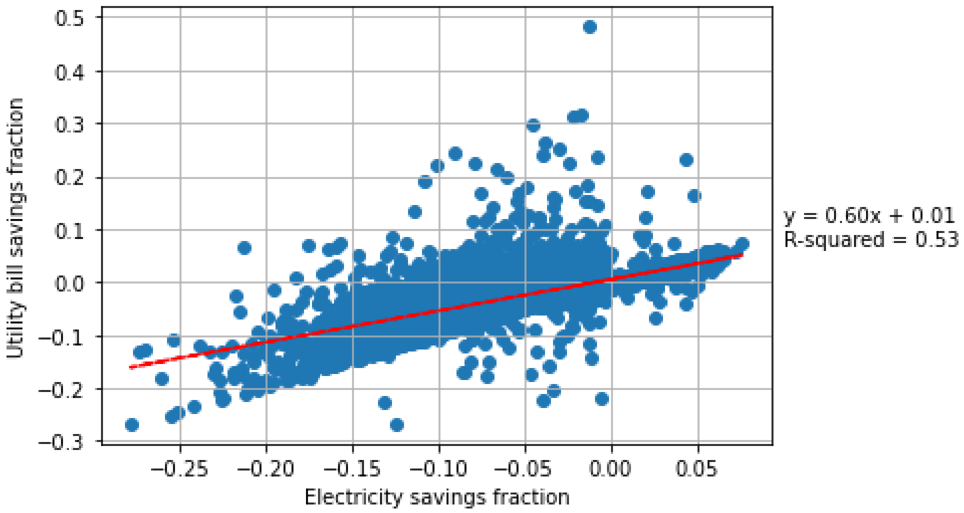


Figure 16. Scatter of utility bill savings fraction vs. electricity savings fraction for buildings with winter demand reduction of at least 1% through the reduced setbacks. Note that some outliers have been removed for concision.

Considering the demand charge and energy components of electricity costs separately is also informative. Of the applicable buildings, 71% observe a reduction in maximum daily demand during winter through the application of this measure, relative to the standard setbacks. Note that this implies only a reduction in demand charges for the month in which the baseline seasonal maximum occurs. Other winter months could see an increase in peak demand. Just over half of applicable buildings (51%) observe either no change, or a reduction in annual demand charges through this measure. Seventy-one percent of applicable buildings observe a small change (an increase or decrease in demand charges of less than 2% through application of the measure).

Figure 21 shows a distribution of the fraction of reduction in maximum daily winter peak demand through this measure, compared with the standard setbacks. A notable fraction (22.4%) of the applicable sample sees a small penalty (an increase, and an increase of less than 2.5%) in maximum daily winter peak demand through the setback reduction. This reflects a version of the behavior observed in the Single Building Measure Test, where the reduction in setbacks can cause an increase in peak demand over a particular period in some cases, such as when a new peak for backup heating aligns with higher building electrical loads than are present during morning warm-up.

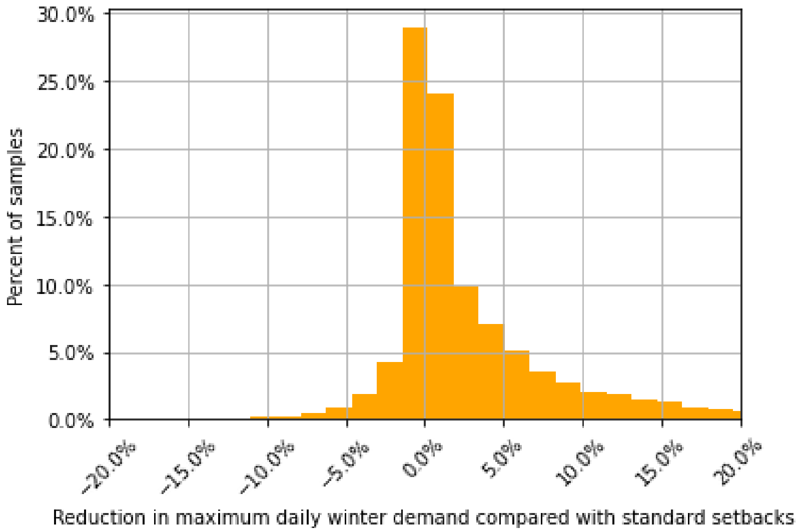


Figure 17. Distribution of reduction in maximum daily winter demand through the reduced setbacks, compared with standard setbacks

Figure 18 shows the distribution of fractional savings in demand charges through the setback reduction, relative to standard setbacks. As expected, the distributions in Figure 17 and Figure 18 generally follow a similar pattern, but with lower magnitudes of savings in demand charges, for the reasons explained previously.

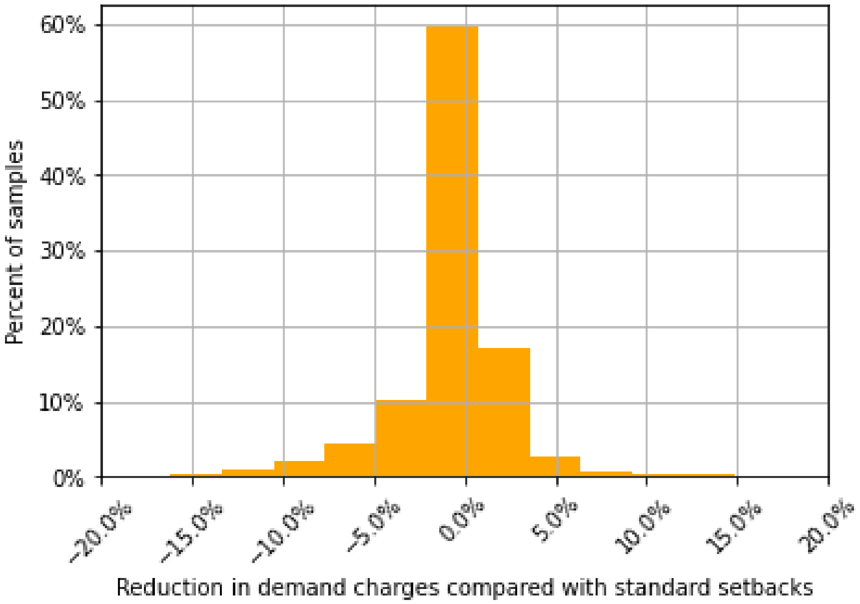


Figure 18. Distribution of fractional savings in demand charges through reduced setbacks, compared with standard setbacks

5.4 Stock CO_2e Impact

Figure 19 shows ComStock simulation results for CO_2e avoided across all electricity grid scenarios and on-site combustion fuel types. Three electricity grid scenarios are presented in this report, but other scenarios are available in the ComStock public dataset.

Depending on the emissions scenario considered, the HP-RTU with reduced setbacks measure results in a 4%–7% reduction in emissions relative to the ComStock baseline.The standard performance HP-RTU measure results in emissions reductions of 5-8% relative to the baseline. The level of emissions reductions for the two measures increases with the penetration of renewable electricity generation associated with the scenario. With greater levels of renewable generation, heating with electricity, as opposed to natural gas, results in greater emissions reductions. Across emissions scenarios, the HP-RTU with reduced setbacks measure results in a small (<= 1%) increase in emissions relative to the measure with standard setbacks. These small increases are the result of a slight increase in heating electricity use under the reduced setbacks measure Emissions reductions are not intended to be a key metric for the thermostat setback portion of this measure scenario.

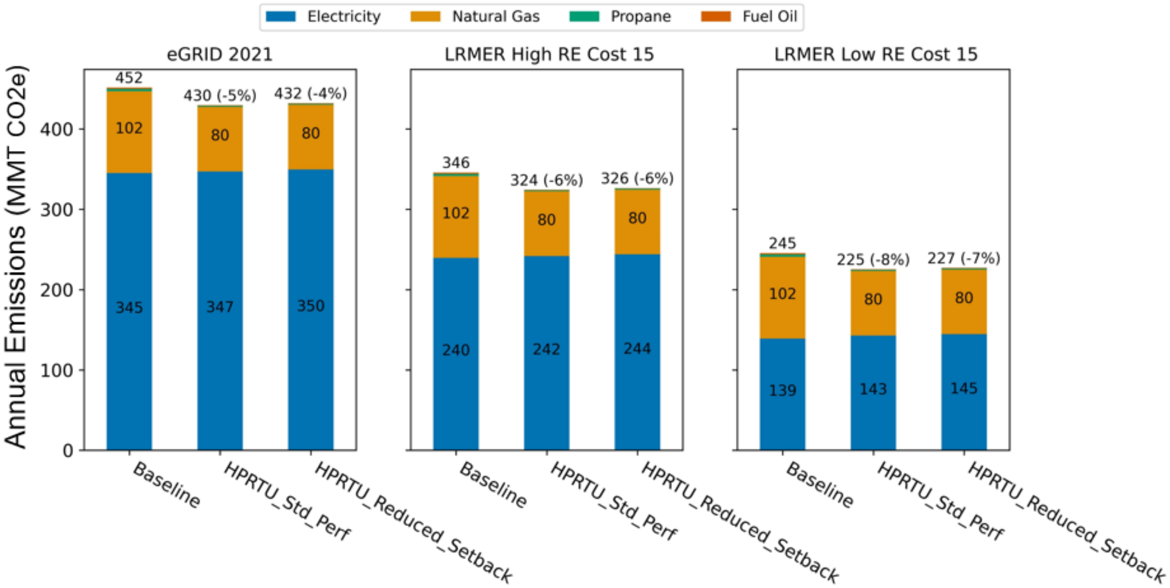


Figure 19. CO_2e emissions comparison of the ComStock baseline and HP-RTU upgrade with reduced setbacks. (The HP-RTU measure with standard setbacks is shown for comparative purposes.)

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.

5.5 Site Energy Savings Distributions

This section discusses site energy consumption for quality assurance/quality control purposes for the Reduced Thermostat Setbacks for Heat Pumps measure. Note that while site energy savings can be informative for these purposes, they don't always correspond directly to outcomes of greater practical significance, such as source energy savings, reduced energy bills, or avoided CO_2e emissions. It's important for a decisionmaker to consider which metrics best align with their specific goals or context. See the documentation for the Standard Performance HP-RTU measure for analysis of the savings impact of that measure alone [11].

Figure 20 shows percent site energy savings distributions by end use for the HP-RTU with reduced setbacks measure compared to the corresponding baseline model. For comparison purposes, Figure 21 shows the same distributions for the HP-RTU measure with standard setbacks. The percent site energy savings by end use are very similar for the two measures. The very small changes in refrigeration energy use observed for some buildings under both measures results from slight variations in indoor air temperature. Both measures show a reduction in interior equipment electricity use for a small number of models (30-40). This is the result of a known issue in the ComStock workflow that results in different schedules between the baseline and upgrade workflows. The effect of this bug on the overall energy results is negligible.

Figure 22 and Figure 23 show percent site energy savings distributions by climate zones for the HP-RTU measures with and without setbacks, respectively. Distributions of energy savings by climate zone are also very similar between the two measures, with a few exceptions. Climate Zones 3A, 4A, 5A, 6B, and 8 have a longer portion of the distribution with negative energy savings under the reduced setbacks, relative to standard setbacks, though this accounts for a small number of datapoints. (Climate Zone 8 has only around 240 samples in total applicable to this measure.) In general, the HP-RTU with reduced setbacks measure has a slight energy penalty relative to the HP-RTU measure with standard setbacks, as expected, due to the greater number of hours with heating operation at higher setpoints.

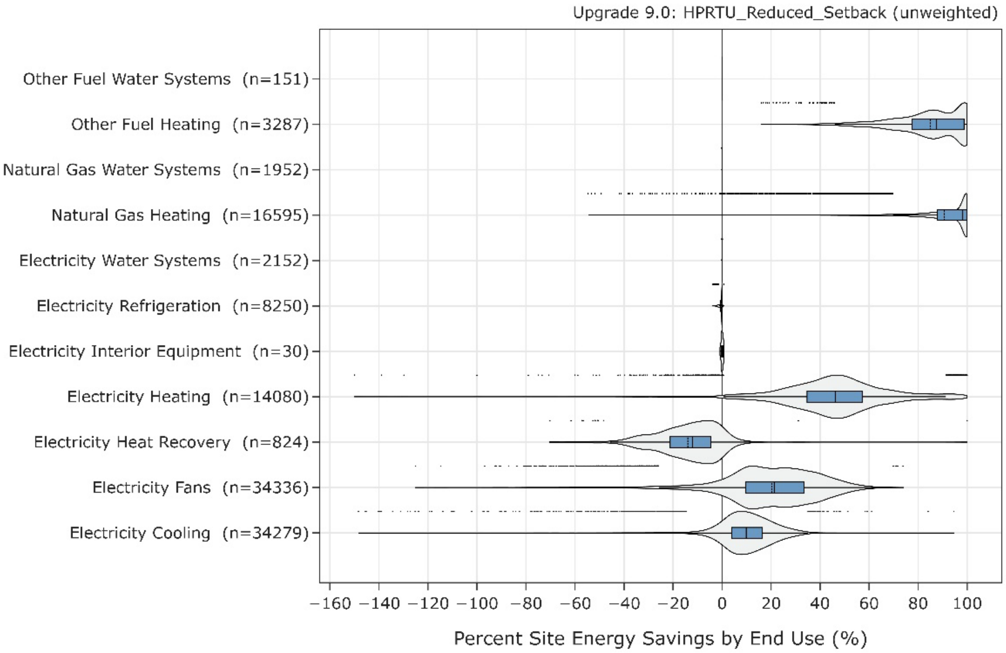


Figure 20. Percent site energy savings distribution for ComStock models with applied measure scenario (HP-RTU with reduced setbacks) by end use and fuel type. The data points that appear above some of the distributions indicate outliers in the distribution, meaning they fall outside 1.5 times the interquartile range. The value for n indicates the number of ComStock models that were applicable for energy savings for the fuel type category.

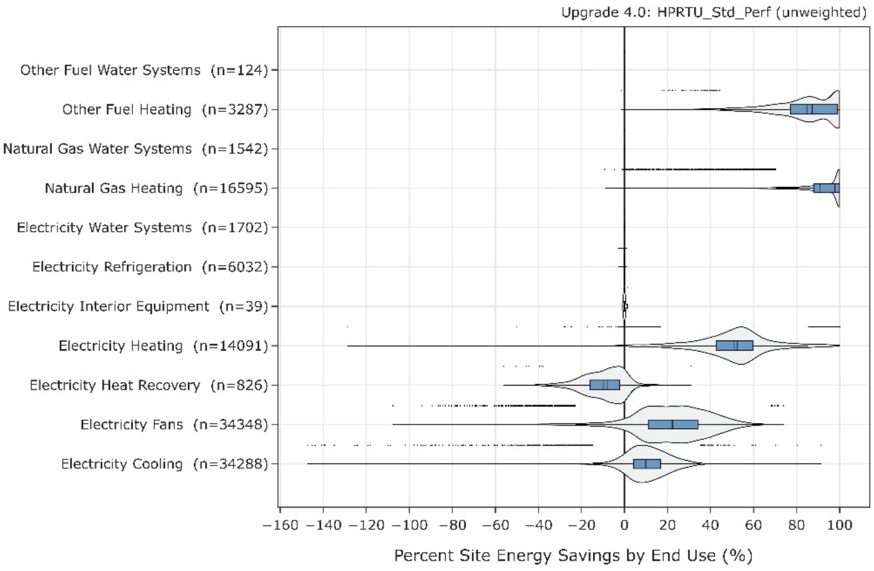


Figure 21. Percent site energy savings distribution for ComStock models with applied measure scenario (HP-RTU with standard setbacks) by end use and fuel type. The data points that appear above some of the distributions indicate outliers in the distribution, meaning they fall outside 1.5 times the interquartile range. The value for n indicates the number of ComStock models that were applicable for energy savings for the fuel type category.

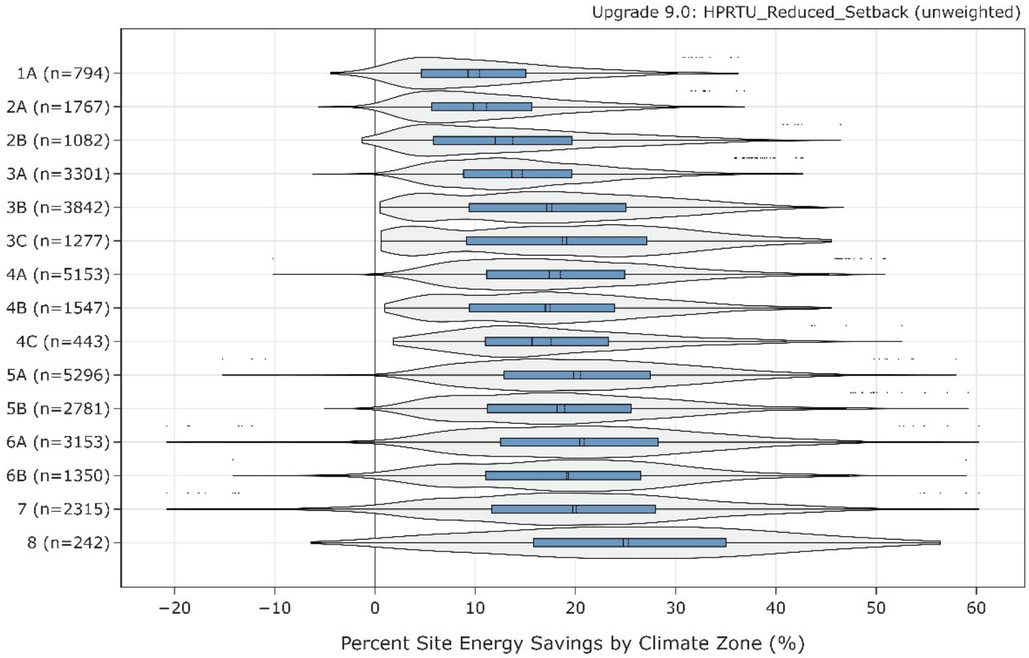


Figure 22. Site energy use intensity savings (compared to baseline) distribution for ComStock models with the applied HP-RTU setback measure by climate zone

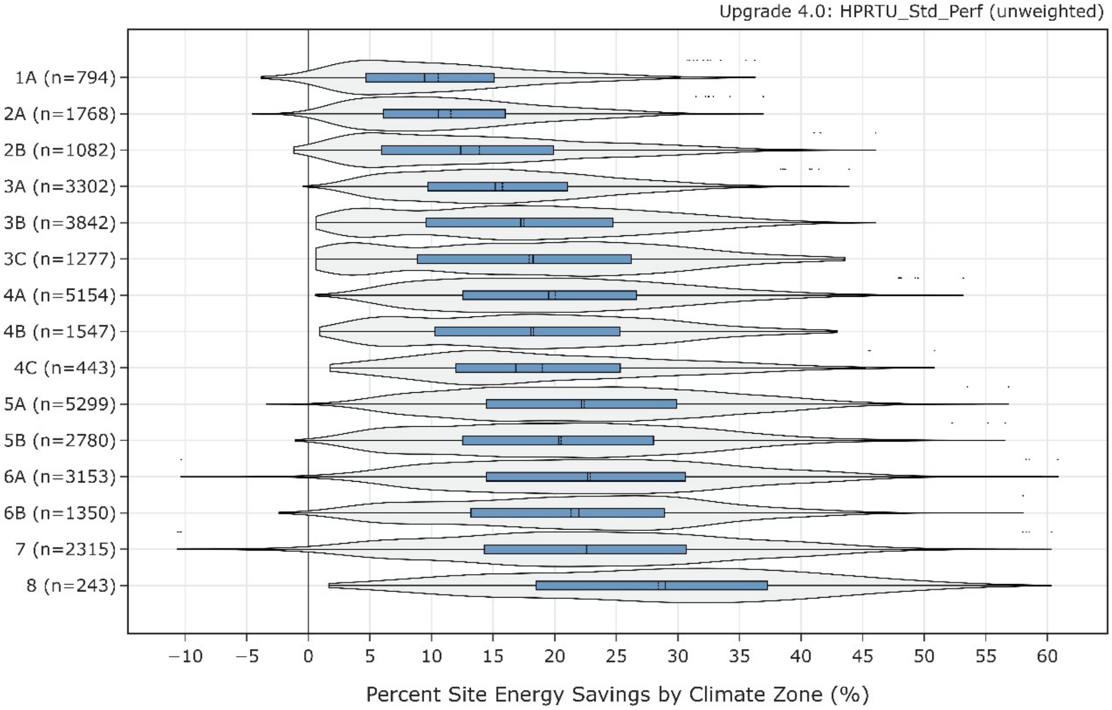


Figure 23. Site energy use intensity savings (compared to baseline) distribution for ComStock models with the applied HP-RTU measure by climate zone

5.6 Peak Demand Impacts

The primary motivation for the reduction in setbacks for HP-RTUs is expected demand reduction during the heating season. It is expected that reduced setbacks would reduce power draw from supplemental heat, and that in some cases, this would reduce overall peak demand in months when heating loads are dominant, which can also translate to lower energy bills, depending on rate structure. Maximum peak daily demand by month, average daily demand, and timing of peak demand by month were among the metrics used to assess impacts on peak demand. Results on maximum peak daily demand in January, timing of winter peak demand, and average daily demand over the winter season are presented here. The months of November through February exhibited generally similar trends with maximum peak daily demand distributions.

Through implementation of this measure, most buildings (71%) experienced a reduction in the average daily peak over the winter season. For the purposes of utility bills, reduction in monthly peak demand is also important to consider. Sixty-one percent of buildings experienced a reduction in January peak demand by using the reduced setbacks.

Figure 24 shows distributions of maximum peak daily demand in January for selected building types for the HP-RTU measure for cases with reduced setbacks and standard setbacks. (Some outliers have been removed, for concision, in both figures.) The reduction in setbacks generally shifts the distributions slightly lower or leaves them unchanged. The reduced setbacks uniformly reduce the median value of peak demand, or leave it virtually unchanged, for all building types. Among the highest reductions in median values of peak demand are primary schools, with a 9% reduction, and secondary schools, with a 7% reduction. Under the ComStock approach for modeling hours of operation (based on an Advanced Metering Infrastructure dataset for commercial buildings), schools tend to have longer unoccupied periods than other building types [12]. The longer unoccupied periods would impose a higher “catch-up” load with larger setbacks, which likely explains the trend with schools.

There can be cases where reducing power demand during the morning warm-up does not necessarily reduce a building’s maximum peak demand for the month. For example, if the building’s electrical peak occurs during the middle of the day due to a dominating prevalence of other non-HVAC loads, e.g., plug loads and lighting, then reducing the morning HVAC peak might not reduce the monthly maximum peak of the building. Increases in peak demand could occur as a result of this measure if the increased operation of heat pumps for heating in unoccupied hours resulted in setting a new peak, especially if supplemental heat were operating due to compressor lockout for cold outdoor air temperatures. (See the Single-Building Measure Test section for discussion of this in more detail.) This likely explains the cases reflected in the distributions in which demand increased slightly through the setback reduction.

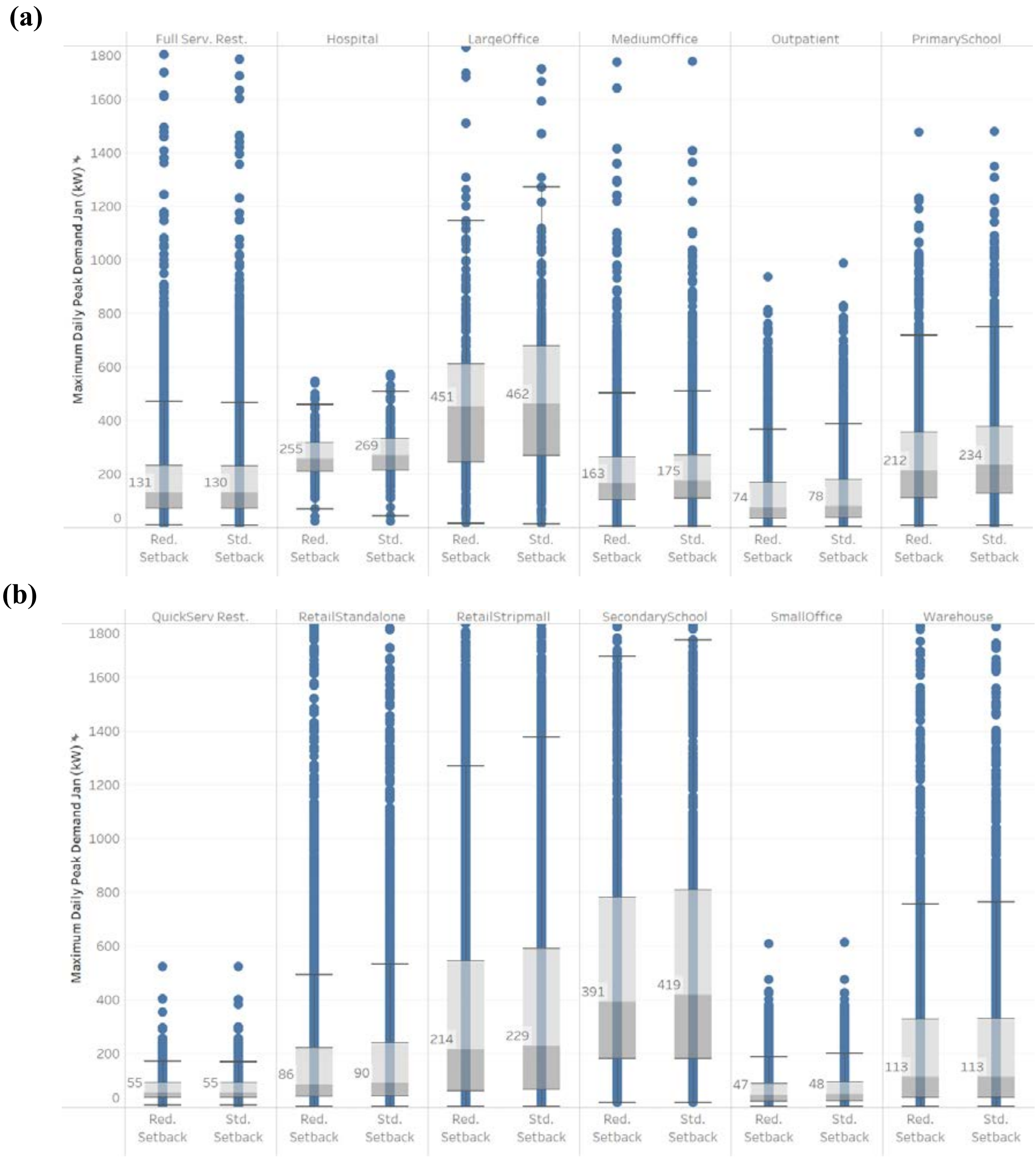


Figure 24. Distributions of maximum peak daily demand in January for selected building types for the HP-RTU measure for cases with reduced and standard setbacks, with median values labeled.

Labels for 25th and 75th percentiles are omitted for readability; please see the Appendix (Figure A-5) for a version with those points percentiles labeled. (Note that some outliers have been removed for concision.)

Figure 25 (a and b) shows the same distributions by climate zone. Across climate zones, the reduction in setbacks generally shifts the distributions of peak demand for January slightly lower, or leaves them unchanged. Some of the largest reductions in peak demand occur in the 75th percentile and median values for climate zone 4C (both 10%). Climate zones with very cold conditions (7 and 8) see small increases in the 75th percentile values of their distributions through the reduced setbacks. This penalty could reflect the behavior discussed in the single-building measure test results, in which the peak reduced slightly in magnitude, and shifted to the evening.

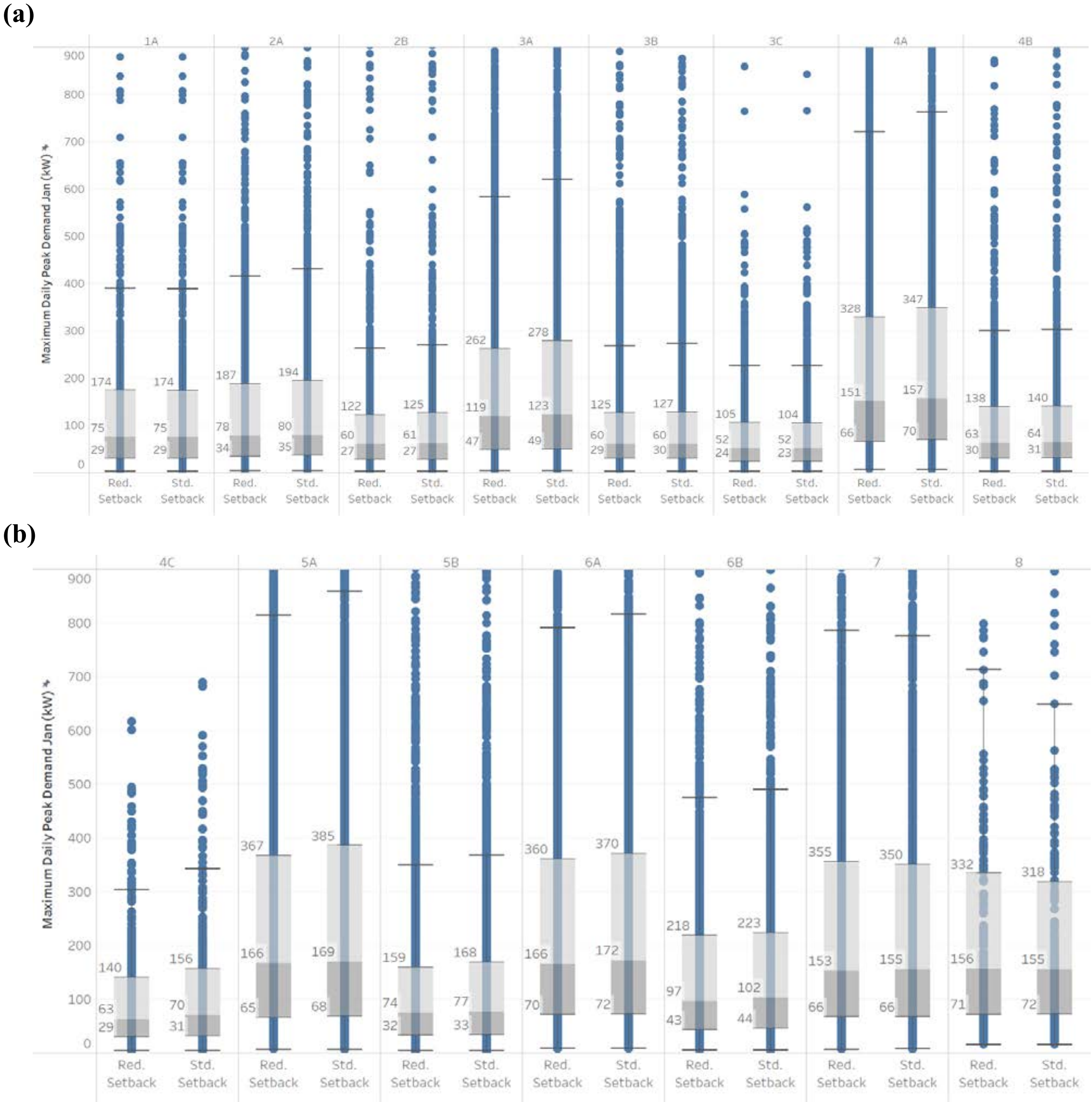


Figure 25. (a) Distributions of maximum peak daily demand in January for climate zones 1–4B for the HP-RTU measure with and without reduced setbacks, with 25th and 75th percentiles shown, and medians. (Note that some outliers have been removed for concision.) (b) The same as (a) but for climate zones 4C–8.

Figure 26 (a and b) shows distributions of average maximum daily demand throughout the winter season by climate zone. By this metric, there are generally slight reductions in each distribution with the setback reduction, including for Climate Zones 7 and 8. Climate Zone 7 seeks a 6% reduction at the 75th percentile level. The fact that these distributions generally show more muted changes than the peak demand for a single month (January) reflects the effect of averaging daily maximum values over an entire season, as opposed to selecting a maximum value for a month.

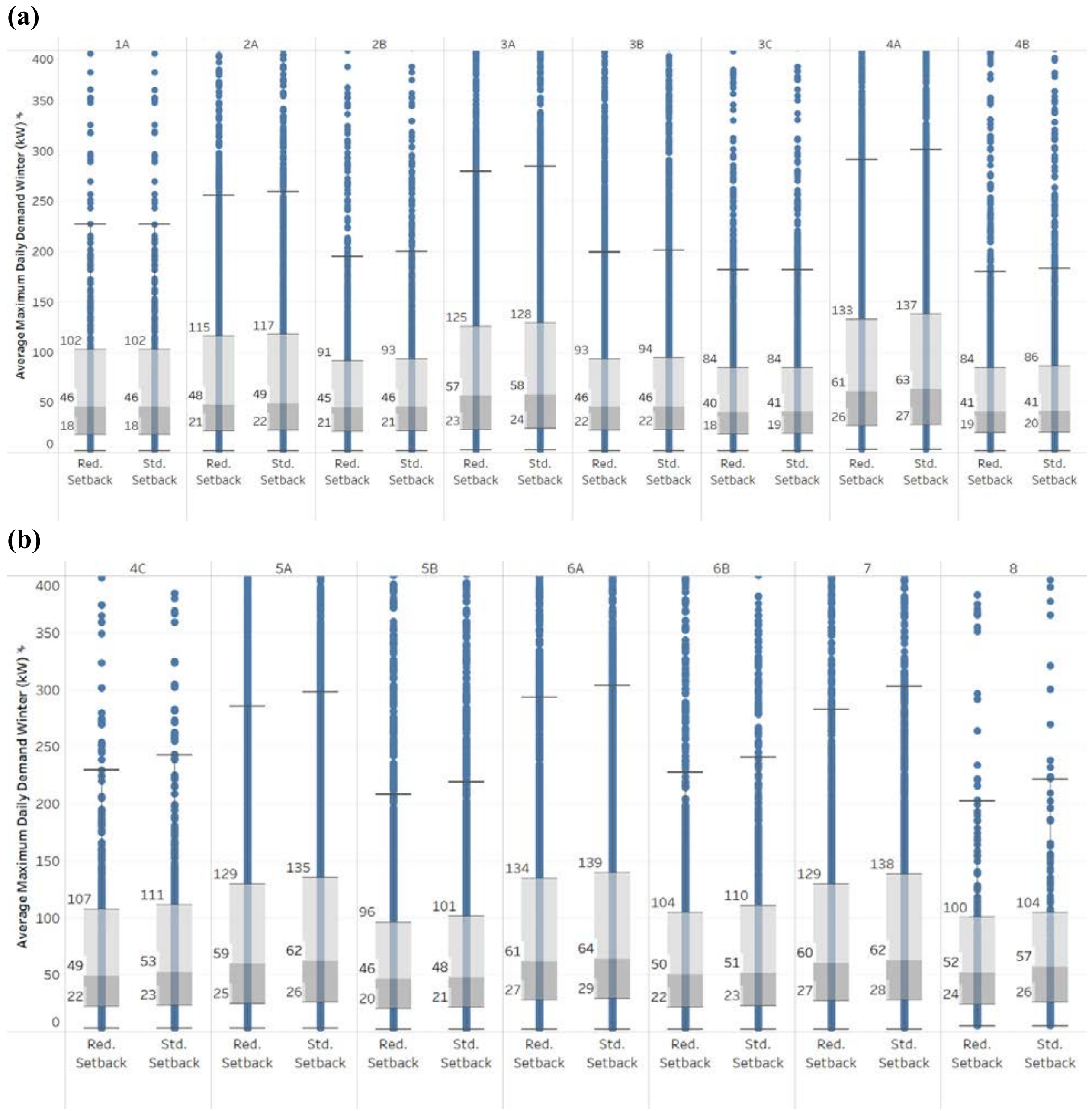


Figure 26. (a) Distributions of average maximum daily demand in winter for climate zones 1–4B for the HP-RTU measure with and without reduced setbacks, with 25th and 75th percentiles, and median values shown. (Note that some outliers have been removed for concision.) (b) The same as (a) but for climate zones 4C–8.

Figure 27 (a and b) shows distributions of the timing of the winter hourly peak by climate zone for the HP-RTU measure with reduced setbacks and standard setbacks. With a few exceptions (including Climate Zones 1A), the reduction in setbacks generally shifts the distributions of peak timing slightly later in the day, which is consistent with the expectation that the reduction in setbacks will reduce the likelihood of a peak during morning warm-up, when occupancy begins or just before. This shift in timing, in the overall distribution, is generally slight, by half an hour or less.

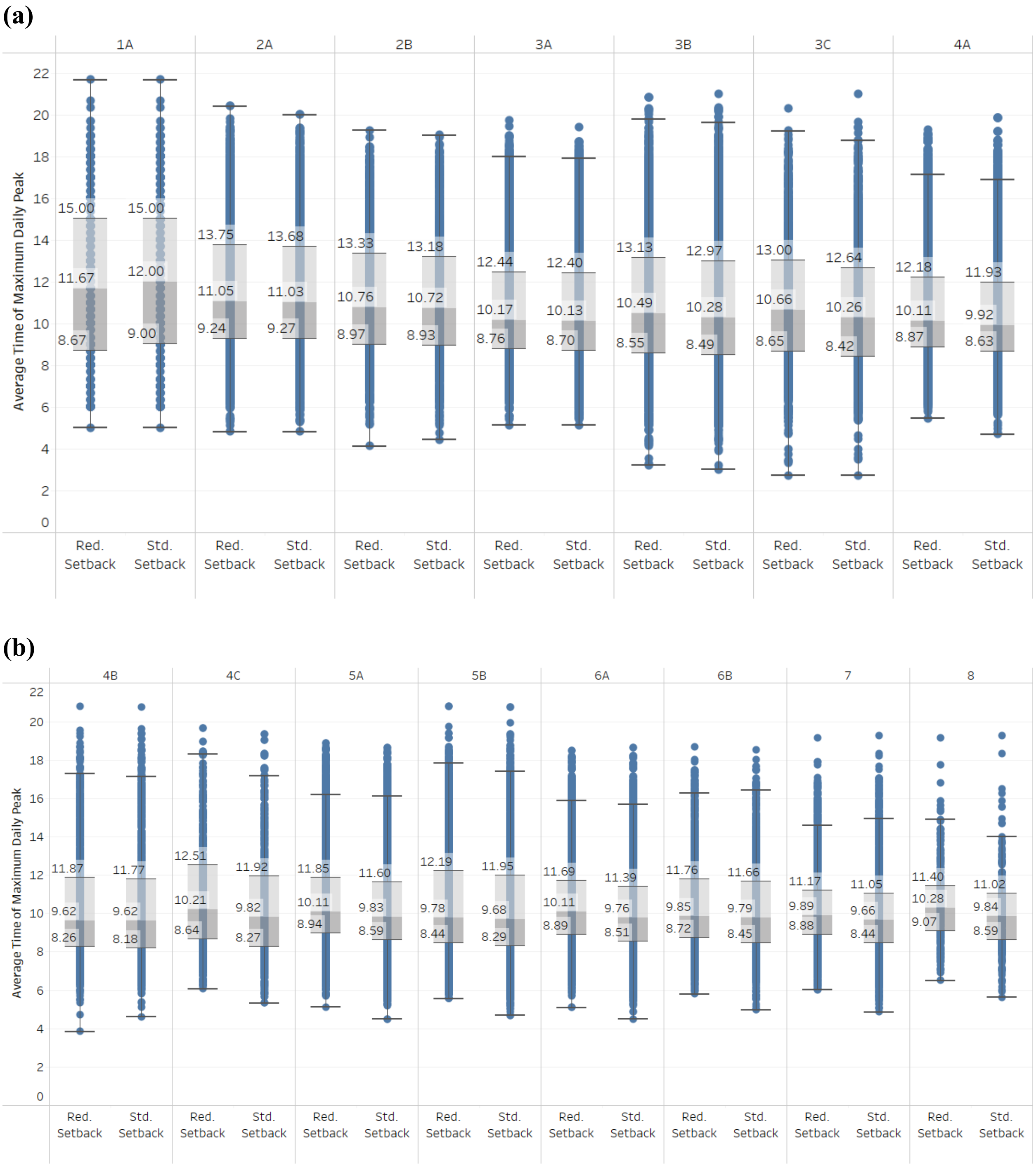
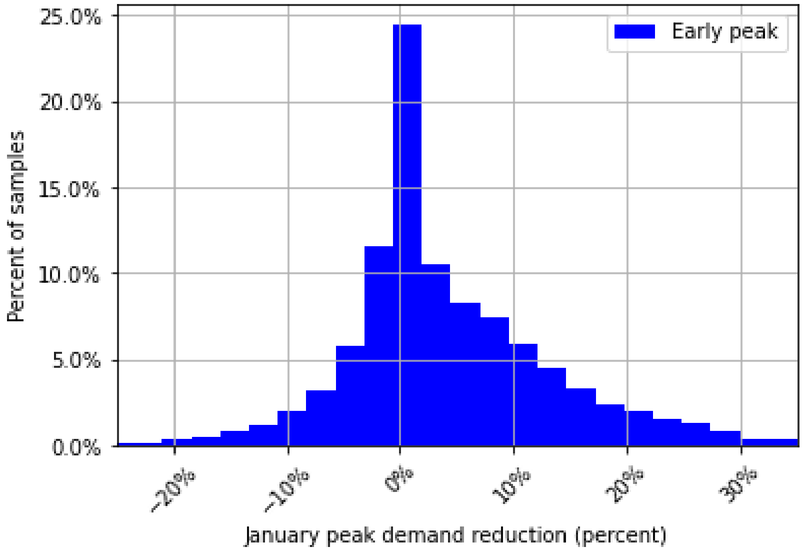


Figure 27. (a) Distributions of timing of the average maximum daily peak during winter by climate zone for climate zones 1A–4A, with 25th and 75th percentiles, and median values labeled, for the HP-RTU measure with and without reduced setbacks. (b) The same as (a) but for climate zones 4B–8.

Buildings with "early" winter peaks (an average timing of maximum peak demand in winter before 10 a.m.) exhibited somewhat higher January peak demand reduction than the sample as a whole. This selection of buildings with early winter peaks was used as a proxy for having winter peaks likely to be contributed to by heat pumps operating in morning warm-up. This trend is illustrated in Figure 28 (a and b). Among buildings with early winter peaks, 37% see a reduction in peak demand for January of greater than 5%, while for the sample as a whole, only 29% do. This trend is also exhibited in overall winter peak demand reduction. Among buildings with early winter peaks, 32% see an overall average winter demand reduction of greater than 5%, while for the sample as a whole, only 22% do. (This is consistent with the trend that seasonal reductions are more muted than those over an individual month.) Distributions of winter peak demand reduction for buildings with early winter peaks and the sample as a whole are shown in Figure 29.

(a)



(b)

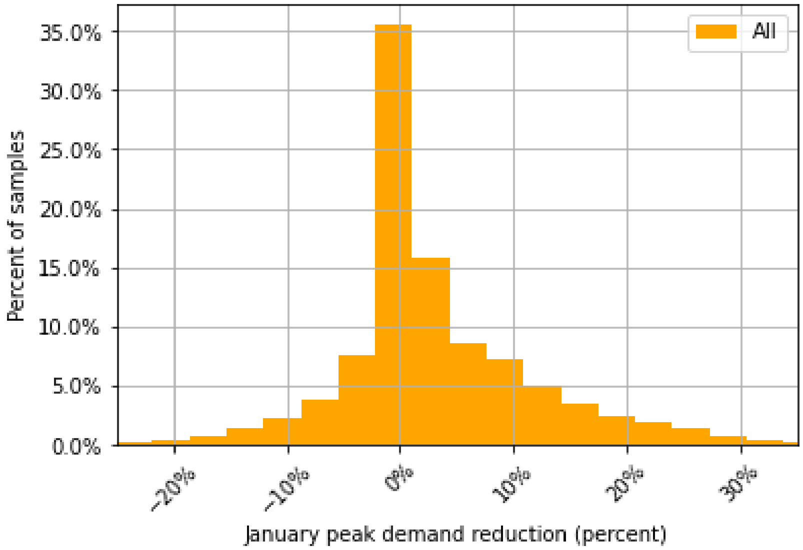
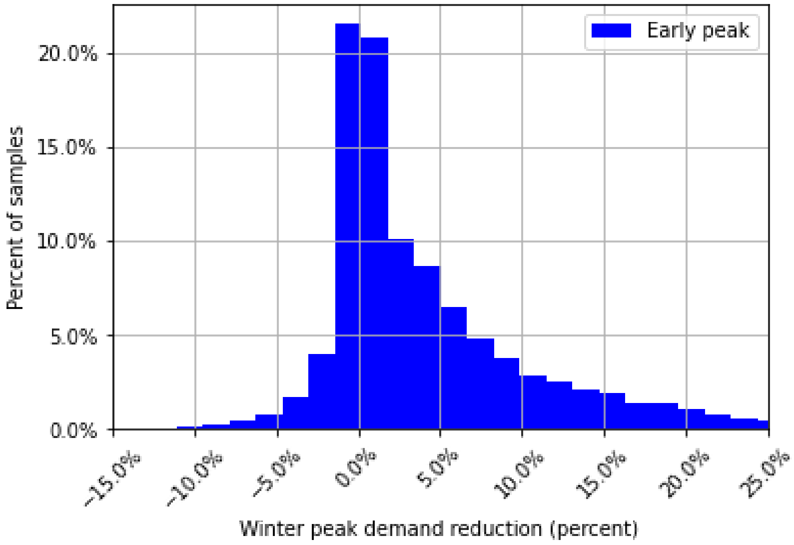


Figure 28. (a) Distributions of January peak demand reduction fraction through the reduced setbacks for buildings with "early" (before 10 a.m.) peak demand values in winter. (b) Distributions of January peak demand reduction fraction through the reduced setbacks for full sample.

(a)



(b)

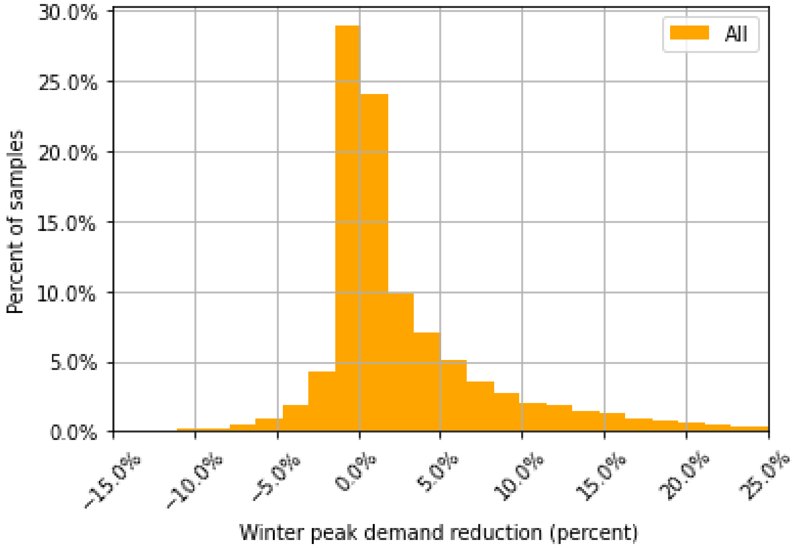


Figure 29. (a) Distributions of winter peak demand reduction fraction through the reduced setbacks for buildings with "early" (before 10 a.m.) peak demand values in winter. (b) Distributions of winter peak demand reduction fraction through the reduced setbacks for full sample.

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Appendix A.

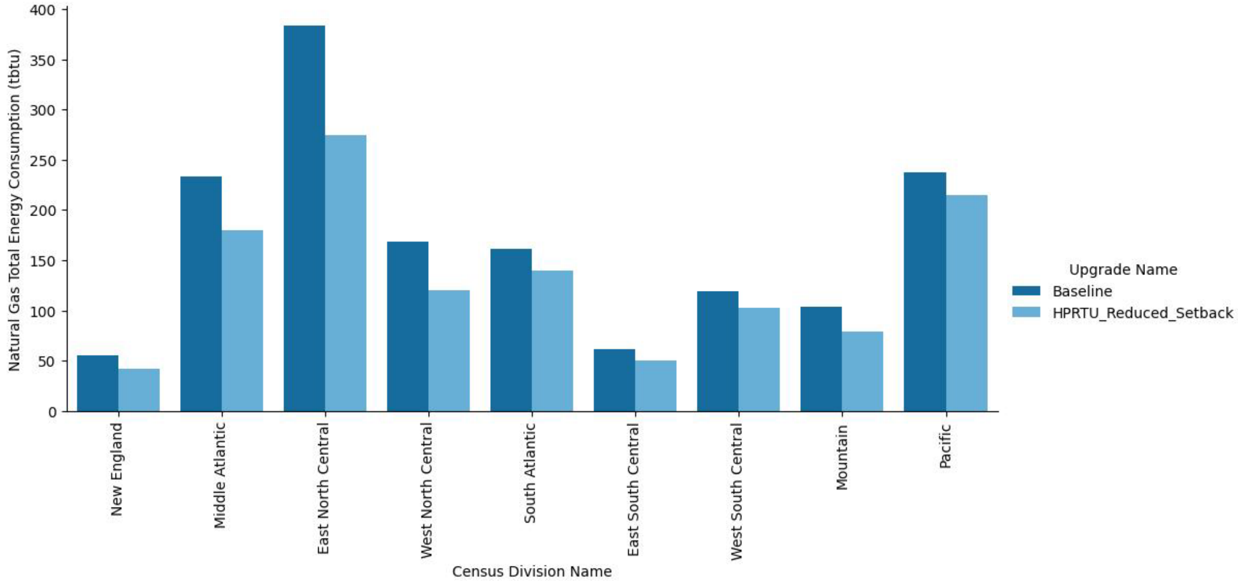

Figure A-1. Site annual natural gas consumption of the ComStock baseline and the measure scenario by census division

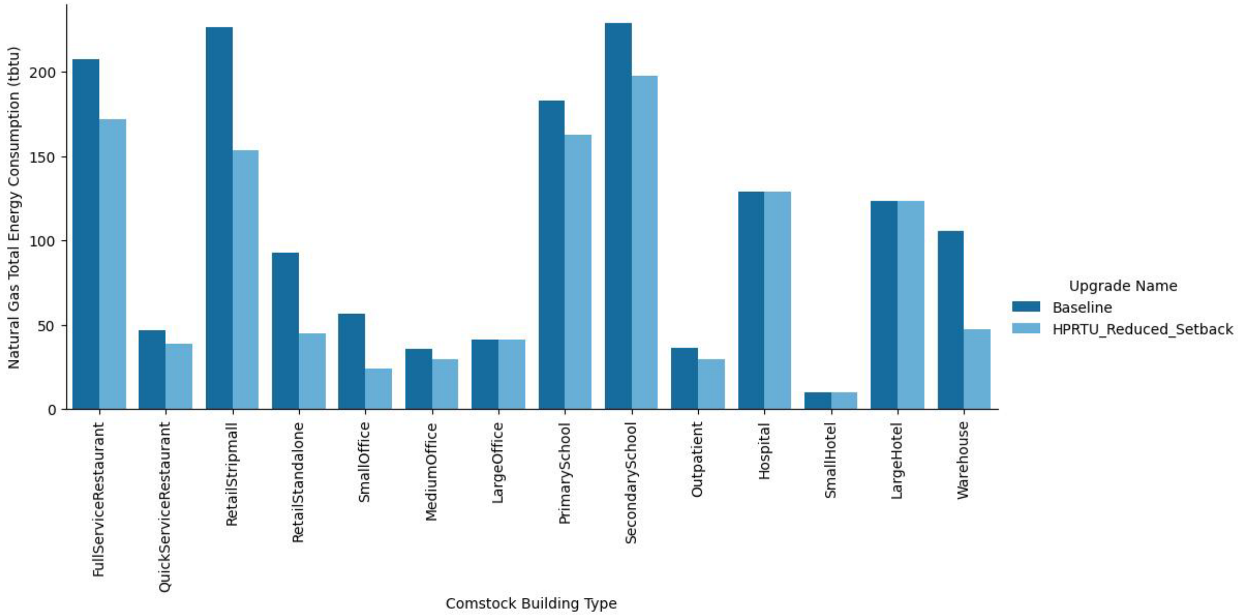

Figure A-2. Site annual natural gas consumption of the ComStock baseline and the measure scenario by building type

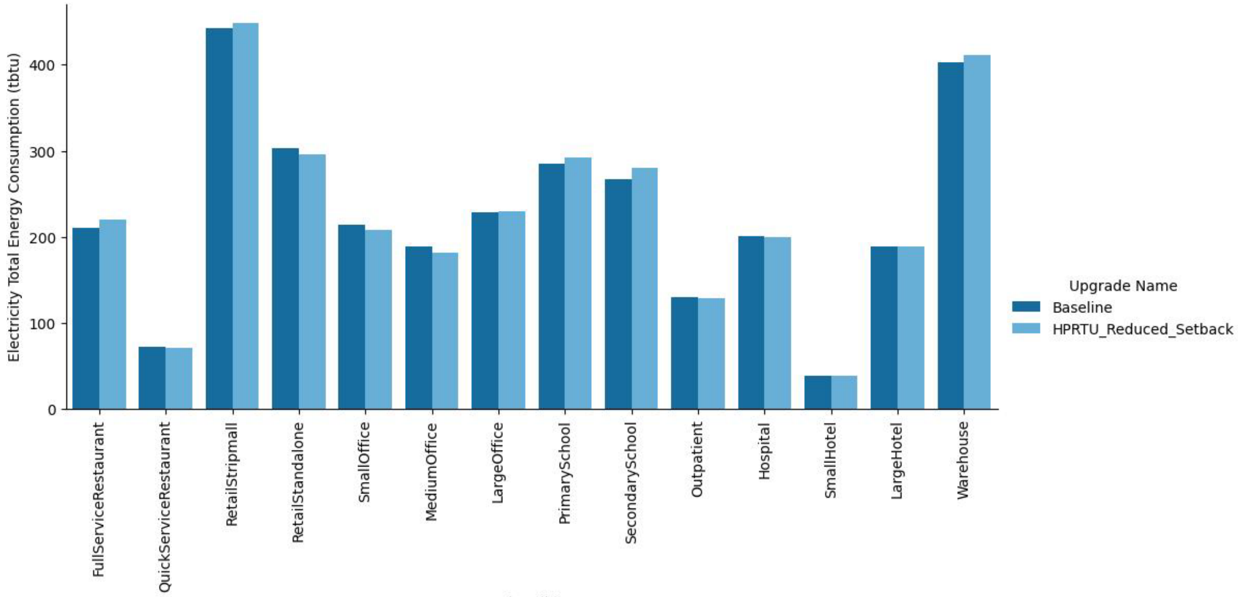

Figure A-3. Site annual electricity consumption of the ComStock baseline and the measure scenario by building type

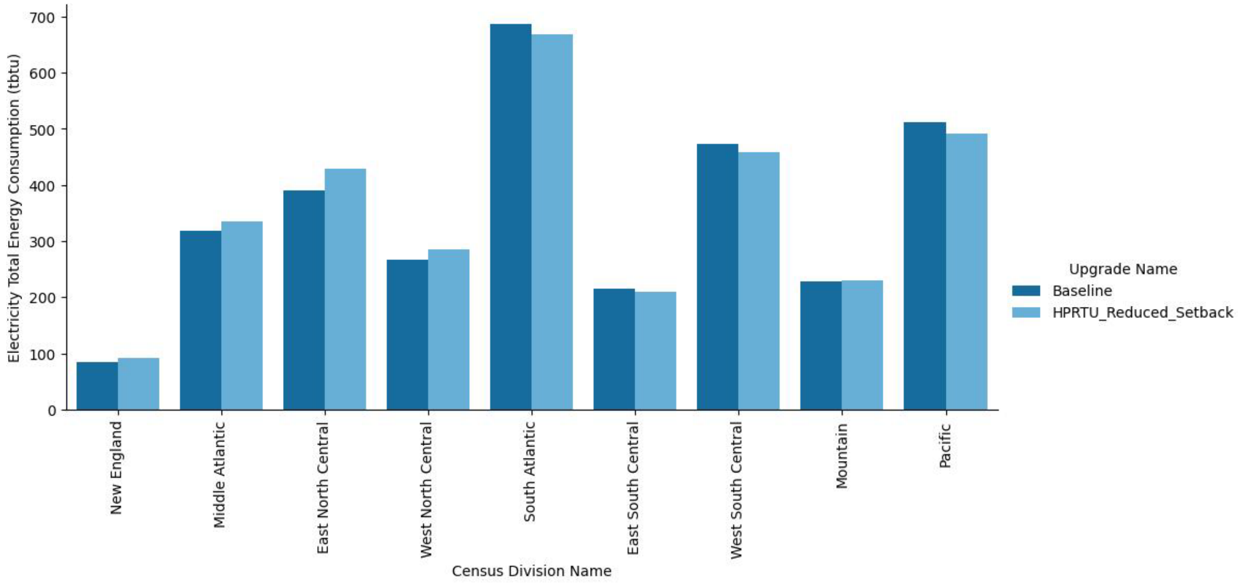

Figure A-4. Site annual electricity consumption of the ComStock baseline and the measure by census division

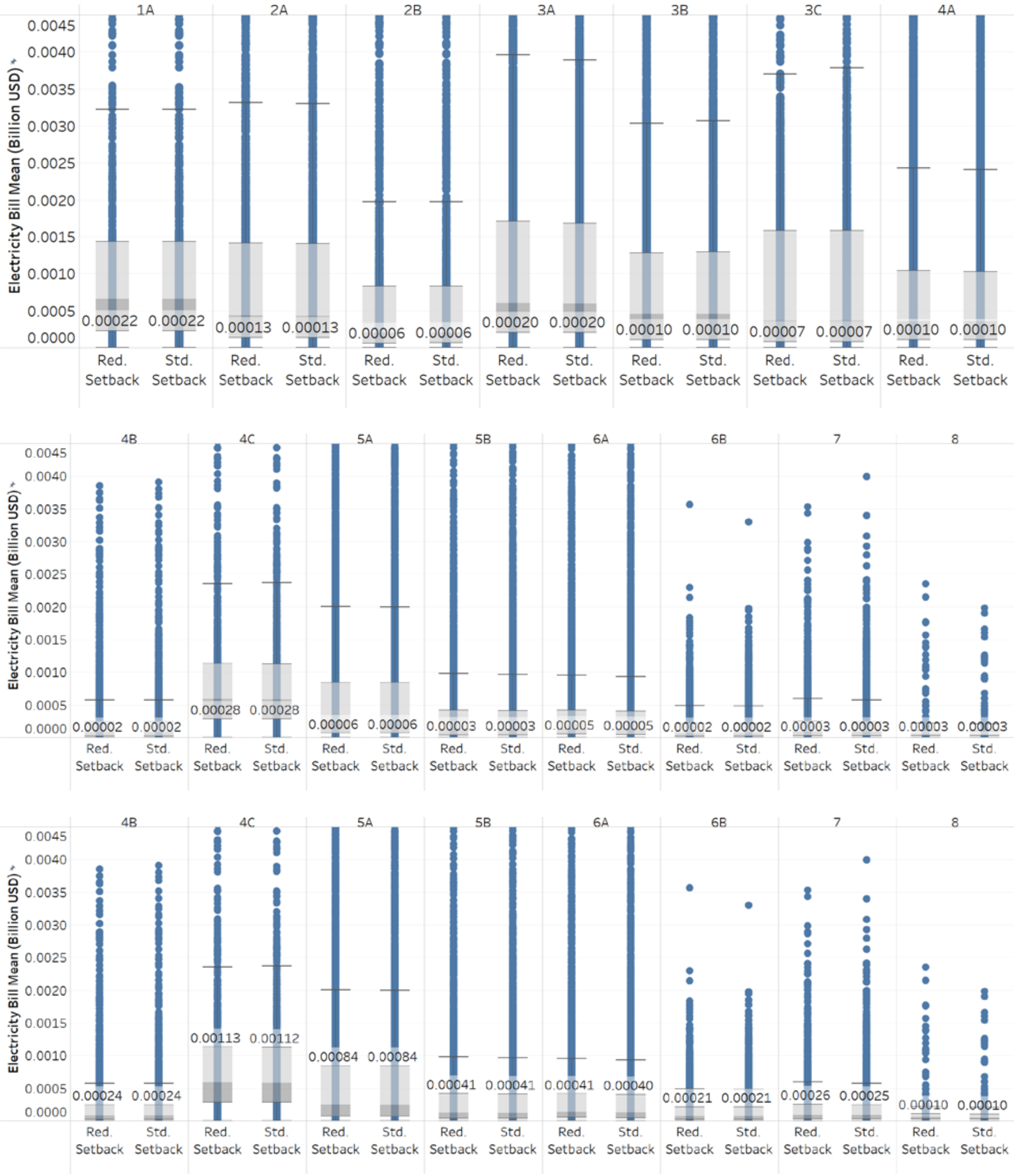

Figure A-5. Distributions of mean electricity bills by climate zone, with 25th percentiles labeled (top and middle figures), and 75th percentiles labeled for Climate Zones 4B-8 (bottom figure). Note that some outliers have been removed for concision.

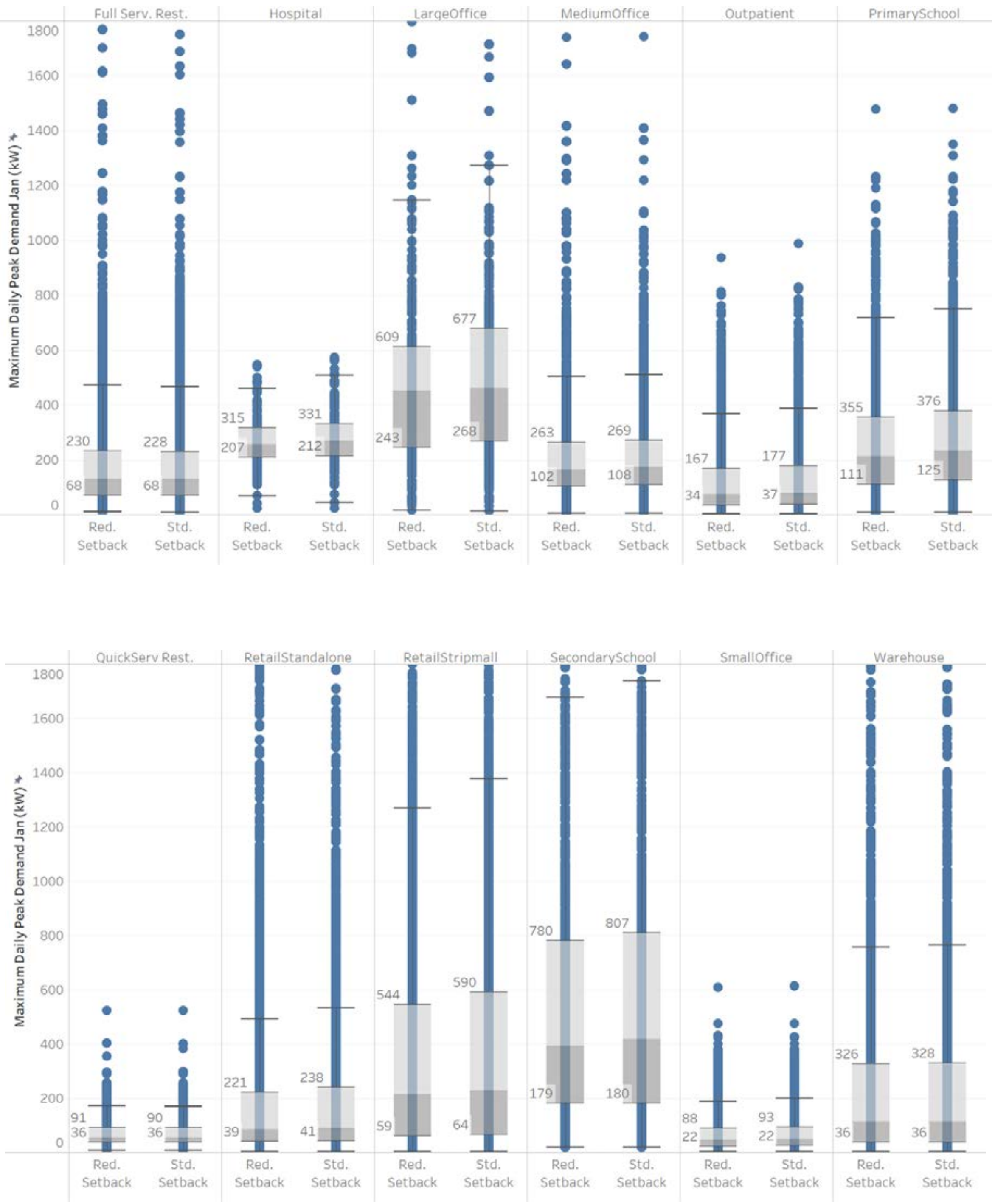

Figure A-6. Distribution of maximum daily peak demand for January for selected building types, with 25th and 75th percentiles labeled. Note that some outliers have been removed for concision.